

Innovation of Digital Periodontal Probe Based on Camera Sensor as Automation for Identification of Gingival Discoloration and Anterior Gingival Recession

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Abstract. *Periodontal disease remains a major oral health problem. This study aimed to develop and conduct a preliminary evaluation of a camera sensor-based digital periodontal probe for detecting gingival discoloration and gingival recession. The study employed a Research and Development (R&D) approach followed by a paired comparative assessment between manual and digital examination methods on the same subjects. The study involved 30 patients and 30 dental health professionals. Product feasibility was evaluated through expert validation using Aiken's V, while reliability was assessed using the Intraclass Correlation Coefficient (ICC). Differences between manual and digital examination methods were analyzed using the Wilcoxon Signed Rank Test. The results showed no statistically significant difference in gingival discoloration detection between manual and digital methods ($p=0.251$). In contrast, a statistically significant difference was observed in gingival recession classification outcomes ($p=0.011$). The digital method identified more moderate and severe recession cases; however, this finding reflects differences in classification outcomes and does not necessarily indicate superior diagnostic performance. Expert validation indicated high content validity (Aiken's $V=0.897$) and acceptable reliability ($ICC=0.796$). This study suggests that the developed tool has potential for use in periodontal screening and digital documentation. Further studies with larger sample sizes, reference standards, and agreement analysis are required to confirm the diagnostic accuracy and broader clinical applicability of the device.*

Keywords: *Digital Periodontal Probe, Camera Sensor, Gingival Color, Gingival Recession, Innovation*

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INTRODUCTION

Periodontal disease remains a highly prevalent oral health problem in many countries. The World Health Organization (WHO) reported that severe periodontal disease is one of the leading causes of tooth loss in adults (Petersen & Ogawa, 2005; Nazir et al., 2020; Hyde et al., 2017). These findings indicate that early detection and prevention of periodontal disease are important priorities in dental and oral healthcare services.

According to Panagakos & Scannapieco (2011), Lang et al. (2009), Mariotti (1999), Dahlen et al. (2019), One of the earliest forms of periodontal disease is gingivitis, an inflammation of the gingiva generally caused by the accumulation of bacterial plaque. Gingivitis is characterized by

gingival discoloration, swelling, and bleeding. Gingival discoloration is considered an important clinical indicator because inflamed gingival tissue tends to appear redder than healthy tissue (Heitz-Mayfield, 2024; Ristic et al., 2019; Goldstein et al., 2018).

In addition to gingivitis, gingival recession is also a common periodontal problem. Gingival recession is defined as the apical migration of the gingival margin, exposing the tooth root surface (Tugnait & Clerehugh, 2001; Mostafa & Fatima, 2022; Kassab & Cohen, 2003; Pradeep et al., 2012; Ravipudi et al., 2017; Niemczyk et al., 2024; Jati et al., 2016). This condition may lead to dentin hypersensitivity, aesthetic problems, and increased risk of root caries.

In clinical practice, periodontal examinations are commonly performed using manual periodontal probes and direct visual observation (Elashiry et al., 2019; Lynch et al., 2006). However, several studies have reported limitations of manual examination methods, including variation in probing pressure, operator dependence, subjective visual interpretation, and inconsistency between examiners (Suchoń et al., 2025; Stochkendahl et al., 2006; Kennedy et al., 2019; Jansen et al., 2026; Ohashi et al., 2025). In addition, environmental conditions such as room lighting and operator fatigue may affect the ability to detect early tissue changes.

These limitations are particularly relevant in primary healthcare facilities such as community health centers (Puskesmas), where healthcare workers are required to perform examinations efficiently in high patient-volume settings. Therefore, innovations that improve examination objectivity and documentation are needed.

Advances in digital technology have created new opportunities in periodontal examination. Previous studies have demonstrated that intraoral cameras and digital image analysis systems may support more consistent visualization and documentation of gingival conditions (Ehrensperger et al., 2025; Smith et al., 2006; Moharrami et al., 2025; Mutawa et al., 2026). Artificial intelligence-based image analysis has also shown potential for detecting gingival inflammation through intraoral photographs.

