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A comparative study of shade-matching performance using intraoral scanner, spectrophotometer, and visual assessment

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This study aimed to explore the clinical applicability of the shade-matching function in intraoral scanners. This study measured the tooth colors of maxillary anterior dentitions of 83 adults using visual matching, a spectrophotometer, and a scanner according to two color systems: VITA Classical (VC) and VITA 3D-Master (V3D). Agreement between each method was assessed by weighted Cohen's kappa coefficient (K_W, α = 0.05). For V3D, the overall agreement between the scanner and spectrophotometer (K_W = 0.498) was higher than that between the scanner and visual matching (K_W = 0.473). Similarly, the agreement between the scanner and spectrophotometer (K_W = 0.283) was higher than that between a scanner and visual matching (K_W = 0.140) for VC. Regarding tooth position, the highest agreement between the scanner and spectrophotometer was observed on the right central incisor (K_W = 0.542) for V3D. Tooth color measurement with a scanner was comparable to that with a spectrophotometer, especially on the central incisors when using the VITA 3D-Master system. A scanner could serve as an alternative to a spectrophotometer for shade selection. However, color matching should still be visually verified.

Keywords Tooth, Color perception, Spectrophotometry, Digital technology

Restorative dentistry now emphasizes achieving a natural-looking appearance that harmonizes with the adjacent teeth, ensuring patient satisfaction and successful aesthetics. Precise shade determination is crucial for creating seamless, visually pleasing outcomes, making the selection of an accurate tooth shade a challenging task for dental practitioners[1]. Tooth color determination can be achieved using either subjective or objective methods. Subjective visual color assessment involves clinicians using a shade guide tab to directly compare the target tooth with the adjacent teeth, aiming for quick and straight forward treatment in practice. Although this method is recognized as effective because the human eye can perceive subtle color differences between two objects, the results can vary depending on factors such as age, sex, lighting conditions, oral environment, eye fatigue, and practitioner experience[2]. As a result, these inherent subjectivities can lead to inconsistencies and variability in outcomes. Additionally, limitations in the number of shade tabs in the shade guide systems and the inability of the manufacturers to perfectly replicate the hues in natural teeth can impede accurate color reproduction, which may compromise the study's validity in assessing visual matching accuracy[3]. However, color identification skills can be improved through lighting adjustments, color education, and clinical experience[4].

A variety of electronic devices, such as spectrophotometers, colorimeters, and digital cameras, can be used for objective methods. Intraoral spectrophotometers are recognized as accurate and reliable tools for selecting natural tooth colors because of their high reliability and accuracy[5–7]. Spectrophotometers measure the reflectance or transmittance of an object at one wavelength at a time and have been employed to assess the visible spectra of natural teeth[8]. These measurements can be reported in CIE L^*, a^*, and b^* values and converted into corresponding shade systems. However, spectrophotometers have limitations, such as their sensitivity to ambient lighting conditions, the positioning of the device, and the surface texture of the tooth. Additionally,

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	Intraoral scanner	Spectrophotometer	Visual matching
Intraoral scanner	1.000	0.498 (*0.024)	0.473 (*0.023)
Spectrophotometer	0.498 (*0.024)	1.000	0.488 (*0.022)
Visual matching	0.473 (*0.023)	0.488 (*0.022)	1.000

Table 1. Inter-method agreement based on VITA 3D-Master shade guide system using weighted Cohen's kappa coefficient (K_W). *ASE: asymptotic standard error.

	Intraoral scanner	Spectrophotometer	Visual matching
Intraoral scanner	1.000	0.283 (*0.030)	0.140 (*0.017)
Spectrophotometer	0.283 (*0.030)	1.000	0.128 (*0.020)
Visual matching	0.140 (*0.017)	0.128 (*0.020)	1.000

Table 2. Inter-method agreement based on VITA classical shade guide system using weighted Cohen's kappa coefficient (K_W). *ASE: asymptotic standard error.

they may not fully account for the natural translucency and gloss of teeth, which can affect the accuracy of the color measurement[7].

