RESEARCH PAPER

Dental Shade Matching: A Comparison Between Visual and Instrumental Method: An in vivo Study

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ABSTRACT

Background: Tooth shade selection is an important step for producing esthetically acceptable restorative and prosthodontic results. Visual shade matching is often used but affected by subjective considerations, while instrumental procedures provide objective color measurements. This study aimed to evaluate the accuracy of visual shade selection compared with spectrophotometric, intraoral scanner and digital image methods utilizing the CIELAB color scheme.

Materials and Methods: Thirty-two subjects with healthy maxillary right central incisor were included in this in vivo comparison investigation. The tooth shade was analyzed using the VITA Classical shade guide (visual approach), VITA Easyshade spectrophotometer, TRIOS 3Shape intraoral scanner, and standardized DSLR digital photography. The CIELAB (L*, a*, b*) coordinates were recorded for each method and color differences (ΔE) calculated. One-way ANOVA, Tukey's post hoc test and Proportion Z-test were used for data analysis and $p<0.05$ was considered statistically significant.

Results: Significant variations were found between the four shade-matching approaches for all CIELAB parameters (L*: F=929.263; a*: F=14.012; b*: F=295.395; $p<0.001$). The spectrophotometer showed the greatest mean L* value (77.88±0.87) and intraoral scanning showed the highest mean b* value (16.25±2.75). Pairwise comparisons indicated substantial differences for most of the approaches. The most comparable method to the visual method was digital photography (68.8%) in terms of ΔE analysis, followed by the intraoral scanner (21.9%) and the spectrophotometer showed no clinically acceptable agreement (0%).

Conclusion: Visual and instrumental shade selection approaches differ significantly. Digital photography was most similar to conventional visual assessment, although spectrophotometry and intraoral scanning offered objective and consistent color measures. The combination of visual and digital methods may enhance the accuracy of shade selection and communication in the laboratory and also achieve better esthetic results in prosthodontic practice.....

Keywords: Dental shade matching, visual shade selection, spectrophotometer, intraoral scanner, digital photography, CIE Lab, prosthodontics..

How to cite this article: Adavikatla S, Kishore KK, Surapaneni H, Sultana N, Yarramaneni DM, Manvi MP..., Dental Shade Matching: A Comparison Between Visual and Instrumental Method: An in vivo Study. Int J Drug Deliv Technol. 2026;16(74s): 943-949. DOI: 10.25258/ijddt.16.74s.114

Source of support: Nil.

Conflict of interest: Nil.

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INTRODUCTION

The need for highly esthetic dental restorations has grown dramatically over the past decade, therefore, precise tooth shade selection is a vital part of modern restorative and prosthodontic practice. The effectiveness of esthetic restorations is associated with both their functional durability and the ability to mimic the color and visual qualities of the neighboring natural teeth. Inaccurate shade matching leads to patient discontent, recurrent laboratory tests, increased treatment costs and poor therapeutic outcomes. Thus, obtaining the ideal shade match has become a prime priority in esthetic dentistry, especially with the increasing expectations of patients for restorations that are virtually indistinguishable from natural teeth.[1]

Shade determination is a complicated clinical process, as natural teeth have unique optical properties. The tooth color is determined by the interplay of enamel and dentin, and is affected by numerous optical phenomena: translucency, fluorescence, opalescence, light scattering and surface texture. Generally, the perception of color is expressed by three coordinates of the color space of the International Commission on Illumination (CIELAB), L* (lightness), a* (red–green axis) and b* (yellow–blue axis). These characteristics give a consistent and objective representation of tooth color and have been used as the foundation of evaluation of shade-matching accuracy in clinical and research contexts.[2]

The visual shade selection with standardized shade guides is considered the gold standard for everyday clinical practice due to its simplicity, cost and convenience of use. The VITA Classical shade guide has been one of the most widely utilized systems worldwide. However, visual shade selection is by definition subjective and affected by several factors including the experience of the observer, color vision, ambient lighting, tooth hydration, surrounding hues, visual weariness, and metamerism. These factors lead to a significant inter- and intra-observer variability, making reliable shade selection challenging even under standardized clinical situations.3,4 The growth of digital dentistry has changed the shade selection with the advent of objective instrumental methods to limit the variability of the operator. Spectrophotometers, colorimeters, intraoral scanners and digital photography systems give quantitative color measurements based on defined optical principles. These systems produce repeatable digital shade information, which minimizes subjective interpretation and enhances communication between clinicians and dental laboratories. Recent systematic data has pointed out that digital shade-matching methods exhibit higher consistency and better reproducibility than traditional visual techniques especially for highly esthetic restoration operations.[5]

