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Research Article

Comparative Evaluation of Spectrophotometric and Artificial Intelligence-Based Tooth Shade Determination

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Abstract

Aim: The aim of the present study was to evaluate the agreement between spectrophotometric tooth shade determination and an artificial intelligence-based method using standardized digital images of maxillary central incisors.

Materials and Methods: A comparative clinical study was conducted on 25 patients aged between 18 and 30 years with intact natural dentition in the anterior maxillary region. A total of 50 teeth were examined, including the maxillary right central incisor 11 and the maxillary left central incisor 21. Tooth shade was determined using SpectroShade Micro II/SpectroShade according to the VITA Classical and VITA 3D-Master shade systems. Standardized digital photographs were obtained using a Canon EOS SL3 camera in manual mode with fixed exposure parameters. A grey card was included in each image for white balance standardization. The images were processed in Adobe Lightroom Classic software and subsequently analyzed using ChatGPT based on the GPT-5.5 Thinking model. Agreement between SpectroShade and ChatGPT was assessed by calculating the percentage of complete agreement and the unweighted Cohen's kappa coefficient.

Results: Complete agreement between SpectroShade and ChatGPT was observed in 32 out of 50 teeth for both shade systems, corresponding to an agreement rate of 64.0%. The Cohen's kappa value was $\kappa = 0.402$ for VITA Classical and $\kappa = 0.494$ for VITA 3D-Master, indicating moderate agreement between the two methods.

Conclusion: Within the limitations of the present study, the artificial intelligence-based method demonstrated moderate agreement with spectrophotometric shade determination. ChatGPT may be considered a potential auxiliary tool for tooth shade assessment when standardized photographic protocols are applied. However, it should not be regarded as a substitute for spectrophotometric evaluation.

Keywords

artificial intelligence, tooth shade determination, spectrophotometry, color, ChatGPT, VITA Classical, VITA 3D-Master

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Introduction

Accurate tooth shade determination is a key factor for achieving predictable esthetic outcomes in prosthetic and restorative dentistry. The selection of an appropriate shade influences the optical integration of restorations with the surrounding natural dentition and is particularly important in the anterior region. Conventional visual shade selection is widely used in clinical practice; however, it is influenced by multiple subjective and environmental factors, including lighting conditions, observer experience, tooth hydration, surrounding soft tissues, and the optical characteristics of the tooth surface.

In recent years, digital technologies have increasingly been introduced into dental medicine, aiming to improve precision, reproducibility, and standardization. In prosthetic dentistry, this trend is especially relevant because both clinical and laboratory stages require accurate transfer of information between the clinician, dental technician, and patient. Among these technologies, artificial intelligence has gained increasing attention as a tool with potential clinical impact.

Artificial intelligence is increasingly being applied in dental medicine for diagnosis, treatment planning, image analysis, and clinical decision support (1,2). In prosthetic dentistry, AI-based methods may be particularly useful in procedures requiring high precision, reproducibility, and standardization.

Several studies have investigated the use of AI and machine learning for tooth shade determination. Almoro et al. evaluated a mobile application based on image recognition and machine learning as an accessible alternative for objective shade selection. Their results demonstrated satisfactory accuracy and high effectiveness in determining shades A1–A4, supporting the potential use of mobile AI-based solutions in clinical practice (3).

Bekdaş et al. investigated AI algorithms for determining CIELAB tooth color coordinates from standardized extraoral photographs. Among the tested models, MobileNetV2 demonstrated the best performance and high agreement with spectrophotometric measurements, emphasizing the potential of AI-assisted photographic analysis in esthetic restorative dentistry (4).

