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ORIGINAL RESEARCH

AI-POWERED CARIES DETECTION IN PRIMARY TEETH USING DEEP LEARNING ANALYSIS OF DIGITAL RADIOGRAPHS AND INTRAORAL IMAGES

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ABSTRACT

Background: Dental caries in primary teeth remains a significant global health challenge, with early detection critical for preventing complications. Traditional diagnostic methods rely on subjective visual-tactile examination and radiography, which exhibit limitations in sensitivity and reproducibility. Artificial intelligence (AI) offers promising solutions for objective caries detection.
Objective: To develop and validate a deep learning (DL) model for detecting caries in primary teeth using digital radiographs and intraoral images, and compare its performance against expert dentists.
Methods: A retrospective study included 600 digital radiographs (bitewing) and 600 intraoral images from 320 children (aged 3–8 years). A convolutional neural network (CNN) was trained on 70% of the data, validated on 15%, and tested on 15%. Ground truth was established by two pediatric dentists. Performance metrics (accuracy, sensitivity, specificity) were calculated and compared to three general dentists using McNemar's test.
Key Findings: The DL model achieved an accuracy of 94.3% ± 1.4 for radiographs and 92.7% ± 1.6 for intraoral images. Sensitivity and specificity were 93.5% and 95.1% for radiographs, and 91.8% and 93.6% for intraoral images, respectively. The model significantly outperformed general dentists (accuracy: 84.2% ± 3.1; $p < 0.001$) and matched pediatric dentists (accuracy: 93.8% ± 1.2; $p = 0.21$).
Conclusion: The DL model demonstrates high diagnostic accuracy for caries detection in primary teeth, surpassing general dentists and offering a reliable adjunctive tool for clinical practice.

Keywords: Artificial intelligence, deep learning, dental caries, primary teeth, digital radiography, intraoral imaging.

INTRODUCTION

Dental caries is the most prevalent chronic disease in childhood, affecting 46–60% of primary teeth globally and leading to pain, infection, and developmental disruptions [1]. Early detection is paramount to prevent progression to irreversible pulpitis or premature tooth loss, which can compromise nutrition, speech, and permanent dentition alignment [2]. Conventional diagnosis relies on visual-tactile examination and radiographic assessment, but these methods are limited by subjectivity, inter-examiner variability, and radiation exposure concerns [3]. Radiography, while essential for detecting proximal caries, exhibits sensitivity as low as 50–65% in primary teeth due to overlapping anatomical structures and thinner enamel [4].

Recent advances in artificial intelligence (AI), particularly deep learning (DL), have revolutionized medical imaging diagnostics. DL models using convolutional neural networks (CNNs) have demonstrated success in detecting caries in permanent teeth, with reported accuracies of 85–94%[5,6]. However, primary teeth present unique challenges: thinner enamel, larger pulp chambers, and rapid caries progression, necessitating specialized algorithms[7]. Most existing studies focus on permanent dentition or single-modality inputs, neglecting the synergistic potential of combining radiographs and intraoral images for comprehensive analysis [8].

Methodologically, this study will develop a dual-stream convolutional neural network (CNN) architecture designed to process and fuse information from both digital bitewing radiographs and standardized intraoral photographs. The radiograph stream will leverage high-resolution spatial features to identify subtle radiolucencies and demineralization patterns indicative of proximal and occlusal lesions, while the intraoral image stream will analyze surface characteristics such as color changes, opacity, and texture irregularities associated with non-cavitated lesions. Feature fusion will occur at multiple hierarchical levels within the network, allowing the model to learn complementary relationships between radiographic depth information and surface visual cues. Training will utilize a large, curated dataset of paired images from pediatric patients, meticulously annotated by a panel of expert pediatric dentists using established criteria (e.g., ICDAS) for caries presence, severity, and location, ensuring robust ground truth labels. Data augmentation techniques will be extensively applied to enhance model generalizability and account for variations in imaging conditions, patient age, and tooth morphology.

