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Article

Comparative evaluation of new caries diagnostic tools-Intraoral scanner and artificial intelligence -based caries detection software with visual examination on the efficacy of caries detection in children.

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Abstract: Background: Early diagnosis of dental caries is fundamental for preserving tooth structure and implementing preventive treatment in pediatric patients. Conventional visual examination remains the most frequently used diagnostic method; however, recent advances such as artificial intelligence (AI) and intraoral scanners (IOS) have introduced new opportunities for improving diagnostic accuracy. Comparative clinical evidence regarding these modalities in children remains limited. The present study evaluated and compared the diagnostic efficacy of AI-based caries detection software, an intraoral scanner, and visual examination in detecting dental caries among pediatric patients. Materials and Methods: A cross-sectional clinical study was conducted among 54 pediatric patients attending the Department of Pediatric and Preventive Dentistry, Inderprastha Dental College and Hospital. Caries assessment was performed using three diagnostic modalities: visual examination based on the International Caries Detection and Assessment System (ICDAS), intraoral scanner assessment, and AI-based caries detection software (CARIO). Diagnostic findings were recorded and statistically analyzed using SPSS Version 27. Intergroup comparisons were performed using the Chi-square test, with statistical significance set at $p \leq 0.05$. Results: Visual examination detected caries in 51 (94.4%) participants, the intraoral scanner detected caries in 30 (55.6%), and AI-based software detected caries in 53 (98.1%) participants. A significant association was observed between visual examination and the intraoral scanner ($p = 0.046$) and between visual examination and AI ($p < 0.001$), whereas the comparison between the intraoral scanner and AI was not statistically significant ($p = 0.259$). AI demonstrated the highest sensitivity for caries detection, while the intraoral scanner showed comparatively lower diagnostic performance. Conclusion: Artificial intelligence–based caries detection software demonstrated superior diagnostic performance compared with the intraoral scanner and showed excellent agreement with visual examination. AI appears to be a promising

adjunctive tool for early caries detection in children, while visual examination continues to remain an essential clinical diagnostic method.
Keywords: Artificial intelligence; caries detection; dental caries; ICDAS; intraoral scanner; pediatric dentistry.

1. Introduction

Dental caries remains one of the most prevalent chronic diseases affecting children worldwide and continues to represent a major public health concern. The disease results from a dynamic interaction between cariogenic microorganisms, fermentable dietary carbohydrates, and susceptible tooth surfaces, ultimately leading to progressive demineralization of enamel and dentin. When left undetected during its initial stages, carious lesions may progress rapidly, resulting in cavitation, pulpal involvement, pain, infection, and premature tooth loss. Consequently, early diagnosis plays a pivotal role in preserving tooth structure and facilitating minimally invasive treatment approaches. [1]

Conventional visual examination remains the cornerstone of clinical caries diagnosis because of its simplicity, affordability, and ease of application. The International Caries Detection and Assessment System (ICDAS) has further enhanced visual diagnosis by providing a standardized and evidence-based scoring system capable of identifying the full spectrum of carious lesions, from initial enamel demineralization to extensive cavitation. Standardized ICDAS assessment improves diagnostic consistency and facilitates comparison among clinical studies. [2]

Despite these advantages, early non-cavitated lesions located within pits and fissures often remain difficult to identify through conventional examination alone. Advances in digital dentistry have therefore led to the development of intraoral scanners capable of producing highly accurate three-dimensional digital images of the dentition. These systems enable detailed visualization of tooth morphology, facilitate digital documentation, and allow longitudinal monitoring of enamel surface changes without exposing patients to ionizing radiation. Their non-invasive nature makes them particularly attractive for use in pediatric dentistry. [3]

Recent developments in artificial intelligence have further transformed diagnostic dentistry. Deep learning algorithms trained using standardized datasets can identify subtle visual features associated with early carious lesions that may not be readily detectable during routine clinical examination. AI-assisted systems have demonstrated considerable potential for improving diagnostic consistency, minimizing examiner variability, and supporting clinical decision-making. Integration of AI with digital intraoral imaging also provides opportunities for teledentistry, large-scale screening programs, and preventive oral healthcare delivery. [4]