Of the numerous digital technologies for clinical shade measurement, spectrophotometers are considered the most precise, as they detect the tooth surface's spectral reflectance and translate that information into standardized CIELAB coordinates. Like-wise, contemporary intraoral scanners are able to combine three dimensional digital impression with real-time shade analysis and therefore improve the efficiency of digital restorative procedures. Standardized digital photography has also become an economical and practical addition to shade communication, allowing doctors to record tooth color precisely and communicate with dental workers using image-analysis software.[6]

Digital technologies have many advantages, but they also have drawbacks. Instrumental accuracy can be influenced by calibration processes, software algorithms, scanning methodologies, ambient lighting, edge-loss effects, and operator training. The widespread use of modern digital technology in many therapeutic settings may also be limited by their relatively high cost. Shade selection is therefore still an important aspect of restorative dentistry and is commonly employed with digital instruments to optimize esthetic results.[7]

In recent years, several studies have been conducted comparing old visual approaches with modern digital shade-selection algorithms. Saiyed et al. revealed that electronic shade-selection devices were more accurate than visual and digital photographic approaches under laboratory regulated settings.[8] Jayasurya et al. also observed substantial disparities between visual, DSLR-based and smartphone-assisted shade selection methods and highlighted the importance of standardization of digital color assessment. 9 Kutkut et al., more recently, found spectrophotometers and colorimeters to be far more accurate and reproducible than standard optical shade matching, suggesting that instrumental procedures may lead to more predictable esthetic outputs.[10] Also, spectrophotometer-based shade selection had the lowest colour difference values among several digital approaches, showing better clinical accuracy, as demonstrated by Şahin and Ural.[11] Similarly, Abu-Hossin et al. stated that intraoral scanners improve digital shade determination, but visual assessment should still be recognized as an essential complementary technique during clinical decision-making.[12]

Although the number of digital shade selection technologies is increasing, there is a lack of direct evidence comparing conventional visual assessment, spectrophotometric analysis, intraoral scanner-based shade determination, and digital photographic methods under the same standardized clinical conditions. A comparative study of various approaches is necessary to find the reliable method that can deliver consistent and clinically acceptable cosmetic results. The present in vivo investigation was performed to evaluate the performance of conventional optical shade matching and three modern instrumental approaches (spectrophotometer, intraoral scanner and digital photography) for dental shade matching. The study was designed to assess the reliability and comparative accuracy of different procedures based on CIELAB color coordinates and to provide evidence-based guidelines for the selection of the most appropriate shade-matching method in contemporary prosthodontic practice.

METHODOLOGY

This in vivo comparison study was undertaken in the Department of Prosthodontics, Sibar Institute of Dental Sciences, Takkellapadu, Guntur, Andhra Pradesh, India, to evaluate and compare the accuracy of conventional visual and instrumental approaches for dental shade matching. The VITA Classical shade guide, VITA Easyshade spectrophotometer, TRIOS 3Shape intraoral scanner and digital photography were compared with each other under defined clinical conditions. The study protocol was approved by the Institutional Ethics Committee, and all subjects provided signed informed consent before enrollment.

A total number of 32 participants were chosen among students of Sibar Institute of Dental Sciences. The study cohort consisted of male and female subjects with a healthy unrestored maxillary right central incisor. Participants with endodontically treated or injured incisors, developmental defects, severe discolouration, restorations, poor oral hygiene, smoking habits, extensive consumption of staining drinks, or parafunctional habits were eliminated.

Prior to shade evaluation, all participants underwent oral prophylaxis to eradicate plaque, calculus, and extrinsic stains. Shade matching was performed before any restorative intervention to preserve the natural tooth color. The middle third of the labial surface of the maxillary right central incisor was selected for examination because it represents the most consistent intrinsic tooth color.

All measurements were done by the same calibrated examiner to reduce inter-operator variability. Normal color vision of the examiner was confirmed using the Ishihara pseudochromatic plate test under the supervision of an ophthalmologist. Participants were asked to remove lipstick and highly colored face make-up before the operation. Shade selection was carried out between 11:00 AM and 1:00 PM under natural daylight on clear sunny days. The participants were placed upright in the same dental chair with the oral cavity at the elbow level of the examiner to standardize the viewing position during the operation. The teeth were kept in moist condition during the examination and each visual observation was limited to 5–7 seconds to prevent retinal fatigue and color adaptation.