With recent advancements in scientific technology, the latest versions of intraoral scanners now include built-in functions for measuring tooth color as well as reproducing intraoral structures in three-dimensional (3D) images[9,10]. The 3Shape TRIOS (3Shape, Copenhagen, Denmark) uses ultrafast optical sectioning, which combines confocal microscopy with structured light projection to obtain in-focus images at different depths, transforming contrast data into 3D surface information pixel by pixel[11]. A previous study[12] reported that artificial intelligence (AI)-based approaches can be used for digital shade matching, leveraging algorithms such as fuzzy logic, backpropagation neural networks, convolutional neural networks, and artificial neural networks to precisely select colors and emulate complex human intelligence. Intraoral scanners may vary in accuracy and precision for tooth shade matching because of variations in light sources, camera sizes, and operating mechanisms[13]. Moreover, the accuracy and reliability of both spectrophotometers and intraoral scanners can be affected by the operator's training and experience, with variability in proficiency potentially impacting the results and the reproducibility of the study. Additionally, environmental and lighting conditions can impact the performance of both visual and instrumental color matching. Variations in these conditions during color measurements could lead to inconsistencies in the findings.

Although intraoral scanners are increasingly incorporating shade-determination functions, it remains uncertain whether an intraoral digital scanner with an integrated shade-determination feature can replace spectrophotometers or subjective visual matching. Previous studies have suggested that intraoral scanners could be viable alternatives to spectrophotometers for shade selection[13,14]. However, the effectiveness of intraoral scanners as substitutes for spectrophotometers in shade determination is not yet fully established. Discrepancies between scanner-based shade matching and spectrophotometric results have also been reported in other studies[15,16]. Therefore, this study aimed to evaluate the clinical applicability of an intraoral scanner's shade-matching function by comparing its agreement with visual matching and a spectrophotometer using two color systems: VITA Classical and VITA 3D-Master shade guides (Vita Zahnfabrik, Bad Säckingen, Germany). The VITA Classical guide organizes shades into four main groups (A, B, C, D) based on hue, making it a long-standing standard in dentistry. The VITA 3D-Master system offers a more precise approach by categorizing shades based on value, chroma, and hue, allowing for more accurate color matching[17]. However, as this study focused exclusively on these two shade guides, the findings may not be generalizable to other shade guide systems, limiting the broader applicability of the results. Additionally, this study concentrated on immediate or short-term shade-matching outcomes, without addressing the long-term stability and consistency of the shade matching, which are crucial factors for the success of restorative dentistry over time. The null hypothesis was that the digital shade matching results would not differ from the visual determination and spectrophotometric results when using the VITA Classical and VITA 3D-Master shade guide systems.

Results

Table 1 presents the inter-method agreement based on the VITA 3D-Master shade guide system using the weighted Cohen's kappa coefficient (K_W). The highest agreement was observed between the intraoral scanner (IOS) and the spectrophotometer (SP) ($K_W = 0.498$), followed by the SP and visual color matching (VM) ($K_W = 0.488$). Table 2 shows the inter-method agreement based on the VITA Classical shade guide system using the weighted Cohen's kappa coefficient (K_W). The highest agreement was detected between the IOS and SP ($K_W = 0.283$), followed by the agreement between the IOS and VM ($K_W = 0.140$). Table 3 reveals the match percentages between each method based on the shade guide system. The percentage of color match between a scanner and a spectrophotometer was 46.9% when the tooth color was recorded using the VITA 3D-Master system, compared to 32.3% with the VITA Classical system. Additionally, the percentage of color match between a scanner and visual matching was nearly twice as high with the VITA 3D-Master system compared to the VITA Classical shade guide.

Measurement comparison	Shade guide system	
	VITA 3D-master (%)	VITA classical (%)
Scanner/ spectrophotometer	46.9	32.3
Scanner/visual matching	39.4	21.1
Spectrophotometer/visual matching	43.6	20.5

Table 3. Match percentages between each method based on the shade guide system.

