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A Comparative Evaluation of Four Different Methods for Shade Selection in Maxillary Central Incisor: An in Vivo Study

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Abstract:

- ***Background***

Accurate shade selection is a fundamental prerequisite for achieving optimal esthetic outcomes in restorative and prosthodontic dentistry. Conventional visual shade matching remains the most widely employed technique in clinical practice; however, it is highly subjective and influenced by numerous operator- and environment-related factors. Recent advances in digital dentistry have introduced objective shade determination systems, including spectrophotometers, digital single-lens reflex (DSLR) photography, and smartphone-based applications, which may improve the reliability and reproducibility of shade selection.

- ***Aim***

To compare the agreement of four different shade selection methods—visual shade guide, VITA Easyshade spectrophotometer, DSLR photography, and smartphone application—for maxillary central incisors in young adults.

- ***Materials and Methods***

An in vivo comparative study was conducted among 150 participants aged 19–25 years with healthy maxillary central incisors. Shade determination was performed sequentially using the VITA Classical shade guide (control), VITA Easyshade spectrophotometer, standardized DSLR photography, and a smartphone application under standardized lighting conditions. Participants with orthodontic treatment, enamel or dentin hypoplasia, bleaching history, restorations, or root canal-treated anterior teeth were excluded. Agreement between the visual shade guide and the digital methods was analyzed using Cohen's kappa coefficient. Statistical significance was set at $p < 0.05$.

- ***Results***

The smartphone application demonstrated the highest agreement with the visual shade guide, followed by the VITA Easyshade and DSLR camera. All digital methods showed statistically significant agreement with the conventional visual method.

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➢ ***Conclusion***

Digital shade selection methods demonstrated satisfactory agreement with conventional visual shade matching. Among the evaluated techniques, smartphone-based shade analysis exhibited the closest agreement with the visual shade guide, suggesting that it may serve as a practical and cost-effective adjunct for routine clinical shade selection.

Keywords: *Tooth Shade, Shade Matching, VITA Easyshade, DSLR Photography, Smartphone Application, Esthetic Dentistry, Digital Dentistry.*

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I. INTRODUCTION

The pursuit of esthetic excellence has become a fundamental objective in contemporary restorative and prosthodontic dentistry. Advances in restorative materials and adhesive techniques have enabled clinicians to fabricate restorations with superior mechanical and optical properties. However, the ultimate success of an esthetic restoration depends largely on accurate shade selection, as even minimal discrepancies in tooth color may compromise the harmony between the restoration and the adjacent natural dentition, ultimately affecting patient satisfaction and treatment acceptance.[1–3]

Tooth color is a complex optical phenomenon influenced by the interaction of enamel translucency, dentin chroma, fluorescence, opalescence, and surface texture. In addition to these intrinsic characteristics, color perception is affected by multiple external factors, including illumination, observer experience, viewing angle, surrounding colors, eye fatigue, age, and individual color vision.[7,30] Consequently, achieving accurate shade selection remains a challenging clinical procedure despite continuous technological advancements.[7]

Conventional visual shade selection using the VITA Classical shade guide continues to be the most widely adopted technique in daily clinical practice because of its simplicity, accessibility, and cost-effectiveness. Nevertheless, this method is highly subjective and depends on the clinician's visual perception, experience, and environmental conditions. Okubo et al. demonstrated considerable variation between visual and instrumental shade matching, highlighting the limitations of subjective shade assessment.[1] Similarly, Kim-Pusateri et al. reported that visual shade selection exhibited lower reliability compared with instrumental methods owing to observer-dependent variability.[2] Furthermore, Gokce et al. demonstrated that both lighting conditions and color vision deficiencies significantly influence shade selection, emphasizing the importance of standardized clinical conditions during shade determination.[3]