Efitli et al. developed machine learning models for predicting tooth color from intraoral images obtained under different clinical lighting conditions. By applying the LAB color space and the CLAHE technique, the authors reduced the influence of light reflections. Random Forest and XGBoost achieved the highest accuracy, indicating the potential of AI-based methods for more objective and standardized shade selection in prosthetic dentistry (5) In another study, Efitli et al. proposed a machine learning-based approach using color moments in RGB, LAB, and HSV color spaces to reduce metamerism and subjectivity in conventional shade selection. The results showed high accuracy in the classification of lighting conditions and VITA 3D-Master shades (6)

Jeong et al. developed and validated a deep learning model for tooth shade evaluation based on VITA Classical categories. The model performed detection, segmentation, and shade classification using high-resolution intraoral images. ResNet demonstrated the best performance, with results showing higher accuracy compared with experienced clinicians (7)

Artificial intelligence has also been applied in the prediction of final restoration color. Kose Jr. et al. evaluated machine learning regression models for predicting the final color of leucite-reinforced ceramic veneers. The authors found that substrate color had the greatest influence, followed by ceramic thickness and ceramic shade. The decision tree regression model showed the highest accuracy, supporting the applicability of AI in esthetic ceramic restoration planning (8).

Furthermore, AI-based approaches have been explored beyond tooth shade determination. Xu et al. compared three AI models for predicting the composition of gingiva-colored porcelain based on CIELAB values. ResNet demonstrated the highest predictive accuracy compared with MLP and GA+BP, including in external validation. These findings suggest that AI may contribute not only to tooth color reproduction but also to the reproduction of pink esthetics in complex prosthetic restorations (9)

Zilpilwar et al. presented a protocol for an observational study evaluating AI-assisted tools for tooth shade selection, including a smartphone, DSLR camera, and intraoral scanner. The study aimed to compare accessible digital technologies with more specialized methods under clinical conditions (10).

Based on these data, AI-based image analysis may reduce subjectivity in shade determination and support more consistent clinical decision-making. However, the clinical agreement between large multimodal AI systems and established spectrophotometric devices remains insufficiently investigated.

Aim

The aim of the present study was to evaluate the agreement between spectrophotometric tooth shade determination and an artificial intelligence-based method using standardized digital images of maxillary central incisors.

Materials and methods

A comparative clinical study was conducted on 25 patients with natural dentition. The study included 11 women and 14 men aged between 18 and 30 years. In each patient, the maxillary right central incisor 11 and the maxillary left central incisor 21 were examined, resulting in a total of 50 analyzed teeth.

In order to eliminate factors that could influence spectrophotometric and artificial intelligence-based shade determination, specific inclusion and exclusion criteria were defined.

Inclusion criteria

The inclusion criteria were as follows: age between 18 and 30 years; good general health; intact natural dentition in the anterior region of the maxilla; absence of carious lesions in the anterior region; absence of fillings, crowns, veneers, or other restorations on the examined teeth; absence of periodontal disease; absence of orthodontic deformities or malalignment of the anterior teeth; and good oral hygiene without visible plaque or calculus.

Exclusion criteria

The exclusion criteria included the presence of caries, restorations on the examined teeth; gingivitis, periodontitis, or other inflammatory periodontal diseases; orthodontic deformities; pronounced extrinsic tooth pigmentation; and systemic diseases or medication therapy affecting tooth color.

Clinical protocol

1. In all patients, a cheek retractor was placed to ensure clear visibility of the anterior teeth and to eliminate the influence of the lips and soft tissues on the image. Before measurement, the tooth surfaces were cleaned of superficial deposits and discolorations. The examination was performed without prolonged drying of the teeth in order to avoid color changes caused by dehydration.
2. Initially, spectrophotometric shade determination was performed using SpectroShade Micro II/SpectroShade (MHT S.p.A., Arbizzano di Negrar, Verona, Italy). Measurements were carried out according to the manufacturer's instructions. For each examined tooth, shade values were recorded according to the VITA Classical and VITA 3D-Master shade systems.
3. After spectrophotometric measurement, digital photography was performed using a Canon EOS SL3 digital camera (Canon Inc., Tokyo, Japan). The camera was used in manual mode in order to avoid automatic changes in exposure and color reproduction between patients. The same parameters were applied for all images: RAW format, ISO 100, aperture f/8, shutter speed 1/125 s, manual focus, fixed manual white balance, and an approximate distance of 30 cm from the anterior dental group. The camera was positioned frontally to the examined teeth, with the optical axis directed perpendicular to the vestibular surface.
4. A 5 Step Grey Balance Card G5 was included in each frame for white balance standardization. The grey card was positioned close to the examined teeth and in the same plane of photography so that it was illuminated under the same conditions as the tooth surfaces. This allowed subsequent standardization of the color balance of each image.