Tooth position		Scanner/spectrophotometer	Scanner/visual matching
#13	VC	0.206 (*0.057)	0.051 (*0.038)
	V3D	0.382 (*0.065)	0.418 (*0.064)
#12	VC	0.268 (*0.070)	0.108 (*0.043)
	V3D	0.439 (*0.060)	0.411 (*0.063)
#11	VC	0.272 (*0.081)	0.209 (*0.053)
	V3D	0.542 (*0.047)	0.412 (*0.057)
#21	VC	0.333 (*0.076)	0.174 (*0.046)
	V3D	0.532 (*0.082)	0.446 (*0.059)
#22	VC	0.359 (*0.822)	0.083 (*0.037)
	V3D	0.370 (*0.069)	0.392 (*0.062)
#23	VC	0.113 (*0.065)	0.030 (*0.042)
	V3D	0.384 (*0.063)	0.411 (*0.063)

Table 4. Inter-method agreement in terms of tooth position using weighted Cohen's kappa coefficient (K_W). *ASE: asymptotic standard error. #13, upper right canine; #12, upper right lateral incisor; #11, upper right central incisor. #21, upper left central incisor; #22, upper left lateral incisor; #23, upper left canine. VC, VITA Classical; V3D, VITA 3D-Master shade guide system.

The upper central incisor, lateral incisor, and canine on the right side were denoted as #11, #12, and #13, respectively, while the central incisor, lateral incisor, and canine on the left side were denoted as #21, #22, and #23, respectively. In terms of tooth position, the agreement between the IOS and SP according to the V3D system ranged from the highest to the lowest as follows: #11 (K_W = 0.542) > #21 (K_W = 0.532) > #12 (K_W = 0.439), whereas the agreement between the IOS and VM varied as #21 (K_W = 0.446) > #13 (K_W = 0.418) > #11 (K_W = 0.412). For the VC system, the agreement between IOS and SP ranged from #22 (K_W = 0.359) > #21 (K_W = 0.333) > #11 (K_W = 0.272), and between the IOS and VM, in the order of #11 (K_W = 0.209) > #21 (K_W = 0.174) > #12 (K_W = 0.108) (Table 4). In both shade guide systems, the agreement between the IOS and SP, as well as between the IOS and VM, was higher for the central incisors than for the lateral incisors or canines. The interpretation range of the weighted Cohen's kappa values was as follows: 0–0.2 (slight), > 0.2 (fair), > 0.4 (moderate), and > 0.6 (substantial)[18]. When converted to percentages, the range corresponded to 0–0.2 (0–4%), > 0.2 (> 4%), > 0.4 (> 16%), > 0.6 (> 36%).

Discussion

This study examined the inter-method agreement between an intraoral scanner, a spectrophotometer, and visual matching to estimate tooth colors. The results indicated that the inter-method agreement between the intraoral scanner and spectrophotometer, as well as between the intraoral scanner and visual matching, was moderate when considering both the VITA Classical and VITA 3D-Master shade guide reference systems. However, a higher agreement was observed between the intraoral scanner and spectrophotometer than between the intraoral scanner and visual matching. Because of their ability to detect subtle color differences beyond the discernment of the human eye, a higher agreement may be achieved between both instrumental methods. Therefore, the null hypothesis of this study was rejected, despite the fact that intraoral scanners proved to be reliable and can serve as a reference tool for tooth shade selection.

The clinical applicability of intraoral scanners for measuring tooth shade remains controversial. Floriani et al.[15] reported that the accuracy of shade determination using a scanner decreased in aged resin composites, particularly for darker shades. Rutkūnas et al.[16] found that the accuracy of shade matching with a scanner was 27.5% based on the VITA Classical shade guide system. They also revealed a visually perceptible color difference between the color values obtained using a scanner and those obtained using a spectrophotometer. In Yoon et al.'s study[19], the average color difference values (ΔE) between shades obtained by an intraoral scanner and by a colorimeter exceeded 10, despite the scanner demonstrating high repeatability in color measurement. In contrast, Czigola et al.[14] suggested that an intraoral scanner could be used for tooth shade assessment combined with visual matching when referring to the VITA 3D-Master shade guide system, which showed higher repeatability than a spectrophotometer.

Previous studies have also indicated that the choice of shade guide during the scanner setup for shade matching is one of the most commonly reported influencing factors. This study showed greater agreement between the scanner and spectrophotometer when using V3D than when using VC. These results support previous findings[13,14,20] suggesting that utilizing VITA 3D-Master settings enhances accuracy, as it is believed to closely align with the capabilities of the human eye. The V3D system offers a more suitable array of natural tooth shades than the VC shade guide, thereby leading to fewer color differences when selecting tooth shades[21].

