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Trueness and precision of different intraoral scanners for shade assessment under variable light conditions-a cross-sectional study

Ahmed Ibrahim Sirkhot [a,*], Smita Musani [a], Aamir Godil [b], Mosin Shaikh [a], Taha Attarwala [a], Afnan Sarguroh [a], Rutika Naik [a]

[a] Department of Prosthodontics, M.A. Rangoonwala College of Dental Sciences and Research Centre, Pune, India
[b] Department of Prosthodontics, Faculty of Dentistry, University of Toronto, Canada

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ABSTRACT

Objectives: To compare the trueness and precision of shade assessment using different intraoral scanners under variable light conditions.
Method: To evaluate shade trueness and precision, color measurements (L*, a*, b*) were obtained using visual assessment, a spectrophotometer (SPM) (VITA Easyshade Advanced V), and two intraoral scanners, intra oral scanner-A(IOS-A) (Carestream 3700, Dexis IS ScanFlow) and intra oral scanner-B(IOS-B) (3Shape Trios 3), were used to scan 20 subjects by single assessor under natural daylight and operatory light. The color difference (ΔE) was calculated. Trueness and precision were assessed for each method across the two lighting conditions. Trueness of the test groups was compared by Analysis of Variance (ANOVA) followed by Tukey's Post hoc Test for pairwise comparisons and precision by Kruskal Wallis test while pairwise comparison was done by Mann Whitney *U* Test. P values < .05 was considered as statistically significant.
Results: For trueness, significant differences were observed among the visual method, IOS-A, and IOS-B. Tukey's test revealed a significant difference between the trueness of IOS-A and IOS-B, while no significant differences were detected between the visual method and either scanner. Regarding precision, significant variations were found among the test groups. A significant difference was noted between the visual method and IOS-A, with a highly significant difference between IOS-A and IOS-B. However, no significant differences were observed between SPM and the visual method or IOS-B, nor between the visual method and IOS-B.
Conclusions: IOS-B shows better precision for shade determination than IOS-A, while the visual method is more reproducible than IOS-A. No significant differences in trueness and precision were found between the visual method and IOS-B.

1. Introduction

Tooth shade matching is the most important clinical step during prosthetic treatment.

According to Billmeyer and Saltzman, color is defined as the result of the physical modification of light by colorants, as perceived by the human eye and interpreted by the brain [1,2]. The physical dimensions of color have been described through various models over the past century, with the Munsell color system (Albert Henri Munsell, 1905) being the most widely used. This system, recognized for its visual color ordering method, defines color based on three dimensions: hue, value, and chroma [3]. These parameters enable precise identification of an object's actual color. Among these, value is considered the most crucial in evaluating color compatibility between dental restorations and natural teeth [3,4]. Notably, differences in value are more readily detected by individuals with limited color perception, and restorations perceived as too white or too dark are frequently associated with mismatched value. Furthermore, value discrepancies are discernible from various viewing distances, while differences in hue and chroma tend to diminish with increased distance [4].

Clinical shade selection has evolved through various tools and techniques, beginning with conventional methods such as dental shade guides and progressing toward advanced digital systems. Conventional dental shade guides offer standardized color samples manufactured for use with denture teeth, restorative materials, and ceramics. These guides allow clinicians to visually compare and select shades that best match a

* Corresponding author.
E-mail address: ahmedsirkhot313@gmail.com (A.I. Sirkhot).

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patient's natural teeth. Although no guide can represent the full spectrum of natural tooth shades, skilled practitioners often achieve high levels of accuracy by combining scientific judgment with artistic interpretation and necessary color modifications. Then after, shade matching relied on filter colorimeters—the first devices designed specifically for dental color measurements. However, their clinical utility was limited by edge loss and inconsistent positioning on teeth, especially when assessing translucent, polychromatic natural dentition, making them less reliable. [5]. To address these limitations, spectrophotometers (SPMs) were introduced which provided objective, quantifiable approaches to color selection, improving consistency and reducing subjective bias. They are known to produce the most accurate color measurements.