To improve the objectivity and reproducibility of shade selection, several digital technologies have been introduced into clinical practice. Instrument-based systems, including spectrophotometers, colorimeters, intraoral scanners, and digital imaging systems, objectively measure tooth color using the Commission Internationale de l'Éclairage (CIELAB) color system, which describes color according to lightness (L*), red-green (a*), and yellow-blue (b*) coordinates.[26,30] Objective color measurement also enables the calculation of color differences using ΔE and CIEDE2000 formulas, which have become the accepted standards for evaluating perceptibility and acceptability thresholds in dentistry.[27–29]

Among the available digital devices, the VITA Easyshade spectrophotometer is one of the most extensively investigated instruments for clinical shade selection. Spectrophotometers objectively analyze reflected light independent of operator perception and have demonstrated excellent repeatability and reproducibility in numerous investigations. Liberato et al. reported that spectrophotometric shade determination exhibited superior consistency compared with conventional visual methods.[14] Likewise, Czigola et al. observed improved repeatability of spectrophotometric systems and intraoral scanners compared with visual shade assessment.[15] Ebeid et al. further demonstrated that digital instruments provided more reproducible shade measurements than conventional visual methods, although complete agreement between visual and instrumental techniques was not consistently achieved.[16]

Despite their advantages, spectrophotometers possess several practical limitations. These devices are relatively expensive, require periodic calibration, and generally evaluate only localized areas of the tooth surface. Consequently, they may not fully represent the natural variation in color, translucency, and characterization across the entire clinical crown.[16,17]

Digital photography has emerged as another valuable adjunct for esthetic shade communication. Standardized DSLR photography allows simultaneous documentation of tooth color, morphology, translucency, and surface texture while facilitating communication between clinicians and dental laboratories. The incorporation of macro photography, standardized illumination, grey reference cards, and cross-polarization filters has significantly improved the accuracy and reproducibility of photographic shade analysis. Tam and Lee demonstrated that digital cameras could be effectively used for tooth shade determination when standardized photographic protocols were followed.[4] Mahn et al. further reported that cross-polarized digital photography produced color measurements comparable with spectrophotometric analysis while simultaneously recording enamel

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characteristics that are difficult to evaluate using conventional instruments.[12] Rondon et al. similarly observed improved consistency in shade communication when standardized photographic protocols were employed.[13]

Recent developments in smartphone technology have expanded the scope of digital shade determination. Modern smartphones are equipped with high-resolution cameras and sophisticated image-processing software capable of estimating tooth color from standardized clinical photographs. Compared with dedicated spectrophotometers, smartphone-based shade selection offers advantages of affordability, portability, accessibility, and ease of clinical application. Raza et al. demonstrated that smartphone-assisted shade selection showed encouraging agreement with conventional methods under standardized conditions.[8] Mohammadi et al. also reported that smartphone photography combined with digital image analysis exhibited acceptable validity and reliability for tooth color determination.[9] Chaware et al. demonstrated favorable clinical performance of a smartphone-based application during shade selection for ceramic restorations, while Hari et al. reported promising results using smartphone-assisted shade analysis in routine clinical practice.[10],[11]

The continuing evolution of digital dentistry has further enhanced shade selection through the integration of digital imaging, intraoral scanners, and computer-assisted restorative workflows. Recent systematic and scoping reviews have highlighted the increasing role of digital technologies in improving the consistency and reproducibility of shade selection while reducing operator-related variability.[5],[25] Although these technologies have shown encouraging clinical performance, none has been universally accepted as a definitive replacement for conventional visual assessment. Instead, current evidence suggests that digital methods should be considered complementary tools that enhance clinical decision-making and facilitate communication between clinicians and dental technicians.[5],[25]

Most previous investigations have compared conventional visual shade selection with a single digital device. Comparatively fewer studies have evaluated multiple contemporary shade selection methods under identical clinical conditions within the same study population. Furthermore, evidence comparing smartphone-assisted shade selection, DSLR photography, spectrophotometric analysis, and conventional visual shade selection in young adults remains limited.