Shade selection was done visually with the help of VITA Classical shade guide. Each participant received shade evaluation on three unique occasions across two consecutive sessions to increase repeatability. Shade determination was carried out in a progressive way by analyzing hue, chroma and value. The tooth was assigned to one of the four VITA Classical hue groups (A, B, C, or D) and then the proper chroma within that hue group was determined. The value was finally calculated by comparing the lightness of the teeth with the appropriate shade tabs under uniform illumination. The examiner intermittently fixated on a neutral gray-blue background between observations to minimize visual fatigue. The shade picked most frequently was considered the final shade, and its related CIELAB (L*, a*, b*) values were retrieved from the VITA shade guide database for subsequent study.

For objective shade assessment the VITA Easyshade spectrophotometer was used. The device was calibrated before each measurement, in accordance with the manufacturer's instructions. The measuring probe was positioned perpendicular to the middle third of the labial surface of the maxillary right central incisor, and shade measurements were collected using the Tooth Single mode. The associated CIELAB coordinates (L*, a* and b*) of the device were recorded for statistical comparison.

Digital shadow assessment was performed utilizing the TRIOS 3Shape intraoral scanner. The scanner was calibrated before each recording following the recommendations of the manufacturer. The integrated Tooth Shade mode was used to scan the middle third of the labial surface of the maxillary right central incisor. The CIELAB colour coordinates were recorded as created by the software to allow comparison with the other shade selection processes.

Standardized digital photos were obtained by a Canon EOS 1500D DSLR camera. All images were taken with identical settings, i.e. a shutter speed of 1/100 sec, aperture of f/3.5 and ISO sensitivity of 500. The camera was 21 inches away from the individual and 4 feet 7 inches in height. A chin rest and cheek retractors were employed to keep the head in a constant position and to give an unimpeded view of the tooth under examination. The obtained photos were processed using the Adobe Photoshop software to acquire the matching CIELAB (L*, a*, b*) color coordinates.

The colour difference (ΔE) was calculated using the following equation from the CIELAB coordinates collected by visual, spectrophotometric, intraoral scanning and digital photographic methods:

$$\Delta E = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2}$$

The shade with the lowest ΔE value was considered the best colour match. A ΔE value < 3.7 was considered clinically acceptable, whereas a value ≥ 3.7 was considered clinically unacceptable.

Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables are expressed as mean ± SD. The differences in CIELAB parameters (L*, a*, b*) across the four shade selection methods were analyzed by one-way analysis of variance (ANOVA) followed by Tukey's post hoc test for pairwise comparison. Statistical significance was considered at p-value < 0.05.

RESULTS

The Total number of participants participated in the study was 32. Mean CIELAB color coordinates acquired with the ocular technique, spectrophotometer, intraoral scanner and digital camera are shown in table 1. The spectrophotometer reported the highest mean L* value (77.88 ± 0.87), followed by the intraoral scanner (74.69 ± 1.38), visual technique (64.56 ± 1.44) and digital camera (63.47 ± 1.57). The mean a* was 0.53 ± 0.72 for the intraoral scanner and 1.47 ± 0.67 for the digital camera. Similarly, the intraoral scanner had the greatest mean b* value (16.25 ± 2.75), followed by spectrophotometer (13.91 ± 2.91), visual method (10.50 ± 1.08) and digital camera (1.69 ± 0.69). Statistically significant differences were observed between the 4 shade-matching approaches in all 3 CIELAB parameters (L*: F = 929.263, a*: F = 14.012, b*: F = 295.395; $p < 0.001$) according to the one-way ANOVA (Table 1).

Pairwise comparison using Tukey's post hoc test (Table 2) showed that almost all approaches were significantly different in L* values. The spectrophotometer showed considerably higher L* values than the eye method (mean difference = −13.31; $p < 0.001$) and intraoral scanner (mean difference = 3.19; $p < 0.001$). The intraoral scanner also showed considerably higher values of L* than the digital camera (mean difference = 11.22; $p < 0.001$). However, the difference in L* values between visual technique and digital camera albeit statistically significant was rather small (mean difference = 1.09; p = 0.008) showing a greater agreement between these two ways of lightness measurement.