Most existing digital periodontal systems focus on periodontal pocket measurements or require expensive equipment. Research regarding simple, portable, and affordable digital tools capable of identifying gingival discoloration and gingival recession in primary healthcare settings remains limited.

Based on this research gap, the present study developed a camera sensor-based digital periodontal probe intended to support periodontal examination, particularly for identifying gingival discoloration and anterior gingival recession. This study aimed to assess the feasibility of the developed tool through expert validation and to conduct a preliminary comparison between manual and digital examination methods.

METHODS

This study employed a Research and Development (R&D) approach consisting of five sequential stages: information collection, product design, expert validation, field testing, and final evaluation. The research was conducted at a community health center in Pangkalpinang City with the objective of developing and evaluating a digital system for periodontal examination. The information collection stage involved an extensive literature review and preliminary clinical observations to identify the limitations of conventional manual periodontal examination methods and to determine the functional requirements of the proposed system. The findings from this stage led to the identification of two key clinical parameters for assessment, namely gingival discoloration and gingival recession, which served as the primary indicators incorporated into the developed system. During the product design stage, a digital periodontal examination system was developed by integrating an endoscopic USB camera, LED illumination, a laptop-based interface, and image analysis software. To ensure consistency and reliability during image acquisition, several standardization procedures were implemented. The camera was positioned at an approximate distance of $\pm 1-2$ cm from the gingival surface, image angles were standardized across examinations, lighting intensity was controlled through integrated LED illumination, and

patient head position was stabilized throughout the examination process. These procedures were intended to minimize variability and improve image quality for subsequent analysis. The acquired digital images were analyzed using image analysis software designed to assess gingival conditions based on predefined classification criteria. Gingival discoloration and gingival recession were categorized into four levels consisting of healthy, mild, moderate, and severe conditions.

The image interpretation process was conducted using a semi-automated approach, with final verification performed by the operator to ensure accuracy and consistency in classification outcomes. Expert validation was conducted to evaluate the feasibility and appropriateness of the developed system. The validation process involved a panel consisting of dentists, information technology experts, and public health experts. Content validity was assessed using Aiken's V coefficient to measure the degree of agreement among expert validators regarding the relevance, suitability, and appropriateness of the system components. Reliability assessment was performed using the Intraclass Correlation Coefficient (ICC), which was employed to evaluate the consistency of ratings provided by the expert validators. Field testing was subsequently conducted involving 30 patients and 30 dental health professionals, consisting of 15 dentists and 15 dental and oral therapists. Participants were selected using purposive sampling techniques. Patients were eligible for inclusion if they were aged 18 years or older, presented with assessable gingival conditions, and were willing to participate in the study. Patients were excluded if they had systemic conditions affecting gingival appearance, had recently undergone periodontal treatment, or presented with conditions that could potentially influence gingival color assessment. The participating dental health professionals were required to have a minimum of one year of clinical experience and familiarity with periodontal examination procedures. To facilitate direct comparison between examination approaches, each patient underwent both conventional manual assessment and digital examination using the developed system. Data analysis was performed to compare the outcomes obtained from manual and digital examination methods. Differences between the two examination approaches were analyzed using the Wilcoxon Signed Rank Test, a non-parametric statistical procedure suitable for paired data comparison. Statistical significance was determined at a p-value threshold of less than 0.05. However, any statistically significant findings were interpreted as indicating differences in classification outcomes between the two examination methods rather than as evidence of superior clinical diagnostic performance of one method over the other.

RESULT AND DISCUSSION

The results are organized to show the characteristics of the respondents, the distribution of dental health professionals involved in the field testing, the expert validation outcomes, and the comparative classification results between manual and digital examination methods. Since this study was designed as a Research and Development study followed by a preliminary paired comparison, the findings should be interpreted as evidence of feasibility, consistency, and initial classification patterns rather than as definitive proof of clinical diagnostic accuracy. The tables therefore provide an overview of how the developed system performed in relation to respondent characteristics, expert judgment, gingival discoloration assessment, and gingival recession classification.