However, while colorimeters and SPM are highly precise they may detect minor shade differences that are not visually significant or clinically relevant. Their sensitivity can lead to inconsistent results within small areas of the same tooth, creating confusion and their accuracy may exceed what is necessary for esthetic harmony, making them less practical for routine clinical use [5].

The accuracy of shade selection is influenced by several external factors, including the type and intensity of light, the surrounding environment, and color adaptation. A key challenge is metamerism, a phenomenon where two colors may appear identical under one light source, such as fluorescent lighting, but look different under another, like natural sunlight. To minimize subjective variables—such as environmental conditions and the observer's experience—digital color measurement methods seem to offer a more reliable and consistent approach [5]. Intraoral scanners (IOS) with integrated shade detection technology represent a recent advancement in digital prosthodontics, enhancing both color matching accuracy and workflow efficiency. These devices combine high-definition imaging and LED illumination with advanced software to enable precise in vivo shade selection. This data can be seamlessly integrated with digital impressions and transmitted directly to dental laboratories, streamlining the fabrication of restorations such as milled crowns. By replacing conventional methods, IOS contribute to improved reproducibility, reduced turnaround time, and enhanced clinical outcomes in restorative dentistry [6]. Additionally, it could result in a more standardized communication between professionals and a more accurate color selection. The use of color-matching instruments can serve as a supplementary tool to improve the outcome of esthetic restorations as they could have greater agreement and effectiveness than visual methods.

In recent years, numerous studies have evaluated the effectiveness of digital IOS in accurately determining the most clinically acceptable shade for dental restorations. While these studies have provided valuable insights, there remains an ongoing debate regarding the reliability and consistency of digital scanners in shade selection. This uncertainty arises due to several influencing factors, including ambient lighting conditions, image capture techniques, the accuracy of color-analyzing software, and the specific shade guide mode employed in the scanning process [5]. The repeatability and overall accuracy of IOS in shade matching depend on multiple variables, such as the type of scanner used, and the size of the area analyzed. It is still unclear whether IOS equipped with shade detection features can match the precision of colorimeters or SPMs. A critical aspect of this discussion is whether a clinician can consistently capture the exact tooth color under varying lighting conditions and whether this measurement remains reproducible when assessed by the same observer at different times or verified by another observer [7].

The present study aimed to compare the trueness and precision of different IOS under varying light conditions. According to the International Organization for Standardization, accuracy refers to the degree of closeness between a measurement result and the true value of the measurand [8]. The accuracy of an IOS for shade matching in dentistry is defined by how closely the color selected or identified by the scanner matches the actual shade of the patient's teeth as perceived and measured by a standard or reference method. This involves two key aspects: trueness and precision. Trueness refers to the degree of closeness of the scanner's selected shade to the actual shade measured by a reference method, such as SPMs (gold standard) and visual shade guides. Precision, on the other hand reflects the ability of the scanner to reproduce the same shade result consistently over multiple scans under the same conditions. High precision means less variability and more reliability. It technically encompasses three components: repeatability, which refers to consistent results under identical conditions (same operator, equipment, and time); intermediate precision, which assesses consistency within the same laboratory but under varying conditions such as different days or operators; and reproducibility, which evaluates the agreement of results across different laboratories or settings using the same method on identical items [8]. By assessing the trueness and precision, this study seeks to determine the reliability of IOS in clinical shade selection. The null hypothesis (H_0) of the study is that there is no significant difference in the trueness and precision of shade determination between the two IOS, nor is there any variation in their performance under different lighting conditions.

2. Materials and methods

The study was conducted abiding by all human ethical principles as per the World Medical Association's Declaration of Helsinki of 1975, as revised in 2000 and was approved by the institutional ethics board.

The sample size was calculated using Openepi software (v3.0) at 95 % confidence interval and 80 % power using the formula

$$n = (Z\,\alpha/2)^2\ P\ (1 - p)\ /\ d^2$$

where,

$Z\,\alpha/2 = 1.6$,

$P = 98.9$ %% color matching by spectrophotometer, and

$d = 5$ % of marginal error was taken.