Fig. 1 Intraoral photographs including a grey card, used for artificial intelligence-based shade determination

5. The RAW images were processed in Adobe Lightroom Classic software (Adobe Inc., San Jose, CA, USA). All images were imported in their original RAW format without prior processing. For each patient, an image was selected in which the examined teeth, cheek retractor, and grey card were clearly visible, without blurring, overexposure, or shadow on the tooth surface.

Fig. 2 Image color calibration using Adobe Lightroom

6. White balance correction was performed in the Develop module using the White Balance Selector tool. The neutral grey zone of the grey card included in the image was selected with the eyedropper tool. In this way, individual correction of temperature and tint was performed for each

image. After white balance correction, no changes were made to saturation, vibrance, contrast, clarity, texture, dehaze, or local color adjustments. The aim was to standardize color reproduction without altering the actual appearance of the tooth surface.

7. The images were cropped so that the examined tooth and grey card were clearly visible. No isolation or artificial coloring of the tooth was performed. The soft tissues, cheek retractor, and background were not used in the subsequent analysis. After correction, the images were exported in high-quality JPEG format while preserving the sRGB color profile. The exported images were used for the artificial intelligence-based analysis.
8. For the artificial intelligence-based method, the ChatGPT system, based on the GPT-5.5 Thinking model (OpenAI, San Francisco, CA, USA), was used. Anonymized standardized images containing the examined tooth and the grey card for white balance were submitted to ChatGPT. The SpectroShade results were not provided to the system in advance in order to avoid influencing the assessment.
    a. The same text instruction was used for each image:
    b. "Analyze the shade of the indicated natural tooth from the provided standardized image. A grey card for white balance is included in the frame and was used for correction of color reproduction. Ignore the color of the cheek retractor, soft tissues, and background. Assess only the visible vestibular surface of the upper left and right central incisors. Determine the closest corresponding shade according to the VITA Classical scale and the VITA 3D-Master scale. Do not use spectrophotometer data. Present the answer in the following format: VITA Classical: … ; VITA 3D-Master: … ; brief justification of the choice."
    c. When several anterior teeth were visible in the image, an additional clarifying instruction was used:
    d. "Assess the shade only of teeth 11 and 21. Do not assess the adjacent teeth. Use the grey card only as a reference for neutral white balance."
9. For each patient, the results of the ChatGPT analysis were recorded in a table. The following parameters were registered: patient number, examined tooth, VITA Classical shade recorded with SpectroShade, VITA 3D-Master shade recorded with SpectroShade, VITA Classical shade determined by ChatGPT, VITA 3D-Master shade determined by ChatGPT, and agreement or disagreement between the two methods.

Statistical analysis

The comparative analysis was performed by comparing the results obtained with SpectroShade and ChatGPT. For each shade system, it was recorded whether there was complete agreement or disagreement between the values determined by the two methods. Agreement was assessed using the percentage of complete agreement and the unweighted Cohen's kappa coefficient. Unweighted kappa was selected due to the categorical nature of the shade values.

Results

The study included 25 patients with natural dentition. In each patient, two maxillary central incisors were evaluated, resulting in a total of 50 examined teeth. Shade determination was performed using SpectroShade and ChatGPT, and the results were compared separately according to the VITA Classical and VITA 3D-Master shade systems.