For the a* coordinate, there was no statistically significant difference between the visual method and spectrophotometer (mean difference = −0.13; p = 0.865) or between the visual method and intraoral scanner (mean difference = 0.09; p = 0.937), suggesting similar measurements of the red-green component. On the other hand, the digital camera showed substantially higher a* values than all the other methods ($p < 0.001$), indicating a bigger variance in the measurement of this color coordinate. Statistically significant differences were found among all the shade matching approaches in the b* coordinate comparison ($p < 0.001$). The intraoral scanner had the greatest b* values, followed by the spectrophotometer and visual method, whilst the digital camera had the lowest b* values. The largest difference was seen between the intraoral scanner and the digital camera (mean difference = 14.56; $p < 0.001$), showing large variance in the evaluation of the yellow-blue component.

The agreement study based on ΔE values showed large disparities between the visual method and the three instrumental techniques (Table 3). No acceptable agreement (ΔE < 3.7) was found between the visual technique and spectrophotometer, with all the individuals (100%) demonstrating clinically unsatisfactory color variations (p = 0.003). The intraoral scanner revealed good agreement in 7 subjects (21.9%) and clinically undesirable color discrepancies in 25 subjects (78.1%), however the difference was not statistically significant (p = 0.052). The digital camera was the best way for agreement with the eye approach, 22 (68.8%) of the participants were in acceptable color matching, and 10 (31.2%) were in unacceptable agreement (p = 0.003).

Table 1. Descriptive statistics of CIELAB color coordinates obtained using different shade-matching methods

Parameter	Visual Method (Mean ± SD)	Spectrophotometer (Mean ± SD)	Intraoral Scanner (Mean ± SD)	Digital Camera (Mean ± SD)	F value	p value
L*	64.56 ± 1.44	77.8 ± 0.87	74.69 ± 1.38	63.47 ± 1.57	929.263	<0.001*
a*	0.63 ± 0.71	0.75 ± 0.44	0.53 ± 0.72	1.47 ± 0.67	14.012	<0.001*
b*	10.50 ± 1.08	13.91 ± 2.91	16.25 ± 2.75	1.69 ± 0.69	295.395	<0.001*

*- One-way ANOVA

Table 2. Pairwise comparison of CIELAB values among shade-matching methods (Tukey's post hoc analysis)

Comparison	L* (Mean Difference)	p value	a* (Mean Difference)	p value	b* (Mean Difference)	p value
Visual vs Spectrophotometer	-13.31	<0.001*	-0.13	0.865	-3.41	<0.001*
Visual vs Intraoral Scanner	-10.13	<0.001*	0.09	0.937	-5.75	<0.001*
Visual vs Digital Camera	1.09	0.008*	-0.84	<0.001*	8.81	<0.001*
Spectrophotometer vs Intraoral Scanner	3.19	<0.001*	0.22	0.528	-2.34	<0.001*
Spectrophotometer vs Digital Camera	14.41	<0.001*	-0.72	<0.001*	12.22	<0.001*
Intraoral Scanner vs Digital Camera	11.22	<0.001*	-0.94	<0.001*	14.56	<0.001*

*Tukey's multiple comparison test; *p < 0.05 indicates statistical significance.*

Table 3. Agreement of ΔE values between the visual method and instrumental shade-matching methods

Instrumental Method	Acceptable Agreement (ΔE < 3.7), n (%)	Unacceptable Agreement (ΔE ≥ 3.7), n (%)	p value
Spectrophotometer	0 (0.0)	32 (100.0)	0.003*
Intraoral Scanner	7 (21.9)	25 (78.1)	0.052
Digital Camera	22 (68.8)	10 (31.2)	0.003*

*Proportion Z-test

DISCUSSION

Accurate tooth shade selection is fundamental to the esthetic success of restorative and prosthodontic treatment. Although conventional visual shade selection remains the most widely used technique because of its simplicity, affordability, and ease of application, recent advances in digital technology have introduced objective methods that minimize operator-related variability. The present in vivo study compared conventional visual shade selection with three instrumental techniques—spectrophotometry, intraoral scanning, and digital photography—using the CIELAB color system. Significant differences were observed among all four methods for the L*, a*, and b* coordinates, indicating that each technique measures tooth color differently.