By substituting the values in the formula,

$$n = \frac{1.6\ x\ 1.6\ x\ 0.98x\ 0.02}{0.05\ x\ 0.05}$$

$$= 20$$

A total of 20 volunteers with non-carious, non-restored, healthy and vital maxillary right central incisors were selected. The teeth were free of any staining or extrinsic deposits and showed no signs of pathologic wear or single tooth malocclusion. Before the procedure, all participants signed informed consent forms after receiving verbal and written information about the study. Teeth were selected for shade determination using a visual shade matching method (Vita Tooth Guide 3D-Master), digital method that were scanned with a SPM (VITA Easyshade Advanced V, Germany), and two different intraoral scanners IOS-A (Carestream 3700, Dexis IS ScanFlow) and IOS-B (3ShapeTrios 3) under two different light conditions that is natural light (Group A) and operatory light (Group B) (Table 1). To minimize inter-observer bias and maintain procedural standardization, a single, experienced female observer was assigned to record the visual shade readings. Only three readings were taken per day, with a 3-min resting interval between each.

The CIE (International Commission on Illumination) proposed CIE L*a*b* colour space in 1976. The colour differences (ΔE) of two objects can then be determined by comparing the differences between

Table 1
Test groups and sample size.

Test Groups							
Group A (Daylight) (n = 20)				Group B (Operatory Light) (n = 20)			
A1 SPM	**A2** Visual	**A3** IOS- A	**A4** IOS- B	**B1** SPM	**B2** Visual	**B3** IOS- A	**B4** IOS- B

respective coordinate values for each object using the following formula: $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ where, ΔL*, Δa* and Δb* are differences in colour parameters for the two specimens [2].

All shade assessments were done at dental office with neutral-colored walls, at the day time, closer to a window providing natural light for Group A and under operatory light for Group B. Each subject was seated on a dental chair in a comfortable and stable head and neck position. teeth were moistened with saliva during shade determination.

2.1. Shade assessment using SPM

The device was calibrated according to the manufacturer's instruction, before each measurement. The labial, middle third surface of the maxillary right central incisors of the patients was in close contact with the instrument probe tip, which produces images when an intraoral adapter protecting against external light is positioned at a 90-degree angle to the targeted tooth center which was then scanned thrice. This was done to obtain the L*, a*, and b* values for each test subject. The mean of the recorded values was used for further calculation.

2.2. Shade assessment using shade guide

The observer was positioned about 3–6 feet from the patient's mouth and the shade of the labial, middle third surface of the maxillary right central incisor was observed using a suitable VITA 3D-Master tab, which was held alongside the tooth being matched. A 5-second gaze was used to compare the shade guide specimen. Other samples were evaluated similarly until a decision was reached regarding the best color match. Following the selection of an appropriate shade tab that corresponds with the concerned region of the tooth. The procedure was carried out three times for the same individual. L*, a*, and b* values of the selected shade tab were obtained using the conversion table. The mean of the L*, a*, and b* values obtained from 3 readings were calculated for further calculation and used for ΔE calculation.

2.3. Shade assessment using IOS-A

The device is self-calibrating when switched on, as per the manufacturer. The entire maxillary arch was scanned even though the central incisor was the concerned tooth, because of its software which can determine shade after completion of the scan. The scan was refined until the blue overlay disappeared from the tooth that was scanned. Once the scan was refined, the shade icon which was on the right side of the screen was selected. The shade measurement circle was placed on the middle portion of the buccal surface of the tooth. Tooth shades were automatically measured by CS3700 software. The procedure was repeated thrice for the same subject. CS3700 software uses the VITA classic shade guide, after determining a suitable shade tab. L*, a*, and b* values of the selected shade tab were obtained using the conversion table. Then the mean of the L*, a*, and b* values obtained from 3 readings were calculated for further calculation.