Although both intraoral scanners and AI-based diagnostic systems have shown promising results in experimental studies, evidence comparing these technologies with conventional visual examination in pediatric clinical practice remains limited. Therefore, the present study was undertaken to compare the diagnostic efficacy of visual examination, an intraoral scanner, and AI-based caries detection software in detecting dental caries among children and to determine their potential role in improving early diagnosis within routine pediatric dental practice. [5]

2. Materials and Methods

2.1 Study Design

A prospective cross-sectional clinical study was conducted in the Department of Pediatric and Preventive Dentistry, Inderprastha Dental College and Hospital, Sahibabad, Ghaziabad, Uttar Pradesh, India. The study was designed to evaluate and compare the diagnostic efficacy of three caries detection modalities: conventional visual examination using the International Caries Detection and Assessment System (ICDAS), an intraoral scanner (IOS), and an artificial intelligence (AI)-based caries detection software (CARIO). Ethical approval for the study was obtained from the Institutional Ethical Committee (RC–IPDC/297), and written informed consent was obtained from the parents or guardians of all participating children before enrolment.

2.2 Sample Size

The sample size was calculated using G*Power software (Version 3.1.9.6) at a 95% confidence level, considering a population proportion of 0.56 and a permissible error of 5%. Based on these parameters, the minimum required sample size was 54 children, which were included in the study.

2.3 Study Population

A total of 54 pediatric patients reporting to the Department of Pediatric and Preventive Dentistry were recruited according to the predefined eligibility criteria. The study population included children presenting with dental caries involving primary molars and/or permanent first molars.

2.4 Eligibility Criteria

Inclusion Criteria

Paediatric patients with carious lesions involving primary molars and permanent first molars.

Cooperative children without any systemic illness.

Parents or guardians willing to provide informed consent.

Exclusion Criteria

Children with special health care needs.

Uncooperative children.

Parents or guardians unwilling to participate in the study.

2.5 Study Groups

The participants were equally allocated into three diagnostic groups comprising 18 subjects each:

Group A: Visual examination using ICDAS criteria.

Group B: Caries assessment using an intraoral scanner with ICDAS-based evaluation.

Group C: Artificial intelligence–based caries detection using the self-developed CARIO software trained on ICDAS-labelled intraoral images.

2.6 Clinical Procedure

Each participant underwent caries assessment using all three diagnostic modalities during separate clinical visits under standardized clinical conditions.

2.6.1 Visual Examination

During the first visit, teeth were cleaned and dried before examination. Visual assessment was performed under adequate illumination using a mouth mirror and dental explorer according to the International Caries Detection and Assessment System (ICDAS). The ICDAS score for each tooth surface was recorded immediately after examination.

Figure 1: Caries assessment using visual examination.

2.6.2 Intraoral Scanner Assessment

During the second visit, all eligible teeth were scanned using the Straumann intraoral scanner. High-resolution three-dimensional digital images were obtained and evaluated using the associated software. Carious lesions were identified and scored according to ICDAS criteria. The scanner provided a non-invasive and radiation-free method for evaluating occlusal and smooth surface changes associated with dental caries.

Figure 2: Caries assessment using an intraoral scanner.

2.6.3 Artificial Intelligence-Based Assessment

During the third visit, standardized intraoral photographs were captured using the Nexus Medodent intraoral camera and uploaded into the self-developed CARIO artificial intelligence software. The AI system had previously been trained using ICDAS-labelled intraoral images to recognize different stages of dental caries. Following image processing, the software automatically generated ICDAS-based diagnostic outputs for each participant.

Figure 3: Intraoral camera images acquired for subsequent AI-based caries detection.

