

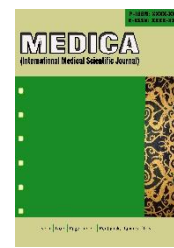
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## Innovation of A Smart Dental Mirror for More Effective and Efficient Plaque Score Assessment

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### Abstract

Dental plaque is one of the primary etiological factors contributing to oral diseases. Therefore, plaque detection and control are essential components of preventive dental care. Conventional plaque detection methods using disclosing agents still present several limitations, including chemical content, complicated application procedures, subjective interpretation, and potential side effects on oral tissues. Consequently, technological innovation is needed to improve the effectiveness and efficiency of plaque examination. This study aimed to develop and evaluate a smart dental mirror based on camera technology and deep learning sensors as an innovative tool for plaque assessment. The study employed a Research and Development (R&D) approach with a quasi-experimental crossover design. A total of 33 dental health professionals were recruited using purposive sampling. Product testing was conducted to evaluate the effectiveness and efficiency of plaque examination through observation and interview methods. Data were analyzed descriptively and statistically using the Wilcoxon test. The results of expert validation showed that the smart dental mirror achieved a feasibility score of 72.2%, indicating that the device was suitable for use. The effectiveness test demonstrated no statistically significant difference between the smart dental mirror and the conventional method ( $p = 0.439$ ), indicating comparable effectiveness in plaque assessment. However, the efficiency test revealed a statistically significant difference ( $p = 0.001$ ), indicating that the smart dental mirror provided greater efficiency compared to the conventional method. In conclusion, the smart dental mirror is considered a feasible, efficient, and innovative alternative for dental plaque assessment, with effectiveness comparable to conventional methods while offering improved operational efficiency in clinical practice.

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## 1. INTRODUCTION

Health development is an effort to fulfill the fundamental rights of the Indonesian people as mandated by Article 28 paragraph (1) of the 1945 Constitution and Law Number 17 of 2023 concerning Health. The primary objective of health development is to improve awareness and the ability of individuals to achieve a healthy life, encompassing physical, mental, and social well-being through promotive, preventive, curative, rehabilitative, and palliative approaches (Undang-Undang Republik Indonesia, 2023). According to the World Health Organization (WHO), health is defined as a state of complete physical, mental, and social well-being, not merely the absence of disease or infirmity (WHO, 2023). Oral health is an integral component of general health because disturbances in the oral cavity can affect mastication, speech, aesthetics, social interaction, and overall quality of life (Fairuz Zuraida Eva, 2023). Consequently, oral diseases remain a major public health concern worldwide due to their high prevalence and significant social and economic impacts. The World Health Organization reported that approximately 3.5 billion people globally suffer from oral diseases, with dental caries identified as the most common chronic oral disease (WHO, 2024).

In Indonesia, oral health problems remain highly prevalent. Data from the 2023 Indonesian Health Survey (SKI) showed that 56.9% of the population experienced oral health problems, with dental caries accounting for 43.6% of cases (Kemenkes RI, 2023). However, the proportion of individuals seeking professional dental care remains very low, as 91.9% of Indonesians aged over three years reported never visiting dental health services because they perceived no need for treatment or had never experienced toothache. This condition reflects limited public awareness regarding the importance of oral health maintenance and preventive dental care. Oral diseases are strongly influenced by behavioral and socioeconomic factors, including poor oral hygiene practices, excessive sugar consumption, low awareness of routine dental examinations, limited access to healthcare services, and low educational levels (Thania, 2025; Salikun, 2016). One of the main etiological factors of dental caries is dental plaque, a biofilm composed of microorganisms that produce acids from carbohydrate fermentation, leading to enamel demineralization and progressive tooth destruction (Edwina, 1991; Motto, 2017; Kusuma, 2016). Therefore, accurate plaque detection and effective plaque control are essential components of preventive oral healthcare.