2.4. Shade assessment using IOS-B

The first step involved calibrating the instruments according to the manufacturer's instructions, which includes an automatic calibration to ensure the scanner's accuracy. Following that, only the anterior teeth were scanned because the software allows for sectional scanning for shade selection, therefore a scan of the entire arch was not necessary. Once the scanning was done, the shade icon which was on the right side of the screen was selected. The shade measurement circle was placed on the middle portion of the buccal surface of the tooth. Tooth shades were automatically measured by 3Shape Trios 3 software. The procedure was repeated thrice for the same subject. (3Shape Trios 3 software uses the VITA 3D MASTER shade guide, after determining a suitable shade tab. L*, a*, and b* values of the selected shade tab were obtained using the conversion table. Then the mean of the L*, a*, and b* values obtained from 3 readings were calculated for further calculation.

2.5. ΔE calculation

The readings of different methods were compared using formula $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$. L* and value are proportional to each other and represent the lightness, brightness, or black/white character of the colour. The a* coordinate corresponds to the red–purple/blue-green axis in the Munsell colour space and the b* coordinate corresponds to the yellow-purple/blue axis.

Assessment of Trueness (Fig. 1): To obtain the accuracy of different methods L*, a*, and b* values of each group was compared with the SPM L*, a*, and b* values under natural light conditions i.e. A.1 was compared with A.2, A.3, and A.4 to check the accuracy of visual, IOS-A, and IOS-B respectively. The color differences (ΔE) of two objects were determined by the formula $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$. L*, a*, and b* values of SPM was compared with L*, a*, and b* of visual, IOS-A and IOS-B the more the difference i.e. greater value of ΔE lesser the accuracy of method, lesser the value of ΔE more accurate the method is.

Assessment of Precision (Fig. 2): To obtain precision of methods, inter-group comparison was done. Grouping was done based on the lighting condition, where Group A was daylight, and Group B was operatory light. The readings of different methods were compared using formula $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$. L*, a*, and b* values of SPM under daylight was compared with L*, a*, and b* values of the SPM under operatory light to obtain precision of SPM Similarly the precision of visual, IOS-A, and IOS-B. L*, a*, and b* values under two light conditions were compared. Greater the value of ΔE lesser the precision of the method, lesser the value of ΔE more reproducible the method.

2.6. Statistical analysis

The data was analyzed using SPSS (Statistical Package for Social Sciences), version 19. Descriptive statistics for trueness and precision were expressed as mean ± standard deviation (SD) for each group. The Shapiro-Wilk test was conducted to assess the normality of the data.

Following the normality test, parametric statistical tests were used for trueness and non-parametric tests were applied to precision. To compare the trueness among the three groups, Analysis of Variance (ANOVA) was employed, followed by Tukey's Post Hoc test for pairwise comparisons. For precision, comparisons across four groups were performed using the Kruskal-Wallis test, and pairwise comparisons were conducted using the Mann-Whitney *U* test. A p-value of $<.05$ was considered statistically significant for all analyses.

3. Results

The results of the study were evaluated across two key parameters: trueness and precision of shade determination using visual methods, two scanners (IOS-A and IOS-B), and SPM in two different light conditions.

In terms of trueness, descriptive statistics revealed that IOS-A had the highest mean value (16.664 ± 7.01), followed by IOS-B (11.178 ± 5.26) and the visual method (10.995 ± 5.06) (Table 2). However, the statistical analysis using ANOVA indicated a significant difference among the three groups ($p = 0.004$). Post hoc Tukey's test (Table 3) further showed that IOS-A was significantly less accurate than both the visual method ($p = 0.009$) and IOS-B ($p = 0.012$), while no significant difference was found between IOS-B and the visual method ($p = 0.995$). This suggests that IOS-B and visual shade selection methods perform similarly in terms of trueness, whereas IOS-A appears to deviate considerably, likely due to algorithmic or calibration differences. Therefore, despite the numerical superiority in mean value, IOS-A's trueness was statistically inferior to the other methods.

