Vol.20, No.1, Page 485- 488, 2026 http://dx.doi.org/10.59628/jchm.v20i1.2516 ISSN 2958-7476 JMCH

Sana'a University Journal of Medical and Health Sciences

Validation of a Portable Digital Skin Tone Sensor Compared to Fitzpatrick Skin Type Scale for Tooth Shade Matching in Esthetic Dentistry

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Abstract

Background: Assessment of skin tone is a fundamental in esthetic dentistry. guiding the accurate selection of tooth shade for patients with missing or compromised dentition. While the Fitzpatrick Skin Type (FST) scale remains a widely used traditional method, digital skin tone sensors offer objective and reproducible alternatives. However, few studies have directly compared these approaches in dental contexts, particularly among underrepresented populations.
Objective: This study aimed to evaluate the reliability of a portable digital skin tone sensor compared to the Fitzpatrick Skin Type Scale in assessing skin tone among Yemeni dental patients.
Methods: This cross-sectional study was conducted among 200 Yemeni participants (equally distributed between males and females), aged from 18 to 50 years old. They were recruited from dental clinics at the Faculty of Dentistry, Sana'a University and affiliated private universities. Skin tone was assessed using the FST questionnaire and a calibrated digital skin-tone sensor. The intraclass correlation coefficient (ICC) was calculated to evaluate the agreement between the two methods.
Results: The ICC value between the digital and questionnaire-based assessments was 0.811, indicating moderate to good agreement. Although the digital method tended to yield slightly lower average skin tone scores, the difference was not statistically significant (p = 0.146).
Conclusion: The findings suggest that the digital skin tone sensor provides reliable measurements comparable to the traditional FST. Its integration into esthetic dental workflows may enhance shade-selection accuracy and support inclusive clinical decision-making.

Article Info

Keywords:
Skin tone assessment, Fitzpatrick scale, digital sensor

Article History:
Received: 18-November -2025,
Revised: 2-January-2026,
Accepted: 30-January-2026,
Available online: 28-February-2026

1. INTRODUCTION

Accurate classification of skin tone is essential in esthetic dentistry, particularly in the selection of prosthetic shades, where visual harmony between dental restorations and adjacent facial features is critical [1]. The Fitzpatrick Skin Type (FST) classification, introduced in 1988, remains one of the most widely adopted frameworks for estimating skin response to ultraviolet radiation based on the tendencies to burn and tan rather than direct assessment of visible pigmentation [2]. Despite its clinical utility, the Fitzpatrick scale is inherently subjective [3, 4]. Reliance on patient self-reporting and clinician interpretation introduces variability and reduces the reproducibility of the results. To address these limitations, digital skin analysis technologies have emerged as objective and reproducible alternatives to traditional visual assessments. Devices such as spectrophotometers, RGB-based sensors (Red, Green, Blue), and AI-powered skin analyzers offer noninvasive and standardized evaluations of skin tone [5–7]. Many of these tools are calibrated using Fitzpatrick-based datasets, enabling consistent comparisons across diverse populations. For instance, [8] Garcia et al introduced a novel classifica-

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tion model (FiSC) that enhances the precision of digital skin analyzers by aligning their outputs with Fitzpatrick standards. Similarly, [9] Yu X, Ong KG, and McGeehan MA demonstrated strong concordance between digitally assessed skin tones and traditional phototype classifications, reinforcing the clinical relevance of such tools in both dermatological diagnostics and cosmetic treatment planning [10]. Gold et al. validated a composite skin quality scale, including pigmentation and texture, confirming its clinical reliability. Based on this evidence, the present study assessed a digital device calibrated to the Fitzpatrick classification for skin tone evaluation [11]. Nijjer et al. investigated the limitations of large language models in dermatology, showing that models trained predominantly on lighter skin tones exhibited reduced diagnostic accuracy for darker Fitzpatrick skin types. Their study emphasized the need for standardized frameworks to mitigate bias and ensure consistent clinical performance across diverse pigmentation profiles. Despite these technological advances, limited research has directly validated the accuracy of portable digital skin tone sensors against FST. Existing studies often focus on dermatological or cosmetic applications, leaving a gap in the evidence regarding their reliability in broader clinical contexts [12]. To date, no previous study has established the validity of this device or systematically addressed its use. Therefore, this study represents the first investigation of its credibility, evaluating the agreement between a portable digital skin tone sensor and FST, and aims to provide a foundation for its application as a reliable clinical tool for objective pigmentation analysis.