Conventionally, plaque detection is performed using disclosing agents that stain plaque deposits to facilitate visualization and assessment (Adnyasari, 2016; Putra, 2017). The use of disclosing agents has been shown to improve oral hygiene awareness, support preventive education, and assist in evaluating oral hygiene status (Fasoulas, 2019). Nevertheless, these materials present several limitations. Chemical compounds such as potassium iodide, iodine crystals, erythrosine, fuchsin, and mercurochrome may trigger allergic reactions, unpleasant sensations, prolonged staining, aesthetic discomfort, and potential cytotoxic effects on oral tissues (Fatmasari, 2021; Yuwono, 2022; Metanfanuan, 2016; Mangiri, 2018; Jung I hee, 2020). In addition, conventional plaque assessment remains largely subjective because it depends on visual interpretation, examiner experience, and lighting conditions, making the procedure time-consuming and less practical, particularly during mass screening or examinations involving uncooperative patients (Keerthana, 2018; Pretty, 2005). Although several alternative approaches, including anthocyanin-based natural disclosing agents, light-induced fluorescence (LIF), and smartphone-based digital plaque assessment, have been developed, these methods still exhibit limitations related to color stability, consistency, sensitivity, and restricted

visualization capabilities (Nurbaeti, 2017; Inggrid Prananta, 2019; Kim, 2014; Van Der Veen, 2006; Azevedo, 2022).

Recent advances in digital technology, optical imaging, and artificial intelligence have created opportunities to improve the objectivity and efficiency of plaque detection systems. High-resolution cameras and optical sensors enable real-time visualization and digital image analysis for more accurate plaque assessment (Erten, 2006). Furthermore, camera-based systems facilitate two-way visualization, allowing both healthcare providers and patients to observe oral conditions simultaneously, thereby enhancing patient education and awareness (Thomas, 2025). The integration of deep learning algorithms such as YOLOv8 also enables automatic and real-time plaque detection with high analytical speed and accuracy. Previous studies have demonstrated the potential of YOLO-based systems in identifying dental plaque patterns through digital imaging approaches. However, most previous studies have focused primarily on software-based image analysis or smartphone-assisted assessments without integrating these technologies into a practical clinical examination device that combines direct intraoral visualization, automated plaque detection, and real-time assessment in a single system. This condition indicates a research gap regarding the development of integrated, user-friendly, and objective plaque examination tools suitable for routine clinical practice and preventive oral healthcare services.

Based on these limitations and research gaps, this study introduces the novelty of a Smart Dental Mirror that integrates a conventional dental mirror with a camera system, LED illumination, wireless sensors, and YOLOv8-based deep learning technology for automatic plaque detection and visualization. Unlike conventional plaque examination methods, this device is designed to provide objective, real-time, and efficient plaque assessment while simultaneously improving patient engagement and educational communication. The integration of artificial intelligence with intraoral visualization technology represents an innovative approach to overcoming the limitations of traditional disclosing agents and subjective plaque assessment methods. Therefore, this study aims to develop and evaluate the feasibility, effectiveness, and efficiency of the Smart Dental Mirror as an innovative tool for more objective, accurate, and efficient dental plaque examination in oral healthcare services.

## **2. METHOD**

This study employed a mixed-methods approach that combined qualitative and quantitative methods within a Research and Development (R&D) framework to develop and evaluate the Smart Dental Mirror as an innovative tool for dental plaque assessment. The R&D method was applied not only to produce and refine the device prototype but also to assess its effectiveness and efficiency in clinical plaque examination. A descriptive approach was used during the preliminary stage to collect information and identify user needs that supported product design and development, while an analytical approach was employed to evaluate the performance of the developed device. The study implemented a quasi-experimental crossover design, in which each participant underwent plaque examination using both the Smart Dental Mirror and the conventional method involving a mouth mirror and disclosing agent, allowing direct comparison between the two examination methods. The sample consisted of 33 dental health professionals including dentists and dental and oral therapists who met both the inclusion and exclusion criteria.

The research and development process was conducted through several systematic stages, including: (1) information gathering and needs assessment; (2) product design and prototype development; (3) expert validation and product revision; (4) product testing;

(5) prototype improvement based on evaluation results; (6) final prototype development; and (7) product implementation. The study participants consisted of dental health professionals selected using purposive sampling techniques according to predetermined inclusion criteria. Data collection was performed using structured questionnaires and observation sheets that had previously undergone validity and reliability testing. Instrument validity was assessed using bivariate correlation analysis with SPSS for Windows, while reliability was evaluated using Cronbach's Alpha coefficient. Instruments were considered valid and reliable if they met the established statistical criteria.