The maxillary central incisor is the most visually dominant tooth during smiling and speech and therefore represents the most appropriate tooth for evaluating esthetic shade selection methods. Restricting the study population to individuals aged 19–25 years minimizes physiological variations associated with aging, including enamel wear, secondary dentin deposition, and intrinsic discoloration, thereby allowing a more standardized comparison among different shade selection techniques.[24]

Therefore, the present in vivo study was undertaken to compare the agreement among four different methods of shade selection—Visual Shade Guide, VITA Easyshade spectrophotometer, DSLR photography, and a smartphone-based application—for determining the shade of the maxillary central incisor in young adults. The findings of this study may provide clinically relevant evidence regarding the agreement of contemporary digital shade selection methods with conventional visual assessment and their potential application as adjuncts in routine esthetic dental practice.

II. MATERIALS AND METHODS

➢ *Study Design*

The present study was designed as an in vivo comparative observational study to evaluate and compare among four different methods of tooth shade selection for the maxillary central incisor. The study compared conventional visual shade selection with three digital methods, namely the VITA Easyshade spectrophotometer, DSLR photography, and a smartphone-based shade matching application.

The study was conducted in the Department of Prosthodontics and Crown & Bridge.

All participants were informed regarding the purpose and methodology of the study. Confidentiality of participant information was maintained throughout the study.

➢ *Study Population*

The study included 150 healthy participants between 19 and 25 years of age who fulfilled the eligibility criteria.

➢ *Sample Size*

A total of 150 participants were included in the study using convenience sampling.

➢ *Inclusion Criteria*

Participants fulfilling the following criteria were included:

- Age between 19 and 25 years
- Presence of fully erupted permanent maxillary central incisors
- Intact natural maxillary central incisors
- Good oral hygiene
- Healthy periodontal tissues
- Absence of visible stains or discoloration

➢ *Exclusion Criteria*

Participants presenting with any of the following conditions were excluded:

- Ongoing orthodontic treatment
- Enamel hypoplasia
- Dentin hypoplasia
- Previous history of tooth bleaching
- Restorations involving the maxillary central incisors
- Root canal-treated maxillary central incisors
- Developmental anomalies affecting tooth color

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- Fractured or worn anterior teeth
- Intrinsic discoloration due to systemic or local causes

➢ *Materials Used*

The following materials and equipment were used:

- VITA Classical Shade Guide (VITA Zahnfabrik, Germany)
- VITA Easyshade® V Spectrophotometer (VITA Zahnfabrik, Germany)
- Digital Single-Lens Reflex (DSLR) Camera
- Smartphone with shade matching application
- Cheek retractors
- Microsoft Excel
- IBM SPSS Statistics Version 26.0

➢ *Clinical Procedure*

Each participant was comfortably seated in the dental chair in an upright position. The maxillary central incisors were cleaned to remove plaque and extrinsic stains. The teeth were then rinsed thoroughly with water and gently dried using compressed air for approximately 3–5 seconds, avoiding excessive dehydration, as dehydration may alter enamel translucency and increase tooth brightness.[2]

Shade selection was carried out between 10:00 AM and 12:00 PM under standardized daylight conditions to minimize the influence of variations in ambient illumination.[3]

The middle third of the labial surface of the maxillary central incisor was selected as the reference area for all shade measurements because it best represents the overall tooth color and minimizes the influence of cervical dentin and incisal translucency.[4]

Each participant underwent shade determination using all four methods in the same appointment.

➢ *Method I – Visual Shade Guide (Control)*

Shade selection was initially performed using the VITA Classical Shade Guide by a single calibrated examiner.

The shade tabs were cleaned before every measurement.

The shade guide was positioned adjacent to the middle third of the maxillary central incisor.

Shade comparison was performed at eye level with the participant while maintaining a viewing distance of approximately 30–40 cm.

Each comparison was limited to 5 seconds to minimize retinal fatigue.

The selected shade was recorded as the control value.