The results of this study revealed that a greater agreement was observed between both electronic methods than between scanning and visual matching. Utilizing a high-definition camera with an LED light, the scanner estimates tooth color using specific software[22]. Consequently, digital approaches offer enhanced repeatability compared to visual systems. The translucency of the enamel, background color, light intensity, and subjective conditions of the examiner may influence the tooth shade perceived by the human eye, although visual matching is still considered the standard technique owing to its simplicity and low cost[23]. In this study, the maxillary anterior teeth were chosen for color measurement because of their prominent visibility during smiling and significant aesthetic influence. In terms of tooth position, a greater agreement was observed between each pair of methods for the central incisors. This could be attributed to their wide and even buccal surfaces, which reduce the edge-loss effect compared to other teeth[24].

Spectrophotometers have demonstrated both repeatability and accuracy in color selection across multiple studies[2,15,24]. However, these devices are typically not readily available in routine dental practice because of their high costs. In this study, the inter-method agreement between the intraoral scanner and spectrophotometer was moderate. Thus, results regarding whether an intraoral scanner with an integrated shade-taking function can effectively substitute for spectrophotometers are inconclusive. Yilmaz et al.[25] suggested that objective instrumental measurement methods could be complemented by subjective visual methods, potentially yielding superior results when used together. However, employing a scanner for shade determination offers advantages in terms of ease of use, time and cost savings, scanning of a wider area with greater susceptibility, and lower operating sensitivity. According to the findings of this study, a scanner could serve as an alternative to a spectrophotometer for shade selection; however, color matching should still be visually verified. Hence, the results of this study affirm the effectiveness of using an intraoral scanner to determine tooth color, although further refinement of computer-based systems is warranted.

The limitations of this study include the lack of standardization of the operating variables of the scanning system, such as scan angle, time, distance, rescanning time, light source, and the presence of shadows from the surrounding tissue. Further research should aim to assess the effects of each variable on color matching using intraoral color scanners. In addition, because the scanner does not provide L^*, a^*, and b^* color values, comparing the color scales obtained using each method is challenging. However, as the technology continues to evolve, improvements in the accuracy and precision of intraoral scanners for tooth color measurement could significantly impact study outcomes. Another limitation is that it included only 83 adult patients from a single dental hospital, which may affect the generalizability of the findings. A more diverse and larger sample size would enhance the validity and applicability of the results to a broader population. Additionally, the visual color matching was performed by a single prosthodontist with over 20 years of experience. The results may be influenced by the practitioner's unique skills and experience, potentially introducing bias. Including multiple practitioners with varying levels of experience could provide a more comprehensive evaluation of the visual matching method, reducing the impact of subjectivity inherent in visual matching and color perception.

Moreover, the subjective color measurements were taken under natural light with participants seated in the same dental chair, but variations in natural light intensity throughout the day or minor differences in participant positioning could affect the results. Controlled lighting conditions might provide more consistent outcomes. Additionally, while the white balance calibration of the spectrophotometer and the calibration of the intraoral scanner were performed before each measurement, slight variations in calibration processes or operator techniques could still impact the consistency and reliability of the measurements. Lastly, tooth color was obtained only from the middle third of the labial surfaces of specific teeth in this study. Since different parts of the same tooth can exhibit varying shades, assessing only one area may not accurately represent the overall tooth color.

Conclusion

The intraoral scanner in this study effectively matched the spectrophotometer for shade selection using the VITA 3D-Master system, but visual confirmation remains the most reliable method for the best clinical results.

Methods

Study design and ethical approval

This study was designed to evaluate the agreement between digital shade matching and traditional methods (visual matching and spectrophotometric analysis) using two commonly employed shade guide systems: VITA Classical (VC) and VITA 3D-Master (V3D). The research adhered to the ethical principles outlined in the Declaration of Helsinki and received approval from the Ethics Committee of Ajou University Institutional Review Board (No. AJOUIRB-OB-2023-114). Written informed consent was obtained from all participants prior to their inclusion in the study.