When analyzing precision, IOS-A again recorded the highest mean value (6.604 ± 6.04), indicating more variability and hence lower

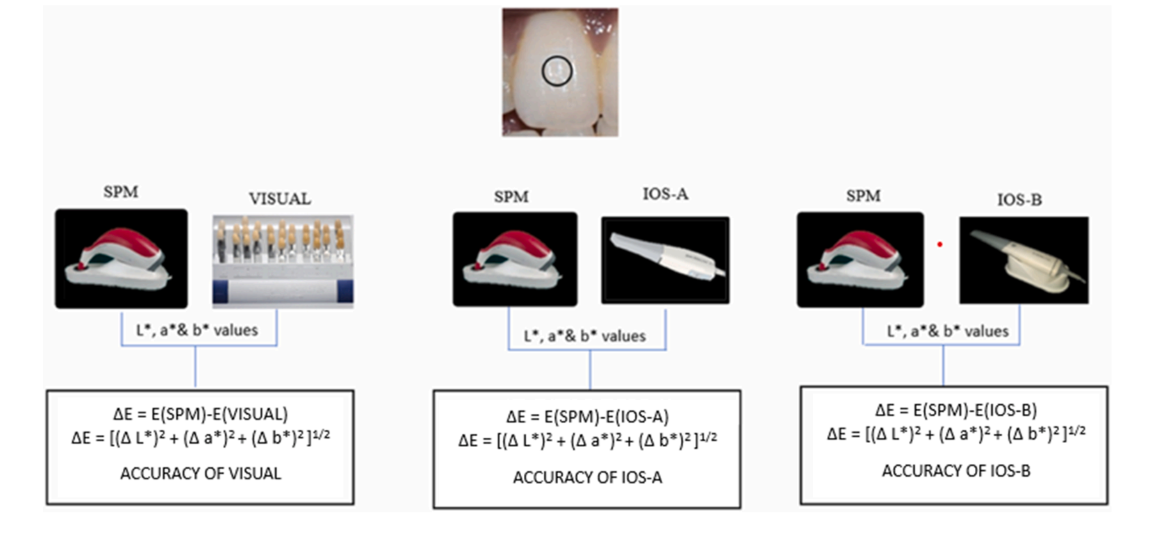

Fig. 1. Workflow for assessment of trueness of test groups for shade determination.