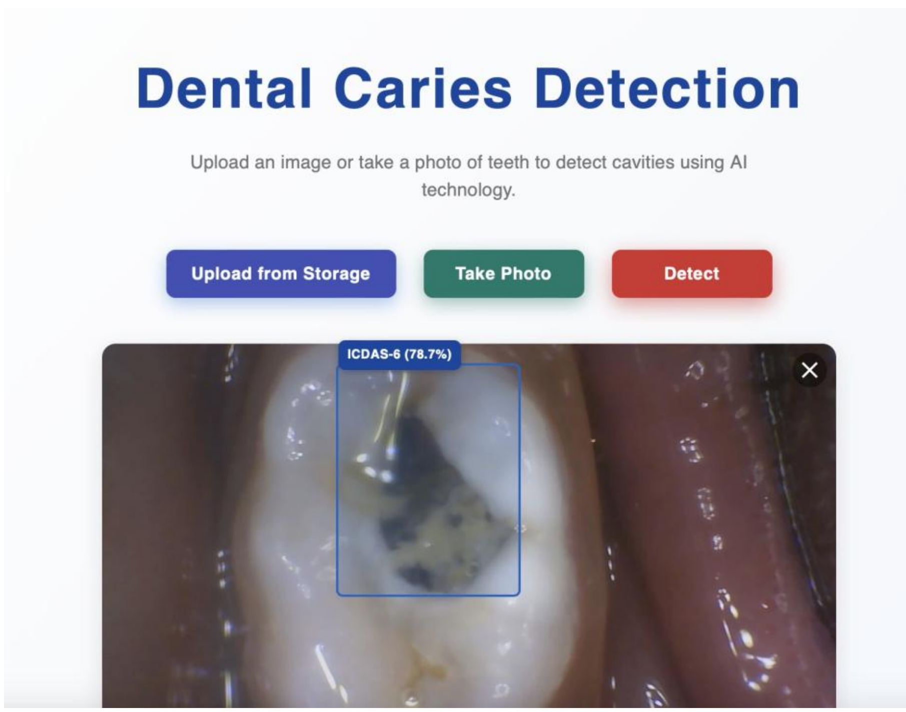

Figure 4: Artificial intelligence software output using ICDAS-based caries classification.

2.7 Data Collection

Diagnostic findings obtained from visual examination, intraoral scanning, and AI-based analysis were documented immediately in a standardized data recording form. All examinations were performed using identical diagnostic protocols to minimize operator-related variability and ensure consistency throughout the study.

2.8 Statistical Analysis

The collected data were entered into Microsoft Excel 2010 and analyzed using IBM SPSS Statistics Version 27.0. Data normality was evaluated using the Kolmogorov–Smirnov test. Descriptive statistics were expressed as frequencies and percentages. Comparisons among categorical variables were performed using the Chi-square test. Statistical significance was considered at $p \leq 0.05$, with a 95% confidence interval.

3. Results

A total of 54 pediatric patients were included in the present study to compare the diagnostic efficacy of visual examination, intraoral scanner imaging, and artificial intelligence (AI)-based caries detection software. The findings obtained from all three diagnostic modalities were statistically analyzed using the Chi-square test at a significance level of $p \leq 0.05$.

3.1 Visual Examination

Visual examination based on ICDAS criteria identified dental caries in 51 of the 54 children (94.4%), whereas only 3 children (5.6%) were classified as caries-free. These findings indicate that visual examination remains a highly effective clinical method for detecting carious lesions in pediatric patients.

Table 1. Evaluation of visual examination for dental caries detection in children

Variable	Frequency	Percent
No	3	5.6
Yes	51	94.4
Total	54	100.0

3.2 Intraoral Scanner Assessment

Table 2. Evaluation of the intraoral scanner for dental caries detection in children

Variable	Frequency	Percent
No	24	44.4
Yes	30	55.6
Total	54	100.0

Table 2 shows the evaluation of the intraoral scanner for dental caries detection in 54 children. The intraoral scanner identified 30 children (55.6%) as having caries, whereas 24 children (44.4%) had no detectable caries.