2. MATERIALS AND METHODS

Study Design and Timeline

This prospective cross-sectional study was conducted at the dental clinics of Sana'a University and private universities. Ethical approval was obtained from the Institutional Research Ethics Committee (No. CD: 04/11/2024), and data were collected between December 2024 and February 2025 in accordance with the Declaration of Helsinki.

A total of 200 Yemeni adults (100 males and 100 females), aged 18–50 years, were selected to encompass a broad adult population expected to use the device in clinical practice. This range enabled the assessment of device performance across age groups with potential variations in skin characteristics, thereby strengthening the generalizability of the results. All participants provided written informed consent prior to participation.

Inclusion and Exclusion Criteria

Participants were included if they were free from skin conditions affecting tone, willing to remove facial cosmetics, and able to complete both assessment methods.

Figure 1. Portable skin sensor device

The exclusion criteria comprised visible makeup during evaluation, history of skin bleaching or tanning, active dermatological disease, facial scars in the measurement areas, or inability to provide informed consent.

Determination of skin tone

Conventional evaluation using the FST

In this study, the participants completed a structured questionnaire. Each item was scored from zero to 4. Cumulative scores were used to classify skin types I–VI, reflecting varying tendencies to burn or tan [1].

• Type I (0–6): Always burns, never tans; pale white skin, blue or grey eyes, freckles, and blond or red hair.

• Type II (7–12): Usually burns and tans minimally; fair skin, blue, green, or hazel eyes, and blond to brown hair.

• Type III (13–18): Sometimes experiences mild sunburn, tans uniformly; cream white or yellowish skin, any hair color.

• Type IV (19–24): Rarely burns and tans easily; light brown or olive skin and dark brown to black hair.

• Type V (25–30): Very rarely burns, tans very easily, and has a brown skin tone. • Type VI (31+): Never burns, always tans deeply; dark brown to deeply pigmented complexion.

Objective evaluation of skin tone

An objective evaluation of the skin tone was performed using a Smart Portable Skin Tone Sensor (Figure 1). The device, commercially identified as the Skin Tone Sensor (model GP531, DEESS, China), was calibrated according to the FST and provided precise digital readings of melanin density. It operates by measuring the diffuse reflectance of the skin at three distinct light wavelengths, generating a melanin index that reflects the individual's pigmentation level. The sensor was designed to accommodate a broad spectrum of skin tones, thereby enhancing the inclusivity of clinical assessments.

To ensure accurate skin tone readings, the participants were instructed to remove any facial cosmetics before the measurement. Assessments were conducted at four standardized facial sites: above and below the right and left corners of the mouth. The sensor was ac-

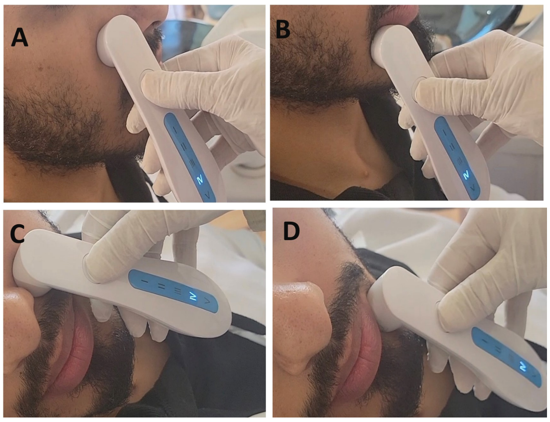

Figure 2. Illustrations of skin tone measurements taken at four facial sites: (A) right side above the mouth corner, (B) left side below the mouth corner, (C) left side above the mouth corner, and (D) left side below the mouth corner.