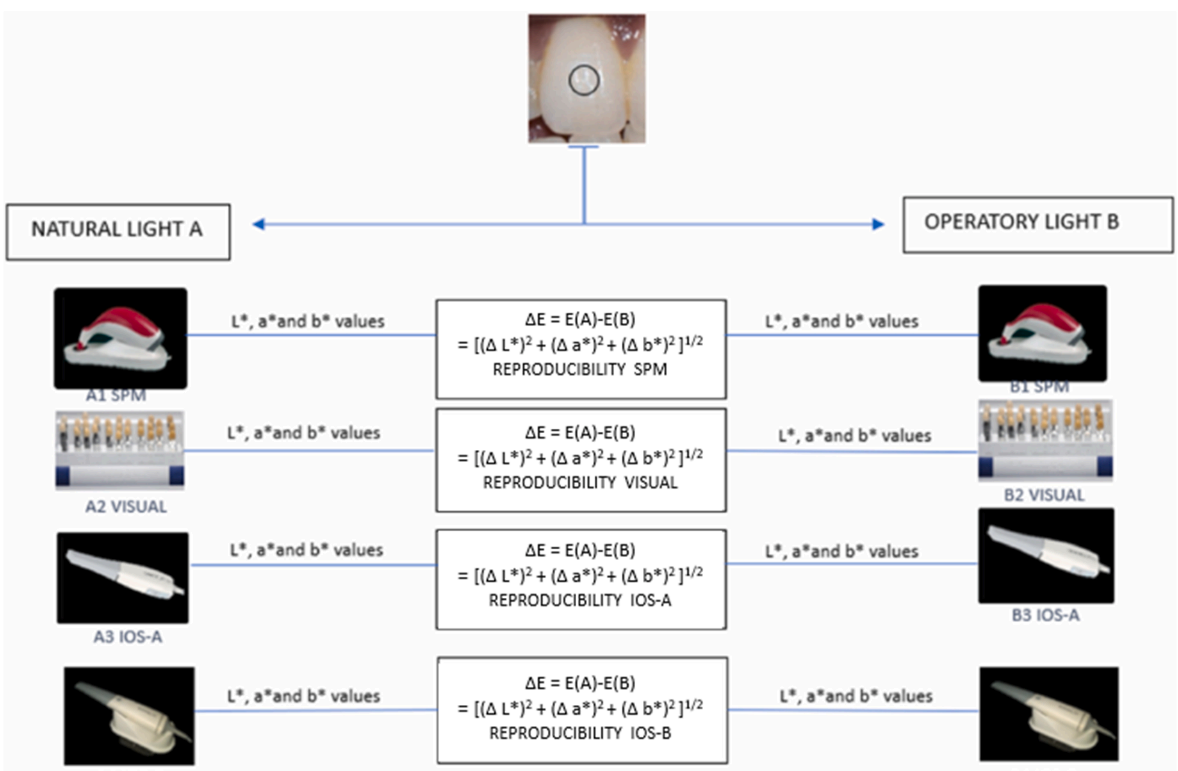

Fig. 2. Workflow for assessment of precision of each group for shade determination under two different light conditions.

precision. This was followed by SPM (2.307 ± 1.71), IOS-B (1.593 ± 2.83), and the visual method (1.370 ± 2.25) (Table 4). The Kruskal-Wallis test (Table 5) confirmed a statistically significant difference among the four groups ($p = 0.001$). Pairwise comparisons using the Mann-Whitney *U* test (Table 6) revealed that IOS-A was significantly less reproducible than both the visual method ($p = 0.003$) and IOS-B ($p = 0.003$). Moreover, SPM was also found to be significantly less reproducible than the visual method ($p = 0.018$) and IOS-B ($p = 0.011$). Interestingly, there was no significant difference between IOS-A and SPM ($p = 0.061$), nor between the visual method and IOS-B ($p = 0.802$), highlighting their comparability.

Table 2
Descriptive statistics for trueness.

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
VISUAL	20	10.9955	5.06273	1.13206	.51	17.77
IOS-A	20	16.6640	7.01409	1.56840	6.56	29.95
IOS-B	20	11.1780	5.26180	1.17657	.51	25.01
Total	60	12.9458	6.32839	.81699	.51	29.95

Table 3
Comparison of Trueness by Analysis of Variance followed by paired wise comparison by Turkey's post hoc test.

Multiple Comparisons (Tukey HSD)
Dependent Variable: Trueness

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig. (p value)	95 % Confidence Interval	
					Lower Bound	Upper Bound
VISUAL	**IOS-A**	−5.66850*	1.84856	.009*	−10.1169	−1.2201
VISUAL	**IOS-B**	−.18250	1.84856	.995	−4.6309	4.2659
IOS-A	**IOS-B**	5.48600*	1.84856	.012*	1.0376	9.9344

*. The mean difference is significant at the .05 level.
*Statistically Significant.

Table 4
Descriptive statistics for precision.

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
VISUAL	20	1.3705	2.25918	.50517	.00	7.49
IOS-A	20	6.6040	6.04509	1.35172	.00	17.22
IOS-B	20	1.5930	2.83401	.63370	.00	6.53
SPM	20	2.3075	1.71004	.38238	.00	7.23
Total	80	2.9688	4.15132	.46413	.00	17.22

Table 5
Comparison of precision by Kruskal Wallis test.

Kruskal Wallis Test
Dependent Variable: Precision

Group	N	Mean Rank	Chi-Square	df	p value
VISUAL	20	31.30	16.410	03	.001*
IOS-A	20	54.40			
IOS-B	20	30.50			
SPM	20	45.80			
Total	80				

*Statistically Significant.

Table 6
Pair wise comparison of precision by Mann Whitney *U* test.

Pair Wise Comparison by Mann Whitney *U* Test
Dependent Variable: Precision

Sr no	Group 1	Group 2	Mann-Whitney U	Wilcoxon W	z	p value
1	**Visual**	**IOS- A**	93.500	303.500	−3.023	.003*
2	**Visual**	**IOS-B**	192.500	402.500	−.250	.802
3	**Visual**	**SPM**	115.000	325.000	−2.362	.018*
4	**IOS-A**	**IOS-B**	97.500	307.500	−2.965	.003*
5	**IOS-A**	**SPM**	131.000	341.000	−1.872	.061
6	**IOS-B**	**SPM**	110.00	320.00	−2.534	.011*

*Statistically Significant.