The independent variable in this study was the plaque examination method, consisting of the Smart Dental Mirror and the conventional plaque examination method, while the dependent variables included plaque score assessment, examination effectiveness, and examination efficiency. Prior to inferential analysis, data normality was tested using the Shapiro–Wilk test due to the relatively small sample size. If the data were normally distributed, comparisons between paired variables were analyzed using the paired t-test, whereas the independent t-test was used for unpaired variables. For non-normally distributed data, the Wilcoxon Signed-Rank test was applied for paired comparisons, and the Mann–Whitney test was used for unpaired data analysis. All statistical analyses were performed using SPSS version 24.0 for Windows, with the level of statistical significance set at  $p < 0.05$ . This study also received ethical approval from the Health Research Ethics Committee of the Health Polytechnic of the Ministry of Health Semarang under ethical clearance number No. 1277/EA/F.XXIII.38/2025. All participants provided informed consent prior to their involvement in the study.

### 3. RESULTS AND DISCUSSION

**Table 1.** Frequency Distribution of Respondents' Characteristics

Characteristics	Frequency (n)	Percentage (%)
Gender		
Male	1	3.0
Female	32	97.0
Occupation		
Dentist	11	33.3
Dental Therapist	22	66.7
Age Group		
17–25 years	1	3.0
26–35 years	21	63.6
36–45 years	5	15.2
46–55 years	4	12.1
56–65 years	2	6.1
Working Experience		
2–12 years	23	69.7
13–22 years	4	12.1
23–32 years	3	9.1
33–42 years	3	9.1

Table 1 presents the demographic characteristics of the respondents involved in this study. Based on gender distribution, the majority of respondents were female, accounting for 32 individuals (97.0%), while only 1 respondent (3.0%) was male. Regarding occupation, most respondents were dental therapists, comprising 22 individuals (66.7%), whereas dentists accounted for 11 respondents (33.3%). In terms of age distribution, the

largest proportion of respondents was in the 26–35 years age group, consisting of 21 individuals (63.6%), indicating that most participants were within the productive working-age category. The smallest proportion was found in the 17–25 years age group, with only 1 respondent (3.0%).

Based on working experience, the majority of respondents had 2–12 years of professional experience, accounting for 23 individuals (69.7%). Meanwhile, respondents with 23–32 years and 33–42 years of working experience each consisted of 3 individuals (9.1%), representing the smallest proportion. Overall, these findings indicate that the respondents were predominantly female dental therapists in their productive age with moderate professional experience, suggesting that they possessed adequate clinical exposure to evaluate the implementation of the Smart Dental Mirror in dental practice.

**Table 2.** Frequency Distribution of Plaque Measurement Results Using Disclosing Agent and Smart Dental Mirror.

Plaque Category	Plaque Score Range	Disclosing Method n (%)	Smart Dental Mirror n (%)
Very Good	0	0 (0%)	0 (0%)
Good	0.1–1.7	0 (0%)	1 (3.0%)
Moderate	1.8–3.4	9 (27.3%)	6 (18.2%)
Poor	3.5–5.0	24 (72.7%)	26 (78.8%)
Total		33 (100%)	33 (100%)

Based on Table 2, plaque examination using the conventional disclosing method showed that the majority of respondents were classified in the poor plaque category, accounting for 24 respondents (72.7%), while 9 respondents (27.3%) were categorized as having moderate plaque levels. No respondents were classified as having very good or good plaque status using this method.

Similarly, plaque assessment using the Smart Dental Mirror demonstrated that most respondents were categorized as poor, with 26 respondents (78.8%), followed by 6 respondents (18.2%) in the moderate category and 1 respondent (3.0%) in the good category. No respondents were classified as having very good plaque status.

Overall, both examination methods showed a similar distribution pattern, with the majority of respondents presenting poor plaque conditions. However, the Smart Dental Mirror was able to identify a small proportion of respondents in the good plaque category, which was not detected using the conventional disclosing method. These findings suggest that the Smart Dental Mirror has comparable capability in plaque detection and may provide additional sensitivity in identifying better plaque conditions.