Table 1. Respondent Characteristics by Gender

Gender	n	%
Male	13	43.3
Female	17	56.7
Total	30	100

Based on Table 1, the respondents consisted of 13 males and 17 females, representing 43.3% and 56.7% of the total sample, respectively. This distribution indicates that female respondents formed a slightly larger proportion of the study participants. Although the difference between male and female respondents was not substantial, the predominance of female

participants provides a useful demographic profile for understanding the sample composition. Since this study was designed as a preliminary evaluation of a camera sensor based digital periodontal probe, the gender distribution should be interpreted as descriptive information rather than as a determinant of clinical outcomes. Therefore, the data mainly serve to demonstrate that the field testing involved respondents from both gender groups.

Table 2. Distribution of Dental Health Professionals

Health Professionals	n	%
Dentists	15	50
Dental and Oral Therapists	15	50
Total	30	100

Table 2 shows that the dental health professionals involved in the study were equally distributed between dentists and dental and oral therapists, with each group consisting of 15 participants or 50% of the total professional respondents. This balanced composition is important because it allows the feasibility and usability of the developed system to be considered from two relevant professional perspectives. Dentists and dental and oral therapists may have different clinical roles and practical experiences in periodontal examination, so their equal representation strengthens the preliminary evaluation of the tool. The balanced distribution also reduces the possibility that the professional assessment was dominated by only one occupational group. However, this result should still be understood as a description of respondent composition, not as evidence of interprofessional differences in evaluation outcomes.

Table 3. Expert Validation Results

Indicator	Score	Interpretation
Aiken's V	0.897	High content validity
ICC	0.796	Good reliability

Table 3 presents the expert validation results of the developed digital periodontal probe. The Aiken's V value of 0.897 indicates a high level of content validity, suggesting that the expert validators generally agreed that the developed tool was relevant, appropriate, and feasible in relation to its intended function. This result supports the suitability of the system components, including the camera sensor, digital visualization process, and classification criteria for gingival discoloration and gingival recession. The ICC value of 0.796 further indicates good reliability, meaning that the assessments provided by the validators showed an acceptable level of consistency. These findings strengthen the preliminary feasibility of the developed system as a supportive periodontal examination tool. However, it is important to emphasize that expert validation and reliability testing do not independently establish clinical diagnostic accuracy. They only indicate that the tool is considered feasible and reasonably consistent at the development and validation stage.

Table 4. Distribution of Gingival Discoloration Classification

Method	Healthy	Mild Inflammation	Moderate Inflammation	Severe Inflammation	Total
Manual	8	16	5	1	30
Digital	7	17	5	1	30

Table 4 shows that the classification of gingival discoloration using manual and digital methods produced relatively similar distributions. In the manual method, 8 respondents were classified as healthy, 16 as having mild inflammation, 5 as having moderate inflammation, and 1 as having severe inflammation. In the digital method, 7 respondents were classified as healthy, 17 as having mild inflammation, 5 as having moderate inflammation, and 1 as having severe inflammation. The small difference between the two methods appears mainly in the healthy and mild inflammation categories, while the moderate and severe categories remained identical. This pattern suggests that the digital method generated classification outcomes that were broadly

comparable to manual assessment in identifying gingival discoloration. Nevertheless, the result should be interpreted cautiously because similar distribution does not automatically prove diagnostic equivalence. It only indicates that, in this preliminary evaluation, the digital system produced a classification pattern that was close to the conventional manual method.