Participant selection

A total of 83 adult patients (44 men and 39 women) from Ajou University Dental Hospital participated in this study. Inclusion criteria required that participants had healthy maxillary central incisors, lateral incisors, and canines without structural defects, discoloration, or restorations to ensure standardized conditions for color

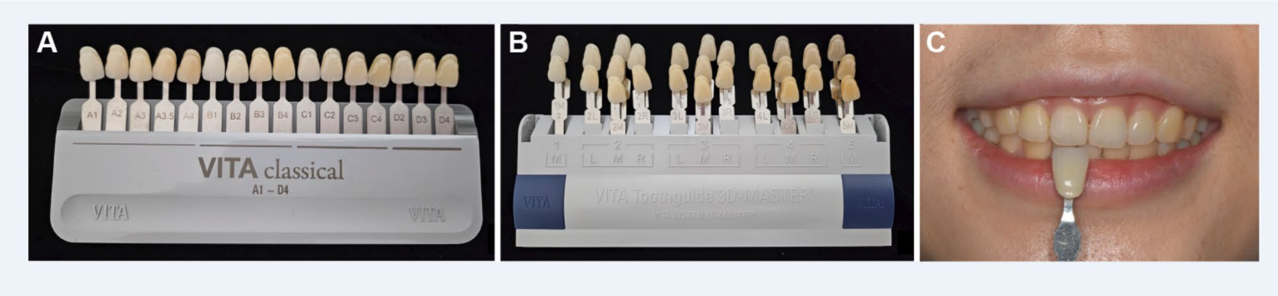

Fig. 1. (**A**) VITA Classical shade guide system; (**B**) VITA 3D-Master shade guide system; and (**C**) visual color matching with a shade tab.

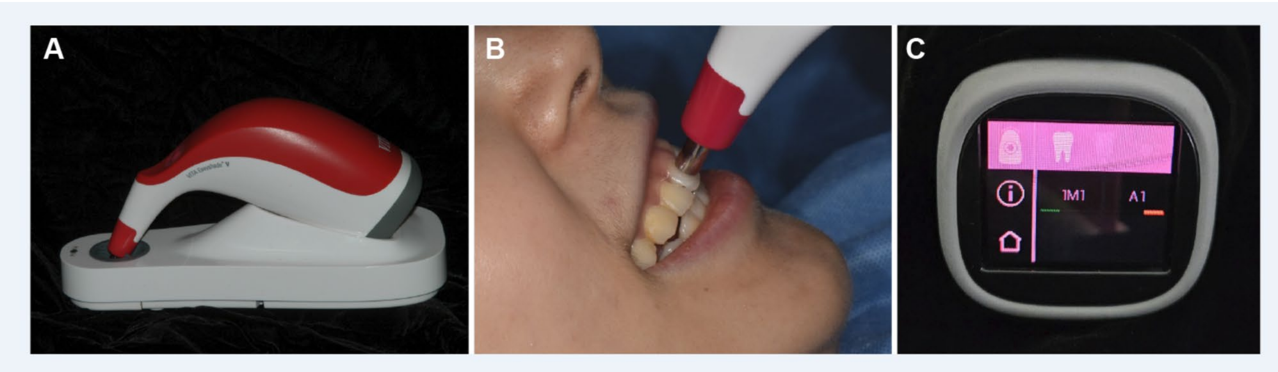

Fig. 2. (**A**) VITA Easyshade V spectrophotometer; (**B**) Shade determination of natural teeth with VITA Easyshade V; and (**C**) Output of the tooth shade in the VITA Classical and VITA 3D-Master systems.

matching. However, this exclusion criterion may limit the applicability of the findings to teeth with similar conditions, which are frequently encountered in clinical practice.

Tooth shade determination methods
Color measurements were obtained from the middle-third of the labial surfaces of 498 teeth (maxillary central incisors, lateral incisors, and canines). To minimize environmental variables, all participants were seated in the same dental chair under natural light, with their heads stabilized on headrests. Foreign substances were removed from the tooth surfaces using gauze before assessments.