**Table 3.** Comparison of Plaque Examination Efficiency Between the Smart Dental Mirror and Conventional Method.

Aspect	Category	Smart Dental Mirror (n)	Conventional Method (n)	p-value
Time Efficiency	Slow	0	23	0.000*
	Moderate	19	7	
	Fast	14	3	
Cost Efficiency	Low	0	5	0.011*
	Moderate	22	24	

	High	11	4	
Labor Efficiency	Few Personnel	18	1	0.000*
	Moderate Personnel	15	4	
	Many Personnel	0	28	

\*Statistically significant at  $p < 0.05$

Based on Table 3, the efficiency comparison between the Smart Dental Mirror and the conventional plaque examination method was evaluated across three main aspects: time, cost, and labor efficiency. In terms of time efficiency, the conventional method was predominantly categorized as slow, with 23 respondents, whereas no respondents rated the Smart Dental Mirror in the slow category. In contrast, the Smart Dental Mirror was more frequently rated as moderate (19 respondents) and fast (14 respondents) compared to the conventional method, which was rated as moderate by 7 respondents and fast by only 3 respondents. Statistical analysis showed a significant difference between the two methods ( $p = 0.000$ ), indicating that the Smart Dental Mirror provides greater time efficiency during plaque examination.

Regarding cost efficiency, the conventional method was more commonly rated as low cost by 5 respondents, while no respondents categorized the Smart Dental Mirror as low cost. Both methods showed relatively similar results in the moderate-cost category, with 22 respondents for the Smart Dental Mirror and 24 respondents for the conventional method. However, the Smart Dental Mirror was more frequently categorized as high cost (11 respondents) compared to the conventional method (4 respondents). The statistical test revealed a significant difference ( $p = 0.011$ ), suggesting that the integration of advanced technology in the Smart Dental Mirror increases operational costs.

For labor efficiency, the conventional method was predominantly classified in the many personnel category, with 28 respondents, whereas no respondents rated the Smart Dental Mirror in this category. The Smart Dental Mirror was more commonly categorized as requiring few personnel (18 respondents) and moderate personnel (15 respondents), compared to the conventional method, which was rated by only 1 respondent and 4 respondents in these respective categories. Statistical analysis also demonstrated a significant difference ( $p = 0.000$ ), indicating that the Smart Dental Mirror requires fewer personnel during the plaque examination process.

Overall, these findings demonstrate that the Smart Dental Mirror offers superior efficiency in terms of examination time and labor requirements compared to the conventional method, although it is associated with relatively higher operational costs due to the use of advanced digital technology.

**Table 4.** Comparison of the Effectiveness of Plaque Examination Between the Smart Dental Mirror and Conventional Method.

Aspect	Category	Smart Dental Mirror (n)	Conventional Method (n)	Asymp. Sig. (2-tailed)
Simplicity	Less Simple	0	2	0.039*
	Simple	20	25	
	Very Simple	13	6	
Ease of Use	Low	0	2	0.108
	Moderate	20	23	

Aspect	Category	Smart Dental Mirror (n)	Conventional Method (n)	Asymp. Sig. (2-tailed)
User Satisfaction	High	13	8	0.006*
	Low	0	4	
	Moderate	19	25	
Diagnostic Accuracy	High	14	4	0.593
	Low	1	0	
	Moderate	21	25	
	High	11	8	

\*Statistically significant at  $p < 0.05$

Based on Table 4, the effectiveness of plaque examination using the Smart Dental Mirror was assessed across several aspects, including simplicity, ease of use, user satisfaction, and diagnostic accuracy. In terms of simplicity, the Smart Dental Mirror was more frequently rated as very simple by 13 respondents, compared to only 6 respondents for the conventional method. Although the conventional method was more commonly categorized as simple (25 respondents) than the Smart Dental Mirror (20 respondents), it still received ratings in the less simple category from 2 respondents, whereas the Smart Dental Mirror received no such ratings. Statistical analysis demonstrated a significant difference between the two methods ( $p = 0.039$ ), indicating that the Smart Dental Mirror tends to provide a simpler plaque examination procedure.

Regarding ease of use, 13 respondents rated the Smart Dental Mirror as having high usability, compared to 8 respondents for the conventional method. Furthermore, the conventional method still received low usability ratings from 2 respondents, while the Smart Dental Mirror received none. However, the statistical analysis showed no significant difference between the two methods ( $p = 0.108$ ). These findings suggest that although the Smart Dental Mirror demonstrated better usability descriptively, the difference was not statistically significant.