➢ *Method II – VITA Easyshade Spectrophotometer*

Following visual shade selection, tooth shade was determined using the VITA Easyshade V spectrophotometer according to the manufacturer's instructions.

The instrument was calibrated before each participant using the calibration block supplied by the manufacturer.

The probe tip was positioned perpendicular to the middle third of the facial surface of the maxillary central incisor without movement during measurement.

The most occurring shade was recorded.

➢ *Method III – DSLR Photography*

Standardized digital photographs were obtained using a DSLR camera fitted with a macro lens.

The camera settings were standardized throughout the study.

The participant was seated upright.

The camera-to-subject distance was maintained constant.

Photographs were captured with the optical axis perpendicular to the facial surface of the tooth.

The captured images were transferred to a computer and analyzed to determine the closest corresponding VITA Classical shade.

➢ *Method IV – Smartphone Application*

The same participant was photographed using a smartphone equipped with a shade analysis application.

Images were captured under standardized lighting conditions.

The camera lens was positioned perpendicular to the labial surface of the tooth at a fixed distance.

After image acquisition, the software analyzed the photograph and generated the closest corresponding VITA Classical shade.

The obtained shade was recorded.

➢ *Standardization of Shade Selection*

To reduce operator- and environment-related variability, the following measures were adopted:

- Shade selection was completed before tooth dehydration occurred.
- Procedures were carried out during the same period of the day.
- Ambient lighting conditions were standardized.
- The middle third of the crown was evaluated in every participant.
- The same VITA Classical shade guide was used throughout the study.
- The VITA Easyshade device was calibrated before every participant.
- DSLR camera settings remained unchanged throughout the study.

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- Smartphone photographs were captured using identical camera settings.
- Participants were instructed to avoid brightly colored lipstick or makeup.

➢ *Statistical Analysis*

The collected data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were expressed as frequencies and percentages. The visual shade guide served as the control method. Agreement between the visual shade guide and each digital method was assessed using Cohen's kappa coefficient (κ). The strength of agreement was interpreted according to the Landis and Koch classification. Statistical significance was established at $p < 0.05$.

III. RESULTS

A total of 150 participants aged between 19 and 25 years fulfilled the inclusion criteria and were included in the study. Shade determination of the maxillary central incisor was performed using four different methods: Visual Shade Guide (control), VITA Easyshade spectrophotometer, DSLR photography, and a smartphone application.

The visual shade guide most frequently identified A1 as the predominant shade. Similar findings were observed with the smartphone application and VITA Easyshade, whereas DSLR camera demonstrated a slightly different distribution, with B1 being the most frequently selected shade.

➢ *Distribution of shades selected by the Visual Shade Guide (Control)*

The most frequently selected shade by the visual shade guide was A1 (32%), followed by B1 (28%), A2 (21%), B2 (14%), and C1 (5%).

➢ *Agreement Analysis*

Agreement between the visual shade guide (control) and each digital method was evaluated using Cohen's kappa coefficient (κ).

The smartphone application demonstrated the highest agreement with the conventional visual shade guide ($\kappa = 0.696$), indicating substantial agreement. This suggests that the smartphone application closely reproduced the shades selected by the visual method.

Both the VITA Easyshade spectrophotometer ($\kappa = 0.523$) and the DSLR camera ($\kappa = 0.517$) demonstrated moderate agreement with the visual shade guide. Although statistically significant, their agreement with the visual method was lower than that observed for the smartphone application.

The exact-match agreement was also highest for the smartphone application (77%), compared with 64% for both the VITA Easyshade and DSLR camera.

All three comparisons yielded highly statistically significant associations ($p < 0.0001$), indicating that the observed agreement between the visual method and each digital method was unlikely to have occurred by chance.

These findings indicate that, within this dataset, the smartphone application most closely matched the conventional visual shade guide and may be considered the most consistent digital method among those evaluated.