3.3 Artificial Intelligence-Based Assessment

Table 3. Evaluation of artificial intelligence software for dental caries detection in children

Variable	Frequency	Percent
No	1	1.9
Yes	53	98.1
Total	54	100.0

Table 3 shows the evaluation of the AI-based caries detection software in 54 children. The software identified 53 participants (98.1%) as having caries, while 1 participant (1.9%) was identified as caries-free.

3.4 Comparative Analyses

Table 4. Comparative evaluation of visual examination and intraoral scanner findings for dental caries detection in children

Intraoral Scanner	Visual Examination		Chi-square value	p-value / significance
	No	Yes		
No	3 (5.6%)	21 (38.9%)	3.971	0.046, S
Yes	0 (0%)	30 (55.6%)		

$p \leq 0.05$ indicates statistical significance; CI = 95%.

Table 4 compares visual examination and intraoral scanner findings among 54 children. Three children (5.6%) were caries-negative with both methods, while 30 children (55.6%) were caries-positive with both methods. Twenty-one children (38.9%) were caries-positive on visual examination but caries-negative on intraoral scanning. The association was statistically significant ($\chi^2 = 3.971$, $p = 0.046$).

Table 5. Comparative evaluation of visual examination and artificial intelligence software for dental caries detection in children

Artificial Intelligence Software	Visual Examination		Chi-square value	p-value / significance
	No	Yes		
No	1 (1.9%)	0 (0%)	17.321	<0.001, HS
Yes	2 (3.7%)	51 (94.4%)		

$p \leq 0.05$ indicates statistical significance; CI = 95%; HS = highly significant.

Table 5 compares visual examination and AI software. One child (1.9%) was classified as caries-free by both methods, and 51 children (94.4%) were classified as caries-positive by both methods. In two cases (3.7%), the AI software detected caries that was not identified during visual examination. The difference was highly significant ($\chi^2 = 17.321$, $p < 0.001$).

Table 6. Comparative evaluation of the intraoral scanner and artificial intelligence software for dental caries detection in children

Artificial Intelligence Software	Intraoral Scanner		Chi-square value	p-value / significance
	No	Yes		
No	1 (1.9%)	23 (42.6%)	1.274	0.259, NS
Yes	0 (0%)	30 (55.6%)		

$p \leq 0.05$ indicates statistical significance; CI = 95%; NS = not significant.

Table 6 compares the intraoral scanner and AI-based caries detection software in 54 children. The AI software identified 1 child (1.9%) as caries-free, whereas the intraoral scanner identified 23 children (42.6%) as caries-free. All 30 children (55.6%) identified as caries-positive by the intraoral scanner were also identified as caries-positive by AI. The association was not statistically significant ($\chi^2 = 1.274$, $p = 0.259$).

Table 7. Comparison of diagnostic performance for visual examination, intraoral scanner, and artificial intelligence software in dental caries detection

Modality	TP	FN	TN	FP	Sensitivity	Specificity	PPV	NPV
Intraoral scanner	30 (55.6%)	21 (38.9%)	3 (5.6%)	0 (0%)	55.6%	5.6%	1	0.12
Artificial intelligence	51 (94.4%)	0 (0%)	1 (1.9%)	2 (3.7%)	94.4%	1.9%	0.962	1

TP = true positive; FN = false negative; TN = true negative; FP = false positive; PPV = positive predictive value; NPV = negative predictive value. Values are reproduced from the submitted manuscript.

Table 7 shows that the diagnostic accuracy of the intraoral scanner and the AI-based software by comparing both modalities with visual examination, which served as the reference standard. For the intraoral scanner, 30 true positive cases (55.6%) were correctly identified, while 21 cases (38.9%) were missed and categorized as false negatives. Only 3 cases (5.6%) were correctly identified as true negatives, and no false positives were recorded. This resulted in a sensitivity of 55.6%, specificity of 5.6%, a positive predictive value (PPV) of 1, and a negative predictive value (NPV) of 0.12, indicating that while the scanner reliably confirmed positive cases, it demonstrated limited ability to detect negative cases and missed a considerable number of lesions. The AI software showed 51 true positives (94.4%) with no false negatives, demonstrating a high capacity to detect carious lesions. However, the software recorded 2 false positives (3.7%) and only 1 true negative (1.9%), resulting in a sensitivity of 94.4%, specificity of 1.9%, a PPV of 0.962, and an NPV of 1.