For user satisfaction, the Smart Dental Mirror demonstrated substantially higher satisfaction levels. A total of 14 respondents rated user satisfaction as high for the Smart Dental Mirror, compared to only 4 respondents for the conventional method. In addition, the conventional method still received low satisfaction ratings from 4 respondents, whereas the Smart Dental Mirror received none. Statistical analysis indicated a significant difference between the two methods ( $p = 0.006$ ), suggesting that the Smart Dental Mirror provides a more positive user experience, likely due to its more practical and less complicated examination procedure.

In terms of diagnostic accuracy, the Smart Dental Mirror showed slightly better performance, with 11 respondents rating it as highly accurate compared to 8 respondents for the conventional method. Both methods were predominantly rated in the moderate accuracy category. However, one respondent still rated the Smart Dental Mirror as having low accuracy. Statistical analysis revealed no significant difference between the two methods ( $p = 0.593$ ), indicating that both methods provide relatively comparable accuracy in plaque examination.

**Table 5.** Results of the Comparative Test of Effectiveness and Efficiency Between the Smart Dental Mirror and Conventional Plaque Examination Method.

Variable	Efficiency Comparison	Effectiveness Comparison
Z Value	-3.409 <sup>b</sup>	-0.775 <sup>b</sup>
Asymp. Sig. (2-tailed)	0.001*	0.439

<sup>b</sup> Wilcoxon Signed-Rank Test

\*Statistically significant at  $p < 0.05$

Table 5 presents the results of the statistical comparison of effectiveness and efficiency between the Smart Dental Mirror and the conventional plaque examination method. In terms of efficiency, the Wilcoxon Signed-Rank Test showed a Z value of -3.409 with a significance value of 0.001. Since the p-value was lower than the significance threshold of 0.05, a statistically significant difference was identified between the two methods. This finding indicates that the Smart Dental Mirror significantly improves the efficiency of plaque examination compared to the conventional method.

In contrast, the effectiveness analysis yielded a Z value of -0.775 with a significance value of 0.439. Because the p-value exceeded 0.05, no statistically significant difference was found between the Smart Dental Mirror and the conventional method in terms of effectiveness. This result suggests that both methods demonstrate comparable effectiveness in plaque examination, although descriptive differences were observed.

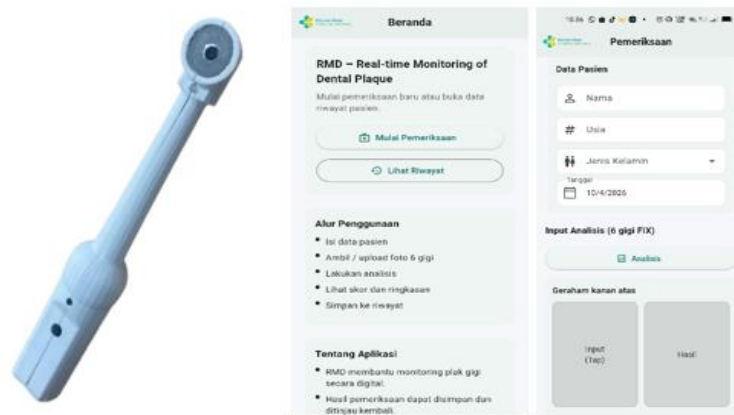
**Table 6.** Feasibility Test Results of the Smart Dental Mirror for Plaque Examination.

Variable	N	Mean Score (%)	ICC	p-value
Feasibility of the Smart Dental Mirror	33	72%	0.796	0.000*

\*Statistically significant at  $p < 0.05$

Based on Table 6, the feasibility test of the Smart Dental Mirror for plaque examination was conducted among 33 oral health professionals, consisting of 11 dentists and 22 dental therapists. The results demonstrated a mean feasibility score of 72%, which falls within the feasible category. Statistical analysis showed a p-value of 0.000, indicating that the Smart Dental Mirror is considered suitable for use by dentists and dental therapists in assisting plaque examination procedures.

Furthermore, the Intraclass Correlation Coefficient (ICC) value obtained was 0.796, indicating a high level of reliability and strong inter-rater agreement among the evaluators. These findings suggest that the Smart Dental Mirror provides consistent assessment results and has good potential for clinical application in dental plaque examination.