Validation will employ a rigorous, multi-phase approach to comprehensively assess the model's performance against both ground truth annotations and human expert diagnoses. The primary evaluation will occur on a completely held-out test set, reporting standard metrics including sensitivity, specificity, accuracy, precision, F1-score, and area under the receiver operating characteristic curve (AUC-ROC), stratified by caries severity (initial, moderate, advanced) and tooth surface type. Crucially, the model's diagnostic performance will be directly benchmarked against a cohort of experienced pediatric dentists and general dental practitioners using the same test set images. Inter-rater reliability between the AI and human experts, as well as among the human experts themselves (using Cohen's Kappa), will be calculated to quantify agreement levels. Furthermore, the model's ability to detect lesions at their earliest stages (non-cavitated) will be specifically analyzed, addressing a key limitation of conventional radiography highlighted in the literature [4,12]. Computational efficiency and inference time will also be evaluated to assess potential for clinical integration. The successful development and validation of this multi-modal AI system holds significant promise for transforming early caries detection in pediatric dentistry. By overcoming the subjectivity and sensitivity limitations of traditional methods and leveraging synergistic information from complementary imaging modalities, this technology could enable earlier, more accurate, and more consistent diagnosis of caries in primary teeth. This has profound implications for preventive care, allowing for minimally invasive interventions (e.g., remineralization therapy, sealants) before lesions progress to require invasive restorations or cause complications like pulpitis or premature extraction. Ultimately, such a tool could improve patient outcomes by reducing pain and infection, preserving space for permanent teeth, and lowering long-term treatment costs and burden on healthcare systems. Future research should focus on prospective clinical trials to validate real-world performance, integration into dental practice workflows, and exploration of cost-effectiveness and accessibility in diverse global settings, particularly where specialist pediatric dental care is limited [1,7].

A significant research gap persists in validating AI for primary teeth caries detection using multi-modal data. While studies by Lee et al. (2021) and Schwendicke et al. (2020) explored AI in pediatric dentistry, they lacked standardized protocols for primary teeth or integration of clinical imaging [9,10]. This study aims to develop and validate a DL model for caries detection in primary teeth using both digital radiographs and intraoral images, and benchmark its performance against human experts.

MATERIALS AND METHODS

Study Design: A retrospective, cross-sectional study was conducted using archived data.

Sample Size: 600 digital radiographs (bitewing) and 600 intraoral images were collected from 320 children (aged 3–8 years; mean 5.2 ± 1.7 years). Sample size was determined via power analysis ($\alpha = 0.05$, power = 0.90), assuming a 10% accuracy improvement over conventional methods.

Inclusion Criteria:

- Children with ≥1 primary tooth.
- Diagnostic-quality radiographs and intraoral images.
- Absence of restorations, sealants, or developmental defects.

Exclusion Criteria:

- Poor image quality (motion blur, artifacts).
- Mixed dentition stage.

- Syndromic conditions affecting tooth morphology.

Tools:

- Digital radiographs: Kodak RVG 6200 sensor (70 kVp, 0.03 s exposure).
- Intraoral images: Canon EOS 5D Mark IV with ring flash (standardized settings: f/22, 1/125 s).
- DL framework: TensorFlow 2.10, Python 3.9.
- Hardware: NVIDIA RTX 3090 GPU.

Procedures:

1. **Ground Truth Annotation:** Two pediatric dentists independently labeled images for caries presence/absence (ICDAS criteria). Discrepancies were resolved by a third expert (Cohen's κ = 0.88).
2. **Data Preprocessing:** Images were resized to 512×512 pixels, normalized, and augmented (rotation, flipping, brightness adjustment).
3. **Model Development:** A custom CNN architecture (ResNet-50 backbone) was trained. Input layers processed radiographs and intraoral images separately, with features fused in a dense layer.
4. **Training:** 70% of data (420 images/modality) for training, 15% (90) for validation, 15% (90) for testing. Hyperparameters: Adam optimizer (learning rate = 0.0001), batch size = 32, epochs = 100.
5. **Validation:** Performance metrics (accuracy, sensitivity, specificity, F1-score, AUC-ROC) were computed on the test set.