Subjective visual matching
The subjective visual color matching (VM) was performed by a prosthodontist with over 20 years of clinical experience using the VC and V3D shade guide systems (Vita Zahnfabrik, Bad Säckingen, Germany) (Fig. 1). The prosthodontist selected shades for each tooth within 10 s to reduce errors related to contrast, residual effects, and eye fatigue[26]. However, despite these precautions, the inherent subjectivity of visual matching presents a risk of individual bias.

Objective spectrophotometric measurement
Objective color measurements were conducted using the VITA Easyshade V intraoral spectrophotometer (SP) (Vita Zahnfabrik, Bad Säckingen, Germany) (Fig. 2). The spectrophotometer was calibrated with white balance before each use to ensure accuracy. The operator, who was trained in the use of the spectrophotometer, placed the measurement tip perpendicular to the middle segment of the target tooth under consistent conditions[27]. The colors were recorded as VC and V3D values (Fig. 2C).

Digital shade matching
Digital shade matching was performed using the Medit i700 wireless intraoral scanner (IOS) (Medit, Seoul, Korea) (Fig. 3A). The Medit i700 wireless, released in 2022 by the Korean digital imaging company Medit, is the latest model in their line of intraoral scanners. As the successor to the Medit i500, it features updated software for enhanced performance including tooth shade matching capabilities. The scanner was calibrated prior to each session. Real-time scan data were acquired from the test teeth, and the color measurement mode of the IOS system was used to match the VC and V3D shade systems. The optimal shade, marked with a star among the three recommended colors, was selected for analysis (Fig. 3B and C).

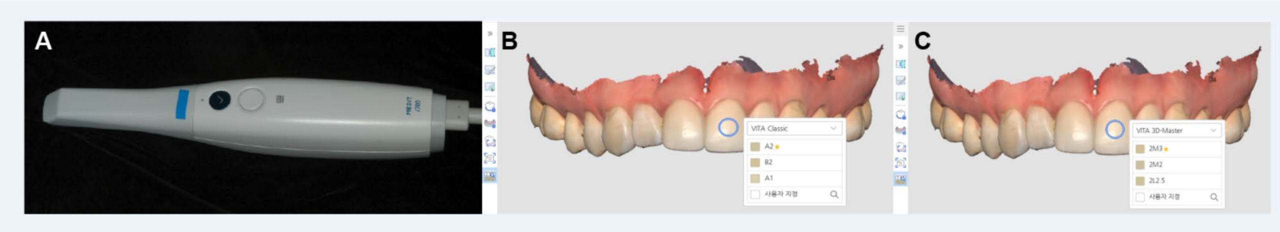

Fig. 3. (**A**) The intraoral scanner tested in this study (Medit i700, Seoul, Korea); Screenshot of the digital color matching on the left central incisor according to (**B**) VITA Classical, and (**C**) VITA 3D-Master shade guide systems.

Hypothesis testing

The null hypothesis of this study was that there would be no significant difference in the shade matching results between the digital (IOS), visual (VM), and spectrophotometric (SP) methods when using the VC and V3D shade guide systems. To test this hypothesis, inter-method agreement was evaluated using weighted Cohen's kappa statistic, with a significance level set at $\alpha = 0.05$.

Statistical analysis

All statistical analyses were conducted using R software (version 4.2.3, https://www.r-project.org/). The inter-method agreement for VC and V3D shade systems was determined using weighted Cohen's kappa to quantify the level of agreement between the digital scanner, visual matching, and spectrophotometric methods. This approach allowed for an assessment of the consistency and reliability of each method in determining tooth color.

However, despite these precautions, the subjective nature of visual matching inherently carries the risk of individual bias.

Data availability

The datasets generated during the current study are available from the corresponding author (H.-K.K.) on reasonable request.

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Author contributions
Conceptualization, H.-K.K.; methodology, H.-K.K.; investigation, H.-K.K., and J.-H.L.; formal analysis, H.-K.K.; data curation, H.-K.K., and J.-H.L.; software, H.-K.K., and J.-H.L.; writing–original draft preparation, H.-K.K., and J.-H.L.; writing–review and editing, H.-K.K.; funding acquisition, H.-K.K. All authors have read and agreed to the published version of the manuscript.

Declarations

Competing interests
The authors declare no competing interests.

Additional information
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