The spectrophotometer recorded significantly higher L* values than the visual method, indicating comparatively brighter shade measurements. These findings are consistent with those reported by Ruiz-López et al.[13] and Gómez-Polo et al.[14], who demonstrated that spectrophotometers objectively quantify tooth color and frequently produce higher lightness values than visual assessment. Similarly, Paul et al.[15] reported that spectrophotometric analysis provides reproducible numerical color measurements by minimizing observer subjectivity. Despite its superior objectivity, the present study found no acceptable ΔE agreement between the spectrophotometer and the visual method. This finding does not imply inferior accuracy of the spectrophotometer but rather reflects the inherent differences between instrumental measurements and human visual perception. Similar observations were reported by Igiel et al.[16], Alshiddi and Richards[17], and Kalantari et al.[18], who concluded that spectrophotometers provide highly reproducible measurements that may not always correspond to visually selected shades because of variations in translucency, hydration, gloss, and ambient lighting.

The intraoral scanner demonstrated intermediate performance among the evaluated techniques. Although no significant difference was observed for the a* coordinate compared with the visual method, significant differences were found for the L* and b* values. These findings indicate that intraoral scanners provide objective and standardized color measurements but cannot completely replicate conventional visual shade selection. Comparable findings have been reported by Liberato et al.[19], who observed moderate agreement between visual, spectrophotometric, and intraoral scanner methods. Likewise, the systematic review by Akl et al.[20] concluded that intraoral scanners are promising tools for shade determination; however, their accuracy depends on scanner technology, calibration, software algorithms, and clinical operating conditions. Similar results were reported by Lee and Kim[21], Floriani et al.[22], and Czigola et al.[23], who recommended the use of intraoral scanners as adjuncts rather than substitutes for conventional visual shade selection.

Among the evaluated instrumental techniques, digital photography demonstrated the highest agreement with the visual method, with 68.8% of participants exhibiting clinically acceptable ΔE values. This suggests that standardized digital photography closely reproduces the clinician's visual perception while providing objective documentation for communication with dental laboratories. These findings are consistent with those of Bhandari et al.[14], Kelkar et al.[24], Miyajiwala et al.[25], and Tam and Lee[26], who reported that digital photographic analysis improves shade communication, reduces observer variability, and provides clinically acceptable shade matching when standardized imaging protocols are followed.

The differences observed among the four techniques may be attributed to the complex optical characteristics of natural teeth. Tooth color is influenced not only by hue, chroma, and value but also by translucency, fluorescence, opalescence, surface texture, hydration, and illumination. Instrumental devices objectively analyze reflected light using optical sensors and software algorithms, whereas visual shade selection relies on the clinician's interpretation of multiple optical cues. Consequently, complete agreement between visual and instrumental methods is unlikely.

Several investigators have emphasized that digital technologies should complement rather than replace conventional visual assessment. Tabatabaian et al.[27] concluded that digital techniques improve precision and reproducibility but cannot eliminate the need for clinical judgment. Similarly, Vivek et al.[28] recommended integrating visual assessment with digital technologies to achieve optimal esthetic outcomes. Sirintawat et al.[29] also reported high repeatability of instrumental techniques while highlighting the influence of calibration, positioning, and environmental conditions. Furthermore, Dozić et al.[30] demonstrated considerable variability among commercially available shade-measuring devices, indicating that results obtained from different instruments should not be considered directly interchangeable.

The findings of the present study have important clinical implications. Although spectrophotometers, intraoral scanners, and digital photography provide objective and reproducible shade measurements, each technique possesses inherent limitations. Within the limitations of this study, digital photography demonstrated the closest agreement with conventional visual shade selection and appears to be the most practical adjunct for routine prosthodontic practice. Combining standardized digital photography with careful visual assessment may improve shade communication, reduce remakes, and enhance patient satisfaction.

The present study has certain limitations. The relatively small sample size and single-center design may limit the generalizability of the findings. Only healthy young adults with unrestored maxillary central incisors were included, and shade assessment was restricted to the VITA Classical shade guide. In addition, all measurements were performed by a single calibrated examiner. Future multicenter studies with larger and more diverse populations, different shade guide systems, and artificial intelligence-assisted shade selection technologies are recommended to further validate these findings.

CONCLUSION

Digital photography demonstrated the closest agreement with conventional visual assessment, while spectrophotometry and intraoral scanning provided objective measurements. Combining visual and digital techniques may improve shade matching and esthetic outcomes..

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