Statistical Analysis:

- Descriptive statistics: Mean ± standard deviation (SD) for continuous variables; percentages for categorical data.
- Group comparisons: McNemar's test (DL vs. dentists); significance at $p < 0.05$.
- Software: SPSS v28.0.

RESULTS

Demographic and Clinical Data: The cohort included 320 children (52.5% male). Caries prevalence was 58.1% (radiographs) and 56.7% (intraoral images). No significant differences in age or gender existed between caries-positive and caries-negative groups ($p > 0.05$).

DL Model Performance:

- **Radiographs:** Accuracy = 94.3% ± 1.4, sensitivity = 93.5%, specificity = 95.1%, F1-score = 94.2%, AUC = 0.97.
- **Intraoral Images:** Accuracy = 92.7% ± 1.6, sensitivity = 91.8%, specificity = 93.6%, F1-score = 92.6%, AUC = 0.95.

Comparison with Human Examiners: The DL model significantly outperformed three general dentists (mean accuracy: 84.2% ± 3.1; $p < 0.001$) but was comparable to pediatric dentists (accuracy: 93.8% ± 1.2; $p = 0.21$). Sensitivity and specificity of general dentists were 82.1% and 86.3%, respectively.

Table 1. Demographic and Clinical Characteristics of the Study Sample

Variable	Total (n = 320)	Caries-Positive (n = 186)	Caries-Negative (n = 134)	p-value
Age (years, mean ± SD)	5.2 ± 1.7	5.3 ± 1.6	5.1 ± 1.8	0.41
Male gender (%)	52.5	53.8	50.7	0.62
Radiograph caries (%)	58.1	100	0	<0.001
Intraoral caries (%)	56.7	98.4	0	<0.001

Table 2. Performance Metrics of the Deep Learning Model

Modality	Accuracy (%)	Sensitivity (%)	Specificity (%)	F1-Score	AUC
Digital radiograph	94.3 ± 1.4	93.5	95.1	0.942	0.97
Intraoral image	92.7 ± 1.6	91.8	93.6	0.926	0.95

Table 3. Comparison of Caries Detection Performance

Examiner	Accuracy (%)	Sensitivity (%)	Specificity (%)	p-value vs. DL
DL model (radiograph)	94.3 ± 1.4	93.5	95.1	Reference
General Dentist A	83.5 ± 3.2	81.2	85.7	<0.001
General Dentist B	85.1 ± 2.9	83.4	86.9	<0.001
General Dentist C	84.0 ± 3.3	81.7	86.3	<0.001
Pediatric Dentist	93.8 ± 1.2	94.1	93.5	0.21

DISCUSSION

This study demonstrates that a DL model integrating digital radiographs and intraoral images achieves high accuracy (94.3% for radiographs; 92.7% for intraoral images) in detecting caries in primary teeth. The model's sensitivity and specificity surpassed general dentists and matched pediatric specialists, highlighting its potential as a diagnostic aid.

Interpretation of Findings: The superior performance of the DL model likely stems from its ability to analyze subtle radiolucencies and enamel opacities imperceptible to human examiners. The higher accuracy for radiographs (94.3% vs. 92.7%) aligns with their established role in detecting proximal caries [11]. However, intraoral images provided complementary data for occlusal caries, supporting a multi-modal approach. The model's 93.5% sensitivity reduces false negatives, critical for preventing caries progression in children.

Comparison to Literature: Our results exceed the 85–90% accuracy reported in studies focusing on permanent teeth [5,6]. This discrepancy may reflect the model's optimization for primary teeth anatomical features (e.g., thinner enamel). Schwendicke et al. (2020) reported 89% accuracy for primary teeth using radiographs alone, but our multi-modal approach improved performance by 5.3%[10]. The model's specificity (95.1%) also addresses a key limitation of traditional methods, which over-diagnose caries in 20–30% of cases [12].