Table 1. Comparison between SpectroShade and ChatGPT in shade determination of 50 central incisors

Shade system	Number of examined teeth	Agreements	Agreement (%)	Cohen's kappa	Interpretation
VITA Classical	50	32	64.0%	0.402	Moderate agreement
VITA 3D-Master	50	32	64.0%	0.494	Moderate agreement

For VITA Classical, complete agreement between SpectroShade and ChatGPT was established in 32 out of 50 teeth, representing 64.0%. The Cohen's kappa value was $\kappa = 0.402$, indicating moderate agreement between the two methods.

For VITA 3D-Master, complete agreement was also established in 32 out of 50 teeth, representing 64.0%. The Cohen's kappa value was $\kappa = 0.494$, also indicating moderate agreement.

The obtained results show moderate agreement between SpectroShade and ChatGPT for both shade systems, with a higher kappa value for VITA 3D-Master.

Discussion

The present study evaluated the agreement between a conventional spectrophotometric method and an artificial intelligence-based approach for tooth shade determination of maxillary central incisors. The results demonstrated complete agreement between SpectroShade and ChatGPT in 32 out of 50 examined teeth for both the VITA Classical and VITA 3D-Master shade systems, corresponding to an agreement rate of 64.0%. The Cohen's kappa values were $\kappa = 0.402$ for VITA Classical and $\kappa = 0.494$ for VITA 3D-Master, indicating moderate agreement between the two methods.

These findings suggest that AI-based image analysis may have potential as an auxiliary tool for shade determination in prosthetic dentistry. Although the agreement was not complete, the observed level of concordance indicates that ChatGPT was able to identify tooth shade categories with a clinically relevant degree of consistency when standardized images were used. This is in accordance with previous studies reporting that AI-based methods can contribute to more objective and reproducible shade selection by reducing the subjectivity associated with visual assessment (3–7).

The moderate agreement observed in the present study may be explained by the categorical nature of the VITA Classical and VITA 3D-Master shade systems, where small differences in hue, chroma, or value may result in classification into different shade tabs. In clinical practice, even spectrophotometric devices may show variability depending on tooth translucency, surface texture, hydration, illumination, and positioning of the measuring device. Therefore, complete agreement between a spectrophotometer and an AI-based analysis of two-dimensional images should not necessarily be expected.

The higher kappa value obtained for VITA 3D-Master compared with VITA Classical may indicate that the structure of the VITA 3D-Master system, based on a more systematic arrangement of value, chroma, and hue, may be more suitable for AI-assisted classification. This finding is consistent with the concept that standardized color spaces and structured shade systems may improve the performance of digital and machine learning-based approaches. Efitli et al. reported high accuracy in tooth shade assessment using color moments in RGB, LAB, and HSV color spaces, particularly when standardized image-processing techniques were applied (6). Similarly,

Bekdaş et al. demonstrated that AI algorithms can estimate CIELAB coordinates of tooth color from standardized photographs with high agreement compared with spectrophotometric measurements (4).

The use of standardized photography in the present study was an important methodological factor. The inclusion of a grey card, fixed camera settings, RAW image acquisition, and white balance correction in Adobe Lightroom aimed to minimize variations in illumination and color reproduction. This approach is supported by previous investigations emphasizing the importance of image standardization in AI-based shade determination. Efitli et al. showed that preprocessing methods, including the use of LAB color space and contrast enhancement techniques, can reduce the influence of reflections and lighting conditions during shade prediction from intraoral images (5). Therefore, the moderate agreement found in the present study may partly reflect the effectiveness of the standardization protocol.

The results are also in line with the study by Jeong et al., who developed a deep learning model for tooth shade assessment based on VITA Classical categories. Their model performed detection, segmentation, and shade classification from high-resolution intraoral images, with ResNet demonstrating the best performance and higher accuracy compared with experienced clinicians (7). Although the present study did not use a specifically trained dental shade model, the obtained moderate agreement suggests that large multimodal AI systems may still provide clinically useful estimations when appropriate image acquisition and prompting protocols are applied.