4. Discussion

The null hypothesis, stating no difference between IOS and precisions in shade determination under different light conditions, was rejected, revealing a statistically significant difference between the two methods. In the present study, the central incisors were selected for shade determination to allow for a clear and consistent comparison with the shade guide specimens. These teeth are commonly used as reference points due to their central position and high visibility within the smile. Focusing on the central incisors helped minimize potential color variations that might arise from adjacent teeth, thereby simplifying the shade-matching process. Additionally, the study specifically targeted the middle third of the labial surface for shade assessment, as this region has been shown in previous research—such as the study by Moussaoui et al. [9]—to offer the most accurate representation of the tooth's overall shade.

The study by Sarafianou et al. [10] investigated the performance of EasyShade SPM in color matching under various lighting condition which showed consistent and reliable color-matching capabilities under two specific lighting conditions natural daylight and dental unit lamp. Based on the findings from the above study, this study also selected similar lighting environments for evaluation. In Seungyee Kim-Pusateri's study [11] four commercially available digital shade assessment devices were evaluated to determine how closely their shade measurements matched the true shade of teeth. Vita EasyShade likely showed superior trueness (92.6 %) and precision among the devices tested, prompting this study to select it as the reference device. To minimize inter-observer bias and ensure procedural standardization, a single examiner was designated to record the visual shade assessments. Research by Jouhar et al., along with other studies, has identified several factors that can affect the accuracy of dental shade matching, including the observer's age, level of experience, and individual color sensitivity, which is influenced by retinal photoreceptor characteristics [5]. Another notable aspect of the present study's design was the use of two different experimental IOS systems Carestream (CS 3700) and 3Shape (TRIOS), each employing distinct principles to capture and analyze tooth shades. The CS3700 IOS utilizes a triangulation technique in conjunction with the Bidirectional Reflectance Distribution Function (BRDF) to generate 3D color images. The BRDF analyzes light reflections from multiple angles and directions, allowing for shade detection independent of the tooth's surface texture and anatomical variations [6]. In contrast, the TRIOS™ system operates on the principles of confocal microscopy and is known for its high-speed scanning capabilities [12]. It employs a light source that projects a specific illumination pattern, inducing light oscillations on the scanned object.

In this study, two distinct lighting conditions were used to evaluate the performance of shade selection methods under varying clinical environments. Revilla-León et al. reported significant differences in shade determination by IOS when exposed to different lighting setups, highlighting the influence of environmental light characteristics on digital color capture [13]. This underscores the sensitivity of intraoral scanning (IOS) devices to lighting conditions, which can introduce inconsistencies in shade matching due to altered color perception and digital recording. Similarly, Nantanapiboon D. emphasized the critical role of lighting in ensuring the accuracy of digital shade selection [14]. Although IOS equipped with integrated illumination sources tend to offer more consistent and reliable results than precisions, their accuracy can decline when affected by uncontrolled ambient lighting. These findings collectively underscore the importance of standardizing lighting conditions to ensure consistent and accurate digital shade measurements in clinical practice.

The present study demonstrated that IOS-A (CS3700) exhibited the highest mean ΔE value (16.66 ± 7.01), indicating the greatest deviation from the reference shade—and thus the lowest trueness—among the groups tested. This finding aligns with the results of Abd Alaziz et al., who also reported lower accuracy of the CS3700 compared to the Vita EasyShade precision [6]. In contrast, no statistically significant difference in trueness was observed between visual shade selection ($\Delta E = 10.99 \pm 5.06$) and IOS-B (TRIOS, 3Shape) ($\Delta E = 11.17 \pm 5.26$), suggesting comparable performance between these two methods. However, this observation differs from the findings of Liberato et al., who concluded that the TRIOS scanner demonstrated superior accuracy over both visual and spectrophotometric techniques [15]. These discrepancies across studies may stem from variations in study design, sample size, device calibration protocols, or operator proficiency. Such factors can significantly influence the consistency and reliability of shade-matching outcomes, highlighting the need for standardization in clinical color determination [16].