4. Discussion

Early detection of dental caries is essential for preventing lesion progression, preserving tooth structure, and promoting minimally invasive treatment in children. In the present study, ICDAS was used as the reference standard for evaluating visual examination, intraoral scanner (IOS), and AI-based caries detection software because it provides a standardized and reliable method for detecting caries at different stages. Similar findings were reported by Ismail et al. (2007) [2] and Jablonski-Momeni et al. (2014) [48], who demonstrated that ICDAS is a reproducible and reliable system for caries assessment.

Visual examination detected caries in 94.4% of children, demonstrating high diagnostic efficacy. These findings are consistent with Ekstrand et al. (2007) [44], Castillo et al. (2012) [45], and Cagetti et al. (2016) [46], who reported high diagnostic accuracy of ICDAS-based visual examination. However, Ferreira et al. (2019) [47] and Jablonski-Momeni et al. (2014) [48] reported comparatively lower diagnostic efficacy.

The intraoral scanner detected caries in 55.6% of children, indicating lower diagnostic performance than visual examination. Similar findings were reported by Mangione et al. (2020) [49] and Bansal et al. (2018) [50], whereas Neves et al. (2018) [51] and Fakhruddin et al. (2019) [59] observed higher diagnostic accuracy using fluorescence-assisted or laboratory-based IOS systems.

AI-based software demonstrated the highest diagnostic efficacy, detecting caries in 98.1% of participants. Comparison between visual examination and IOS showed a significant difference ($p = 0.046$), consistent with Mangione et al. (2020) [49] and Bansal et al. (2018) [50]. In contrast, Neves et al. (2018) [51] reported no significant difference.

Comparison between visual examination and AI showed a highly significant difference ($p < 0.001$), in agreement with Xiao et al. (2021) [9], Prados-Privado et al. (2020) [53], and Devlin et al. (2022) [54]. However, Lee et al. (2020) [10] and Johari et al. (2021) [55] observed no significant difference between AI and visual examination.

Comparison between IOS and AI showed no statistically significant difference ($p = 0.259$), similar to the findings of Michou et al. (2021) [57] and Ntovas et al. (2023) [18]. In contrast, Ahmed et al. (2025) [20] and Jones et al. (2025) [42] reported significantly better performance of AI than IOS.

Diagnostic accuracy analysis demonstrated that the intraoral scanner had low sensitivity (55.6%) and specificity (5.6%), consistent with Mangione et al. (2020) [49], Bansal et al. (2018) [50], and Alqarni et al. (2022) [56]. Conversely, AI demonstrated very high sensitivity (94.4%) but low specificity (1.9%), supporting the findings of Xiao et al. (2021) [9], Devlin et al. (2022) [54], and Moufti et al. (2023) [57].

Overall, the present study demonstrated that AI-based software achieved the highest diagnostic performance for detecting dental caries, while visual examination remained a reliable and clinically practical diagnostic method. The intraoral scanner showed comparatively lower diagnostic accuracy and should be considered an adjunctive rather than a primary diagnostic tool for caries detection in children.

5. Conclusion

The present study provides important clinical insight into the comparative performance of visual examination, intraoral scanner imaging, and artificial intelligence (AI)–based software for caries detection in children. The results demonstrated that digital innovations, particularly AI software, had the potential to enhance early identification of carious lesions in the children. While visual examination continues to serve as a dependable and clinically practical method, the intraoral scanner showed notable limitations. The present study highlights the shifting landscape of pediatric dentistry, where AI software may gradually take a more prominent role in preventive care. The findings reinforce the importance of selecting diagnostic methods that offer both accuracy and clinical feasibility, particularly in children where early detection plays a critical role in preventing further disease progression.

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