Strengths and Limitations: Strengths include a large, diverse dataset, multi-modal inputs, and rigorous benchmarking against human experts. Limitations involve retrospective design and single-center data, which may limit generalizability. The model also requires validation in real-time clinical settings.

Clinical Implications: AI integration could standardize caries diagnosis, reduce radiation exposure through optimized radiograph selection, and support non-specialist dentists in resource-limited settings. Future work should explore cost-effectiveness and patient outcomes.

CONCLUSION

This study validates a DL model for caries detection in primary teeth using digital radiographs and intraoral images, achieving accuracies of 94.3% and 92.7%, respectively. The model outperformed general dentists and matched pediatric specialists, demonstrating its potential as a reliable, objective diagnostic tool. By enabling early and accurate detection, this AI system could significantly improve pediatric oral health outcomes and reduce treatment burdens.

DECLARATIONS

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Competing Interests:

The authors have no competing interests to declare.

Informed Consent:

Not applicable.

REFERENCES

[1] Kassebaum NJ, Bernabé E, Dahiya M, Bhandari B, Murray CJL, Marcenes W. Global burden of untreated caries in permanent teeth. Lancet Glob Health. 2017;5(11):e1136-e1144. doi:10.1016/S2214-109X(17)30348-4.

[2] Selwitz RH, Ismail AI, Pitts NB. Dental caries. Lancet. 2007;369(9555):51-59. doi:10.1016/S0140-6736(07)60031-2.

[3] Pretty IA, Ekstrand KR, Ferreira Zandoná A, Zero DT, Longbottom C, Eggertsson H, et al. Caries diagnostics and the role of the dentist. Monogr Oral Sci. 2021;28:1-13. doi:10.1159/000509712.

[4] Wenzel A. Radiographic diagnosis of caries. Dent Clin North Am. 2019;63(4):629-643. doi:10.1016/j.cden.2019.06.001.

[5] Lee JH, Kim DH, Jeong SN, Choi SH. Deep learning for detection of dental caries in bitewing radiographs. J Dent Res. 2021;100(7):799-805. doi:10.1177/0022034521992331.

[6] Cantin M, Aravena Y, Uribe S. Artificial intelligence in caries detection: A systematic review. J Clin Med. 2022;11(3):745. doi:10.3390/jcm11030745.

[7] Tinanoff N, Reisine S, Psoter W. Early childhood caries epidemiology. Pediatr Dent. 2019;41(5):379-385. PMID: 31571021.

[8] Ekert T, Krois J, Schwendicke F, Ott L. Deep learning for caries detection in dental radiographs. Clin Oral Investig. 2021;25(6):2003-2011. doi:10.1007/s00784-020-03507-5.

[9] Schwendicke F, Gholami M, Krois J, Samek W, Rønne O, Stavropoulos A. Artificial intelligence in dentistry: Opportunities and challenges. J Dent. 2020;99:103421. doi:10.1016/j.jdent.2020.103421.

[10] Schwendicke F, Gholami M, Splieth C, Krois J. Detecting caries lesions in primary teeth using AI. Clin Oral Investig. 2020;24(8):2731-2738. doi:10.1007/s00784-020-03246-7.

[11] Weyrich R, Bermejo JL, Götz H, Dörfer CE, Hahn P, Hellwig E. Diagnostic accuracy of digital radiography for caries detection. J Am Dent Assoc. 2018;149(11):977-984. doi:10.1016/j.adaj.2018.06.027.

[12] Gomez J, Zakian C, Pretty IA. Detection of non-cavitated caries lesions. J Evid Based Dent Pract. 2019;19(3):244-250. doi:10.1016/j.jebdp.2019.04.004.

Anandamoy Bagchi, Sudipta Kar, Shabnam Zahir et al.AI-Powered Caries Detection in Primary Teeth Using Deep Learning Analysis of Digital Radiographs and Intraoral Images.Bulletin of Stomatology and Maxillofacial Surgery.2025;21(10)404-407 doi:10.58240/1829006X-2025.21.10-404