Table 5. Distribution of Gingival Recession Classification

Method	Healthy	Mild	Moderate	Severe	Total
Manual	8	16	5	1	30
Digital	9	9	8	4	30

Table 5 indicates a clearer difference between manual and digital methods in the classification of gingival recession. The manual method classified 8 respondents as healthy, 16 as mild, 5 as moderate, and 1 as severe. In contrast, the digital method classified 9 respondents as healthy, 9 as mild, 8 as moderate, and 4 as severe. This distribution shows that the digital method identified fewer mild cases but more moderate and severe cases compared with the manual method. Such a pattern suggests that the digital system may have produced a more differentiated classification of gingival recession severity, possibly because digital visualization, magnification, and image review allowed more detailed observation of gingival margins. However, this finding should not be interpreted as evidence that the digital method is clinically superior. Without a reference standard or agreement analysis, it remains unclear whether the higher number of moderate and severe cases reflects improved detection, overclassification, or differences in interpretation between the two methods. Therefore, the result should be presented as evidence of different classification outcomes rather than as proof of better diagnostic performance.

Table 6. Wilcoxon Signed Rank Test Results

Variable	p-value	Interpretation
Gingival Discoloration	0.251	Not statistically significant
Gingival Recession	0.011	Statistically significant difference

The Wilcoxon Signed Rank Test showed no statistically significant difference between manual and digital methods in gingival discoloration assessment ($p=0.251$). In contrast, gingival recession assessment demonstrated a statistically significant difference between methods ($p=0.011$). It should be noted that statistical significance indicates differences in classification outcomes and does not necessarily indicate superior clinical performance.

The findings of this study suggest that the developed camera sensor-based digital periodontal probe has potential as a supportive tool for periodontal examination and digital documentation in primary dental healthcare settings (Pachiou et al., 2025; Rajendran et al., 2026; Surdu et al., 2025). The integration of a camera sensor, LED illumination, and digital image visualization may contribute to improved examination consistency and facilitate clinical documentation during periodontal assessment. The expert validation results demonstrated high content validity (Aiken's $V=0.897$) and acceptable reliability (ICC=0.796).

These findings indicate that the validators considered the developed tool appropriate in terms of design, usability, and functional feasibility. In development-based research, expert validation is an important early step because it evaluates whether the system concept, operational workflow, and technical design are suitable for implementation. However, these validation results should be interpreted as evidence of preliminary feasibility rather than definitive proof of clinical diagnostic accuracy.

The results of gingival discoloration assessment showed no statistically significant difference between manual and digital methods ($p=0.251$). The classification distribution between both methods was also relatively similar. This finding suggests that the digital system produced comparable classification outcomes to the conventional visual examination method in this preliminary evaluation. Nevertheless, the absence of statistical significance should not be interpreted as evidence of complete diagnostic equivalence (Braeken & van, 2026; Rigo-Bonnin

et al., 2026). Agreement analysis between methods was not performed in this study, and therefore the consistency of classification outcomes between manual and digital examination cannot yet be fully established (Tang et al., 2012; Azam et al., 2021).

Several factors may explain the relatively comparable findings in gingival discoloration assessment. Gingival color evaluation is highly dependent on visual perception and may be influenced by environmental lighting conditions, operator experience, examiner fatigue, and viewing angle (Schnitzer et al., 2004; Iacomussi et al., 2017; Atri et al., 2026; Sirintawat et al., 2021). The use of LED illumination and digital image magnification in the developed system may help reduce some of these variations by providing more stable visualization of gingival tissue (Hegde & Hegde, 2016; Stambaugh et al., 2002; Angelino et al., 2017; Strauss et al., 2024). Enhanced image visualization may also assist examiners in identifying subtle color changes associated with early inflammation.

Previous studies have also reported the potential of digital imaging systems in supporting periodontal assessment. Chau et al. (2023) demonstrated that artificial intelligence-based photographic analysis could identify gingival inflammation with relatively good performance. Similarly, Ehrensperger et al. (2025) reported that intraoral camera systems combined with digital analysis may improve visualization of gingival tissue conditions. These findings support the possibility that digital image-based systems may contribute to more standardized periodontal screening procedures.