**Figure 1.** Design of the Smart Dental Mirror Innovation and Application.

Figure 1 shows that the Smart Dental Mirror developed in this study is an innovative dental plaque examination device designed to improve the effectiveness and efficiency of oral health assessments. This device is a modification of a conventional dental mirror equipped with a camera, LED lighting, and wireless sensors integrated with a deep learning-based application. The system utilizes an object detection algorithm based on the YOLOv8 (You Only Look Once version 8) model to assist in identifying and visualizing dental plaque more clearly through a digital display.

The results of information gathering indicate that dental examinations in healthcare facilities still tend to focus primarily on patients' chief complaints, while comprehensive examinations including oral hygiene assessment and plaque detection have not been optimally performed. This condition is influenced by limited service time, a high volume of patient visits, and constraints in human resources. In fact, plaque examination is a crucial component of risk-based prevention strategies aimed at reducing the incidence of oral diseases. From a promotive and preventive perspective, a risk-based approach is essential because it enables the identification of underlying causes of disease, allowing for more precise and sustainable interventions (Moss, 2023). However, in practice, healthcare services at primary care centers (puskesmas) are still dominated by curative and rehabilitative approaches, while promotive and preventive efforts remain suboptimal (Ministry of Health, 2014).

The implementation of plaque examination as part of preventive care also faces several challenges, particularly related to the limited availability of disclosing agents and the relatively complex and time-consuming examination procedures. The use of disclosing agents requires sequential steps that cannot be simplified, as each step plays a critical role in ensuring accurate visualization of plaque. Consequently, the examination process becomes longer and less efficient, especially in healthcare facilities with high workloads. This procedural complexity also affects healthcare providers' perceptions of the method's usefulness and ease of use, which ultimately influences its adoption in clinical practice (He, 2024). Additionally, prolonged examination time can reduce service productivity and increase patient waiting time, potentially lowering patient satisfaction (Marliza, 2023).

Conventionally, plaque examination using disclosing agents is based on chemical interactions between the dye and plaque biofilm, allowing plaque to be visualized according to the intensity of the resulting color (Datta, 2017). Although this method is relatively accurate, it has several limitations, including lengthy procedures (You, 2020), patient discomfort due to the taste of the agent, and difficulty in removing residual dye from surrounding soft tissues (Jumriani, 2023). Furthermore, the interpretation of results largely depends on the examiner's subjective judgment, which may introduce diagnostic bias.

These limitations highlight the need for innovation in plaque examination methods that are more practical, efficient, and objective. Based on field needs, healthcare professionals expect tools that are not only easy to use but also capable of providing accurate results and serving as educational media for patients. In this context, the development of the smart dental mirror represents an innovative solution by integrating camera technology, LED lighting, wireless sensors, and deep learning. This technology enables real-time visualization of plaque without the need for additional staining agents, making the examination process more practical and efficient. Previous studies have also shown that digital technology in dentistry can improve procedural efficiency, diagnostic accuracy, and patient satisfaction (Lee, 2024).

The integration of artificial intelligence systems, particularly the YOLOv8 algorithm, enables real-time object detection through a deep learning approach based on

Convolutional Neural Networks (CNN). This algorithm can identify objects in a single analytical process (single pass), making it faster and more efficient than conventional detection methods (You, 2020). Several studies have also demonstrated that YOLO-based approaches can detect various types of dental plaque with good accuracy (Charter, 2004). In addition, the use of wireless sensors allows real-time data transmission with high reliability, supporting more objective and systematic clinical evaluation (Haider-Neto, 2007).

The development of the smart dental mirror in this study demonstrated excellent validity and reliability based on expert evaluation, with an Aiken's V value of 0.83 and an Intraclass Correlation Coefficient (ICC) of 0.962. These results indicate that the developed tool meets feasibility criteria in terms of design, functionality, and clinical utility. Expert perspectives from both technology and clinical domains suggest that the device is relatively easy to use and has the potential to improve time efficiency, although further clinical validation regarding diagnostic accuracy is still required.