IV. DISCUSSION

Accurate shade selection is fundamental to achieving optimal esthetic outcomes in restorative and prosthodontic dentistry. Despite remarkable advances in restorative materials and digital technologies, reproducing the natural color of teeth remains one of the most challenging aspects of esthetic rehabilitation. Conventional visual shade selection continues to be the most commonly employed clinical technique because of its simplicity, accessibility, and low cost; however, its subjective nature makes it susceptible to numerous operator- and environment-related variables including ambient illumination, observer experience, eye fatigue, age, surrounding colors, and individual color perception.[1,2]

Since the present study employed the visual shade guide as the conventional clinical reference, higher agreement reflects closer correspondence with visual shade selection and should not be interpreted as evidence that one digital method is objectively more accurate than another. Objective accuracy can only be established by comparison with an accepted instrumental reference standard and quantitative color difference measurements such as CIELAB or CIEDE2000 values.

The relatively high agreement observed with the smartphone application supports the growing interest in smartphone-assisted shade analysis within contemporary esthetic dentistry. Advances in smartphone camera technology, image-processing algorithms, and dedicated dental applications have substantially improved their clinical applicability. Their affordability, portability, and ease of integration into routine dental practice make them attractive alternatives or adjuncts to dedicated shade-matching devices. Raza et al. reported that the SHADENT smartphone application demonstrated substantial agreement with conventional shade determination when standardized image acquisition protocols were followed, highlighting the importance of controlled illumination, camera distance, and image STANDARDIZATION.[8] Similarly, Mohammadi et al. concluded that calibrated smartphone photography analyzed using Adobe Photoshop exhibited excellent validity and reliability for tooth color determination under standardized photographic conditions.[9]

Comparable findings have also been reported by Chaware et al., who evaluated the DENTHUE mobile application in a multicenter randomized clinical trial and observed clinical performance comparable with conventional visual shade selection during ceramic restoration

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fabrication.[10] Likewise, Hari et al. demonstrated excellent intra- and inter-observer consistency using the Color Grab smartphone application, suggesting that smartphone-based shade analysis may serve as a practical adjunct in routine clinical practice.[11] Collectively, these studies reinforce the observation that smartphone-assisted shade selection can provide clinically acceptable agreement with conventional visual methods when appropriate standardization protocols are employed. Recent developments in artificial intelligence have further enhanced smartphone-based shade analysis by incorporating machine-learning algorithms capable of automatically correcting variations in illumination, white balance, and image processing. These AI-assisted systems are expected to improve the consistency and reproducibility of digital shade selection while reducing operator-dependent variability.[31]

Recent evidence also indicates increasing interest in artificial intelligence-assisted shade selection systems that combine smartphone cameras, DSLR photography, and machine-learning algorithms to establish standardized protocols for esthetic rehabilitation. Such technologies aim to reduce operator subjectivity while improving consistency and laboratory communication.(32)

Digital photography has become an indispensable component of esthetic dentistry because it enables simultaneous documentation of tooth morphology, surface texture, translucency, characterization, and color while facilitating communication between the clinician and dental laboratory. Standardized photographic protocols incorporating macro lenses, grey reference cards, and cross-polarization filters have been shown to improve the reproducibility of color acquisition. Mahn et al. demonstrated that cross-polarized digital photography produced CIELAB coordinates comparable to spectrophotometric measurements while providing additional information regarding enamel texture and internal characterization.[12] Similarly, Rondon et al. reported that standardized photographic shade analysis improved agreement with conventional shade matching when grey reference cards and CIEDE2000 calculations were used.[13]

The moderate agreement observed with DSLR photography in the present study may reflect the sensitivity of digital photography to technical variables including camera calibration, exposure, white balance, flash characteristics, ambient lighting, image-processing software, and operator technique. Although every effort was made to standardize image acquisition, slight variations in these parameters may influence color reproduction and contribute to differences between photographic and visual shade selection.