In the present study, the digital method identified a greater number of moderate and severe gingival recession cases compared to the manual method, and statistical analysis demonstrated a significant difference between methods ($p=0.011$). This finding indicates that the digital system generated different classification outcomes in gingival recession assessment. However, this result should be interpreted cautiously because the study did not include an external reference standard or gold standard examination to confirm diagnostic accuracy.

Several technical factors may contribute to the differences observed in gingival recession classification (Pini-Prato et al., 2010; Romandini et al., 2020; Cairo et al., 2011). Digital image magnification may improve visualization of gingival margins and exposed root surfaces, particularly in mild-to-moderate recession cases. In addition, stable LED lighting may improve contrast between gingival tissue and tooth structures, making gingival margin identification more visible during image evaluation (Gkantidis et al., 2024; Pasupuleti et al., 2025; Ko et al., 2021). The ability to enlarge and repeatedly review digital images may also reduce momentary observation errors that can occur during direct visual examination.

Despite these possible explanations, the current findings cannot confirm whether the additional moderate and severe recession cases identified by the digital system represented true positive findings or potential overclassification. Without calibration against a standardized periodontal reference examination, it remains unclear whether the observed differences reflect improved detection capability, classification variability, lighting-related image effects, or operator interpretation differences.

The findings of this study are generally consistent with previous reports regarding the use of digital systems in periodontal examination (Farina et al., 2025; Chung et al., 2022; Peikert et al., 2020; Stødle et al., 2025). Laugisch et al. (2021) reported that electronic periodontal systems may improve examination consistency and reduce inter-operator variation compared to conventional manual methods. Other studies have also suggested that digital visualization systems may support more objective clinical assessment by minimizing variability caused by direct visual interpretation. Nevertheless, most previous studies emphasized measurement reproducibility and standardization rather than definitive diagnostic superiority.

In addition to examination support, the developed digital system may provide practical benefits in healthcare services. Digital image storage allows documentation of gingival conditions over time, which may facilitate longitudinal monitoring and comparison between patient visits

(Patel et al., 2023; Hausmann, 2000; Al-Yaseen et al., 2025). Visual documentation may also support communication between healthcare professionals and patients because patients are able to directly observe their gingival condition through digital displays (Tobias & Spanier, 2020; Asan et al., 2013). Improved visualization may contribute to better patient understanding regarding oral health conditions and preventive care.

From a healthcare management perspective, digital documentation systems may also support service efficiency in primary healthcare facilities such as community health centers (Puskesmas) and primary care clinics. Standardized image recording may facilitate patient monitoring, clinical reporting, and integration with future electronic health record systems. These features may become increasingly relevant as digital transformation continues to expand within healthcare services.

Several limitations should be considered when interpreting the findings of this study. First, the sample size was relatively limited, which may reduce generalizability of the results. Second, the study did not include a calibrated clinical reference standard to confirm diagnostic accuracy. Third, agreement analysis such as Cohen's kappa or Bland-Altman analysis was not performed. Fourth, the image classification process was still semi-automated and involved operator verification, which may introduce subjective interpretation variability.

Therefore, this study should be interpreted as a preliminary feasibility and comparative evaluation rather than definitive evidence of clinical effectiveness. Further studies involving larger sample sizes, standardized periodontal reference examinations, repeated measurement protocols, and additional agreement analyses are needed to further evaluate the diagnostic performance and broader clinical applicability of the developed digital periodontal probe.

CONCLUSION

The developed camera sensor-based digital periodontal probe demonstrates potential as a supportive tool for periodontal examination and digital documentation. The findings showed relatively comparable outcomes with manual methods for gingival discoloration assessment and differences in classification outcomes for gingival recession. However, these findings should be interpreted cautiously because the study did not include a reference standard and involved a limited sample size. Further studies with larger sample sizes, standardized clinical reference methods, and additional agreement analysis are required to evaluate the diagnostic accuracy and broader clinical applicability of the developed device.

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