Efficiency testing results showed that the use of the smart dental mirror significantly improved time, cost, and labor efficiency compared to conventional methods. Time efficiency is primarily attributed to the elimination of procedural steps required in the disclosing method, allowing direct examination. This finding aligns with evidence that digitalization in healthcare reduces service time and enhances productivity (Gawali, 2024). Moreover, automation through artificial intelligence can reduce healthcare providers' workload and improve overall system efficiency (Naemi, 2024; Dwi, 2025).

In terms of effectiveness, the smart dental mirror demonstrated comparable results to conventional methods, particularly in plaque detection accuracy. The absence of significant differences indicates that the technology maintains diagnostic accuracy. Additionally, the device showed advantages in simplicity and user satisfaction, likely due to improved visualization and a more practical examination process. This is consistent with the concept that digital technologies can simplify clinical procedures without compromising outcomes (Spagnuolo, 2020). However, no significant difference was found in ease of use, indicating that usability remains a critical factor in technology adoption (Al, 2026).

From a feasibility perspective, the smart dental mirror was deemed suitable for use based on statistical testing and user observations, with an ICC value of 0.796 indicating high inter-user consistency. The application of deep learning technology enhances objectivity and consistency in examination results compared to conventional methods, which tend to be more subjective (Moharrami, 2025). Furthermore, the digital visualization produced by the device can serve as an educational tool, improving patient understanding and adherence to oral health care (Versteeg, 1997).

Despite these advantages, the study found no significant difference between the smart dental mirror and the disclosing method in determining plaque scores ( $p > 0.05$ ), indicating comparable accuracy between the two methods. However, limitations were identified in detecting very thin plaque, which may be influenced by sensor quality, lighting conditions, and the algorithm's ability to distinguish early-stage plaque from clean tooth surfaces. This finding is consistent with previous studies showing that YOLO-based systems may have limitations in detecting objects with low visual intensity (Ramírez-Pedraza, 2025). Sensitivity is a critical component in diagnosis, as it reduces the likelihood of false negatives and enhances early detection accuracy (Stojanović, 2014).

Overall, the smart dental mirror demonstrates strong potential as an innovative tool for dental plaque examination, maintaining diagnostic accuracy while improving efficiency and objectivity. Its implementation is expected to enhance the quality of oral healthcare services, particularly in promotive and preventive efforts. Additionally, the use of this

technology can strengthen the role of dental professionals especially dental therapists in patient education and in raising awareness of oral hygiene (Alkalah, 2016; Health Workforce Council, 2020).

Nevertheless, this study has several limitations, including a relatively small sample size that limits generalizability, and the study setting being confined to specific healthcare environments. Furthermore, the device is still in an early development stage and requires further refinement in ergonomic design, visualization system optimization, and calibration to improve accuracy. Therefore, future research is needed to further develop this technology, including comprehensive algorithm performance evaluation and broader clinical validation.

#### 4. CONCLUSION

In conclusion, the innovation of the smart dental mirror demonstrated feasibility as an alternative tool for dental plaque examination and achieved the study objective of developing a more effective and efficient plaque assessment method compared with conventional approaches. The findings indicate that conventional plaque examination using disclosing agents still presents several limitations, including procedural complexity, longer examination time, and dependence on subjective examiner interpretation. In contrast, the smart dental mirror, which integrates intraoral camera technology, LED lighting, wireless sensors, and deep learning systems, was shown to provide comparable effectiveness to conventional methods in terms of plaque detection accuracy and plaque index assessment while offering significantly greater efficiency in examination time, operational procedures, and workforce utilization. Expert validation and feasibility testing further confirmed that the device is appropriate for clinical use by dentists and dental therapists in supporting oral health examinations. The implementation of this innovation has important implications for improving the quality, objectivity, and productivity of dental healthcare services, particularly in promotive and preventive programs and in healthcare facilities with high patient workloads. In addition, the digital visualization produced by the device may enhance patient education and awareness regarding oral hygiene maintenance. Nevertheless, further research is recommended to optimize the visualization system, improve artificial intelligence-based image processing and automatic plaque detection accuracy, and refine the ergonomic design of the device. Future studies involving larger sample sizes and broader healthcare settings are also necessary to strengthen the generalizability and scientific evidence regarding the effectiveness, efficiency, and clinical applicability of the smart dental mirror.

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