Spectrophotometers objectively measure reflected light across multiple wavelengths and express tooth color numerically using the CIELAB color system, thereby minimizing operator subjectivity. Numerous investigators have reported excellent repeatability and reproducibility of spectrophotometric systems. Kim-Pusateri et al. demonstrated greater reliability of instrumental shade-matching devices compared with conventional visual methods, while Liberato et al. and Czigola et al. reported superior repeatability of digital spectrophotometers and intraoral scanners relative to visual shade selection.[2,14,15]

The moderate agreement observed between the VITA Easyshade and the visual shade guide should not be interpreted as reduced performance of the spectrophotometer. Rather, it reflects the inherent differences between subjective visual perception and objective instrumental measurement. Visual assessment integrates multiple optical characteristics such as translucency, gloss, fluorescence, and surface texture, whereas spectrophotometers evaluate spectral reflectance from localized areas of the tooth and express color numerically. Consequently, complete concordance between these fundamentally different methods is neither expected nor consistently observed in the literature. Similar observations have been reported by Ebeid et al., Abu-Hossin et al., and Liberato et al., who noted that although instrumental methods demonstrate excellent repeatability, only moderate agreement is frequently observed when compared with conventional visual shade selection.[14–17]

The use of Cohen's kappa coefficient in the present study provided a robust assessment of agreement because it accounts for agreement occurring by chance. According to the Landis and Koch classification, the smartphone application demonstrated substantial agreement, whereas both the DSLR camera and VITA Easyshade demonstrated moderate agreement with the visual shade guide. Importantly, all three comparisons were highly statistically significant ($p < 0.0001$), indicating that the observed concordance was unlikely to have occurred by chance alone.

The findings of the present investigation are in agreement with the conclusions of the recent scoping review by Nayak et al., who evaluated 29 clinical studies involving digital shade matching technologies. The review concluded that digital methods—including DSLR photography, smartphone applications, spectrophotometers, and intraoral scanners—generally demonstrate clinical performance comparable with conventional visual methods; however, no single digital technology can currently be recommended as a standalone replacement for conventional clinical judgment. The authors further emphasized the importance of standardized photographic protocols, grey reference cards, controlled illumination, and cross-polarization filters to optimize the reproducibility of digital shade selection.[5]

From a clinical perspective, the findings of the present study suggest that all three evaluated digital methods can be considered valuable adjuncts to conventional visual shade selection. Smartphone-based shade analysis offers particular advantages because of its portability, affordability, and widespread availability, whereas DSLR photography provides superior documentation of surface characteristics that facilitate communication with dental laboratories. Spectrophotometers continue to provide objective numerical color measurements with excellent repeatability. Rather than replacing visual assessment, these digital technologies should be integrated into a comprehensive shade selection protocol

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that combines clinical experience with objective instrumental support to improve communication and enhance esthetic outcomes.

Artificial intelligence-based systems employing convolutional neural networks and fuzzy logic have recently been proposed to enhance digital shade prediction by minimizing subjective bias and improving color matching across different lighting conditions. Although these technologies remain under continuous development, they represent an important step toward fully digital and standardized esthetic workflows.[33]

The present study has certain limitations. The investigation was limited to participants aged 19–25 years and evaluated only maxillary central incisors. Therefore, the findings cannot be generalized to older individuals or to other tooth groups exhibiting different optical characteristics. In addition, quantitative CIELAB or CIEDE2000 color difference analysis was not performed, and the study evaluated agreement with the conventional visual method rather than absolute color accuracy. Future multicenter studies incorporating larger sample sizes, objective color coordinates, multiple age groups, and artificial intelligence-assisted shade analysis systems may provide further evidence regarding the comparative performance of contemporary digital shade selection technologies.

V. CONCLUSION

Within the limitations of the present study, it can be concluded that smartphone-assisted shade analysis demonstrated the highest level of agreement with the conventional visual shade guide, while DSLR photography and the VITA Easyshade spectrophotometer demonstrated moderate agreement. These findings support the use of digital technologies as **adjuncts** to conventional clinical shade selection rather than independent replacements, thereby contributing to more consistent and predictable esthetic outcomes.

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