Table 1. Frequency Distribution– Skin tone in the questionnaire

Skin tone in the questionnaire	Frequency	Percent
II	2	1.0%
III	61	30.5%
IV	122	61.0%
V	15	7.5%
Total	**200**	**100%**

tivated by pressing its control button until light emission occurred, and a reading was registered. Each site was measured at least twice to confirm the consistency and reliability of the results (Figure 2). For male participants with facial hair, measurements were repeated on adjacent areas free of beard growth to minimize interference and maintain uniformity across all the readings.

3. RESULTS

Skin tone in the questionnaire

Table 3.1 presents the distribution of skin tone categories (II, III, IV, and V) based on the questionnaire responses from 200 participants. Category IV was the most frequently reported, accounting for 61.0% (n = 122), followed by category III at 30.5% (n = 61). Categories V and II were less common, representing 7.5% (n = 15) and 1.0% (n = 2), respectively.

Skin Tone in Digital Assessment

Table 3.2 summarizes the digital distribution of skin category (I–V) among the 200 participants. Category IV was the most prevalent, observed in 57.5% (n = 115), followed by category III at 32.0% (n = 64). Categories V, II, and I were less frequent, accounting for 9.0% (n = 18), 1.5% (n = 3), and 0.0%, respectively.

Table 2. Frequency Distribution– Skin Tone in digital

Skin tone in digital	Frequency	Percent
II	3	1.5%
III	64	32.0%
IV	115	57.5%
V	18	9.0%
Total	**200**	**100%**

Table 3. Assessment of the interobserver reliability

Skin tone				
Digital Mean±SD	Questionnaire Mean± SD	ICC [b]	Mean difference	P-value [c]
4.23 ± 0.95	4.29 ± 0.094	0.811	-0.06	0.146

b: Intraclass correlation coefficients**; c:** p-value: Comparison between two repetitions using paired t-tests, $p < 0.05$ indicates statistical significance

Reliability Analysis

Table 3.3 presents the inter-observer reliability between the digital and questionnaire-based skin tone assessments. The Intraclass Correlation Coefficient (ICC) was 0.811, indicating moderate to good agreement. The mean difference between the methods was -0.06, with the digital approach yielding slightly lower values. However, the p-value of 0.146 suggests that there was no statistically significant difference between the two methods. Overall, both techniques demonstrated consistent and comparable reliability in evaluating the skin tone.

4. DISCUSSION

The findings of this study revealed moderate to good agreement between the portable digital skin tone sensor and the Fitzpatrick questionnaire (ICC = 0.811), supporting the sensor's reliability in esthetic dentistry. Although the digital method yielded slightly lower scores, the difference was not statistically significant (p = 0.146), confirming the consistency across both tools. Although this study validates a portable skin tone sensor for esthetic dental applications, its methodological approach parallels [13], who applied Fitzpatrick skin types to evaluate PPG heart rate monitoring. Their results, which showed consistent performance across various pigmentation levels, highlighted the value of the Fitzpatrick classification as a benchmark and the importance of inclusive testing across diverse skin tones. The findings of the present study align with those of [4], who demonstrated a strong correlation between digital skin tone device readings and FST. Their work highlights the clinical relevance of objective skin tone analysis and supports the use of portable devices for the reliable assessment of pigmentation, thereby reinforcing the methodological approach adopted in this study. The study is limited by its focus on Yemeni nationals and data collection from dental clinics in Sana'a, which may restrict its generalizability. In addition, the relatively small sample size limits the statistical power of the findings.

5. CONCLUSION

These findings support the integration of calibrated digital tools for the objective assessment of pigmentation across diverse populations. However, exclusive reliance on the Fitzpatrick scale may limit the inclusivity of the results, as recent literature suggests that this classification may not adequately represent darker skin tones. Future studies should adopt broader skin tone frameworks and more diverse sampling to enhance generalizability and ensure equitable diagnostic accuracy.

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