In the present study, precision varied significantly among the different shade selection methods. Notably, the visual method demonstrated significantly greater precision than IOS-A ($p = 0.03$). These results are consistent with those of Moussaoui et al., who reported that visual methods offered precision comparable to that of digital systems [9]. This suggests that, despite advancements in technology, traditional visual techniques remain dependable, particularly in clinical scenarios requiring high precision. One possible reason for the consistent performance of visual methods is their inherent adaptability to clinical variables such as ambient lighting and tooth surface conditions—factors that may compromise the reproducibility of IOS.

Interestingly, no significant difference in precision was found between the visual method and IOS-B (TRIOS, 3Shape). This finding aligns with Brandt et al., who reported high repeatability for both IOS and precisions, with repeatability rates of 78.3 % and 76.6 %, respectively [17]. Furthermore, our study found that IOS-B was significantly more reproducible than IOS-A ($p = 0.03$), supporting the findings of Vohra et al., who observed enhanced reproducibility with the 3Shape TRIOS 3 scanner compared to other digital and visual methods [18]. Collectively, these results highlight that while visual methods remain reliable, certain IOS—such as IOS-B—can match or even surpass them in precision, depending on the specific device and clinical conditions.

The variability observed in scanner performance highlights the dynamic evolution of intraoral scanning technologies. As manufacturers refine their devices through advancements in software algorithms and hardware configurations, the precision and clinical applicability of these tools continue to improve. However, this rapid progression also emphasizes the need for standardized protocols and robust comparative studies to objectively evaluate scanner performance. Establishing evidence-based guidelines will be instrumental in aiding clinicians to select the most suitable scanner for specific clinical scenarios, ultimately contributing to more predictable treatment outcomes and improved patient care.

The study highlights the increasing integration of intraoral scanners (IOS) into esthetic workflows, underlining the importance of tool-specific performance in shade selection. IOS-B exhibited precision comparable to traditional visual methods, reinforcing its clinical reliability. However, the variability among IOS devices cautions against assuming universal accuracy. These findings suggest that clinicians should critically assess scanner performance and consider combining digital and visual methods, particularly in esthetically demanding cases, to ensure predictable and optimal outcomes.

This study is subject to several limitations. First, it utilized only two IOS types, limiting the applicability of findings to the broader range of available technologies. The scope was confined to natural, vital tooth shades, excluding non-vital teeth and prosthetic materials with differing optical properties, thus reducing clinical generalizability. Shade evaluation by a single observer, while minimizing inter-observer variability, restricts external validity due to unaccounted influences such as clinical experience and perceptual biases [5,6]. Additionally, ambient lighting variables such as illuminance and color temperature were not controlled or documented, which could have affected shade perception and introduced inconsistency [13]. Finally, the study lacks detailed reporting of participant shade or lightness distribution. If the included samples represented a narrow tonal range, it further limits the extrapolation of results to diverse clinical populations.

5. Conclusion

Within the limitations of the study, it can be concluded that precision of IOS-B is better than IOS-A for shade determination and the precision of the visual method for shade determination is better than the IOS-A. No statistically significant difference was found between visual and IOS-B methods in terms of trueness and precision.

CRediT authorship contribution statement

Ahmed Ibrahim Sirkhot: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Smita Musani:** Supervision, Validation, Conceptualization, Writing – review & editing. **Aamir Godil:** Writing – review & editing, Visualization, Validation, Supervision, Investigation, Formal analysis, Data curation, Conceptualization. **Mosin Shaikh:** Writing – review & editing, Visualization. **Taha Attarwala:** Writing – review & editing, Visualization, Supervision. **Afnan Sarguroh:** Writing – review & editing, Investigation. **Rutika Naik:** Visualization, Validation, Supervision, Investigation, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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