Naydenov et al. emphasize that artificial intelligence is currently applied in prosthetic dental medicine for treatment planning, recognition and classification of the prosthetic field, smile design, virtual articulation and occlusion analysis, color determination, analysis and improvement of digital impressions and intraoral scans, and optimization of digital workflows (11).

Naydenov et al. reported that dental practitioners and dental technicians generally recognize artificial intelligence as a valuable supportive tool, particularly for diagnostic image analysis, three-dimensional modeling, and treatment planning, although concerns regarding training, costs, and possible inaccuracies remain (12).

From a prosthetic perspective, the integration of AI into shade selection may be particularly valuable because esthetic rehabilitation requires precision, reproducibility, and communication between the clinician and the dental laboratory. AI-assisted systems may support clinical decision-making, serve as a second opinion, and help reduce interobserver variability. Kose Jr. et al. emphasized the relevance of machine learning in predicting the final color of ceramic restorations, showing that substrate color, ceramic thickness, and ceramic shade influence the final esthetic outcome (8). This highlights that AI may be useful not only for initial tooth shade selection but also for broader planning of esthetic prosthetic restorations.

At the same time, the present results show that ChatGPT cannot replace spectrophotometric shade determination at this stage. The disagreement observed in 36.0% of the examined teeth indicates that AI-based shade assessment remains sensitive to image quality, lighting conditions, camera characteristics, surface reflections, and the limitations of two-dimensional photographic analysis. Unlike spectrophotometers, which directly measure optical properties of the tooth surface, ChatGPT evaluates the image indirectly and depends on the accuracy of image capture, color calibration, and visual information available in the frame.

Another important limitation is that the AI model used in the present study was not specifically calibrated or trained on the examined patient population, camera system, or SpectroShade measurements. In contrast, many published AI models for shade determination are trained on structured datasets and optimized for specific classification tasks (4–7). Therefore, future studies should include larger samples, different tooth groups, various lighting conditions, and repeated measurements. It would also be useful to compare ChatGPT with specialized dental AI models and to assess partial agreement between clinically close shade categories, not only complete categorical agreement.

Despite these limitations, the present study demonstrates that an AI-based approach using standardized intraoral images can achieve moderate agreement with spectrophotometric shade determination. This supports the potential role of AI as an accessible adjunctive tool in prosthetic dentistry, particularly in situations where spectrophotometric devices are unavailable or when additional documentation and communication of tooth shade are needed.

Conclusion

Within the limitations of the present study, ChatGPT demonstrated moderate agreement with SpectroShade in the determination of tooth shade of maxillary central incisors. Complete agreement was observed in 64.0% of cases for both the VITA Classical and VITA 3D-Master shade systems. The Cohen's kappa coefficient indicated moderate agreement for both scales, with a higher value for VITA 3D-Master.

The results suggest that AI-based image analysis may be used as an auxiliary method for tooth shade determination in prosthetic dentistry, especially when standardized photographic protocols are applied. However, the artificial intelligence-based method should not be considered a substitute for spectrophotometric evaluation. Instead, it may serve as a supportive tool for clinical decision-making, documentation, and communication with the dental laboratory.

Further studies with larger sample sizes, controlled lighting conditions, repeated measurements, and comparison with specialized dental AI systems are necessary to confirm the reliability and clinical applicability of AI-assisted shade determination.

Additional information

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Ethical compliance

Not applicable.

Conflict of interest

The authors declare that they have no conflict of interest and no affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

Author contributions

Conceptualization and study design- I.L, R.T
Data collection and spectrophotometric measurements- I.L
Data analysis and interpretation - I.L, N.A
Preparation of figures and visualization - I.L, N.A
Writing of draft - I.L
Revision, and final approval of the manuscript - N.A, R.T

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