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Using artificial intelligence in the evaluation of periapical, caries, and restoration status: a new methodological and technological study

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Abstract

Introduction This study aimed to assess and compare the accuracy of the radiographic diagnosis of caries and periapical status conducted by undergraduate students, endodontics residency students (ERS), and artificial intelligence (AI) applications. The gold standard for diagnosis was based on the conclusions of an endodontist.

Methods Among the 1,540 patients who visited the Department of Endodontics of the Faculty of Dentistry for endodontic treatment from 2020 to 2023, 68 patients met the inclusion criteria and were selected for this retrospective study. A total of 191 endodontically treated teeth were examined based on 68 panoramic radiographic images at two years post-treatment. The examiners were two undergraduate students, two endodontics residency students, two endodontists, and an AI application. Each examiner made independent diagnoses by evaluating the same panoramic radiographs and evaluating periapical conditions, caries, and restoration assets of the included teeth. Restoration and caries were scored as present or absent. The radiographic periapical status of teeth was evaluated using Periapical Index Scoring (PAI). Data were statistically analysed using the chi-squared test and Pearson's correlation coefficient. Intra-observer and inter-observer agreement were calculated using the kappa test ($\alpha = 0.05$).

Results The AI system demonstrated moderate agreement with the gold standard in detecting caries ($\kappa = 0.653$) and dislodged coronal restorations ($\kappa = 0.879$), but only slight agreement for periapical status ($\kappa = 0.155$). In the detection of caries, AI showed 65.3% sensitivity and 96.8% specificity, while expert raters achieved over 91% in both metrics. For dislodged coronal restorations, AI yielded high performance, with 82.1% sensitivity, 100% specificity, and 100% positive predictive value (PPV). In periapical status assessment, although AI achieved high sensitivity (92.9%) and negative predictive value (99%), its low specificity (58.6%) and PPV (15.3%) indicated a high false-positive rate. Overall, expert raters consistently outperformed students and AI across all diagnostic categories.

Conclusion These findings indicate that AI has the potential to support clinicians in detecting dislodged coronal restorations with high accuracy. Meanwhile, its performance in caries detection remains moderate, and its periapical status assessment is insufficient due to high false-positive rates. Although expert raters consistently demonstrated

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superior diagnostic performance, AI may serve as a supplementary tool in dental diagnostics, particularly for the identification of restoration failures. Further refinement and training of AI algorithms are necessary to enhance their reliability in comprehensive dental radiographic evaluation.

Clinical trial number Not applicable.

Keywords Artificial intelligence, Periapical pathology, Computer-aided diagnosis, Restoration status, Panoramic radiograph

Introduction

Dental caries represents a primary burden on oral health, a globally prevalent multifactorial disease that affects individuals of all ages [1]. It is characterised by the localised destruction of dental hard tissue caused by acid produced by the bacterial fermentation of dietary carbohydrates [2, 3]. Untreated caries can progress to involve the dental pulp and lead to subsequent periapical lesions, manifesting as radiolucent areas around the apex of the tooth on radiographic images [4, 5]. Early detection of lesions greatly improves treatment success and minimises risk factors [6].

Traditional methods for evaluating periapical status, detecting caries, and assessing restorations rely heavily on visual and tactile examinations alongside radiographic interpretation [7]. Although cone-beam computed tomographic (CBCT) imaging has a higher discriminatory ability, it is not widely used in general dental examination due to its high cost and associated radiation dose [8]. Overall, the current methods are subjective and can exhibit considerable inter-examiner variability, potentially leading to inconsistencies in diagnosis and treatment planning.

The advent of artificial intelligence (AI) in dentistry presents a paradigm shift, offering the potential for enhanced precision, efficiency, and objectivity across various diagnostic and therapeutic applications. Applications of AI in dentistry have demonstrated improved diagnostic accuracy and efficiency in identifying dental caries [2], periodontal diseases, and other oral conditions [9].

Developing AI methods for dental diagnoses remains a considerable challenge, because the existing literature has yet to fully explore approaches specifically tailored to such tasks. This study addresses this gap by investigating the accuracy and reliability of AI techniques designed for specific dental evaluations, namely periapical-periodontal assessment, dental caries classification, and restoration status analysis. The integration of AI into these areas holds potential for improving diagnostic interpretations and clinical outcomes [10, 11].

The detection of apical lesions (ALs) through a radiograph can vary greatly between examiners. The ability to discriminate the lesion is heavily influenced by the examiner's experience, with differences reported between undergraduate or postgraduate residency students, for example [12]. Automated assistance for dental radiographic image diagnosis has been proposed as a solution to eliminate this variability, if it can be proven to be as reliable and accurate as evaluation by specialists [13].

Accurate evaluation of panoramic radiographs is crucial for preventing recontamination of root canal-treated teeth and for early diagnosis of existing or emerging lesions [14]. Considering the potential advantages of AI, we aimed to assess the diagnostic accuracy for periapical lesions, caries, and restoration status in root canal-treated cases at two-year follow-up. We compared the performance of undergraduate students, endodontic residency students, and AI applications, based on follow-up panoramic images taken at a general dental examination. The null hypothesis was that there would be no differences between the groups.

Methods

Data collection was approved by the Ankara Yıldırım Beyazıt University (AYBU) Health Science Ethics Committee (EA4/080/18). Panoramic radiographs were retrospectively examined from 1,540 patients who had undergone dental examination between 2020 and 2023 at the Ankara Yıldırım Beyazıt University, Faculty of Dentistry Clinic. Radiographs had been taken in panoramic mode (66 to 68 kVp, 8 to10 mA, and 15.8 s) using the Planmeca ProMax 2D (Planmeca Oy, Helsinki, Finland) device. Analysed radiographs had been obtained as part of previous routine clinical care in compliance with radiation safety regulations, either for diagnostic purposes or for follow-up evaluations, rather than solely for research purposes.

Sixty-eight patients who met the inclusion criteria were selected for retrospective study. The inclusion criteria were as follows: (1) Healthy individuals between the ages of 18 and 50 years. (2) Teeth that had undergone root canal treatment in the same hospital, at least two years before the study, as confirmed by clinical and radiographic examination documents. (3) Absence of apical lesions on initial diagnostic panoramic radiographs of the teeth. Exclusion criteria were as follows: (1) Presence of systemic disease (e.g., diabetes mellitus, immunosuppression, or bone disorders that could affect periapical bone healing). (2) Age under 18 or over 50 years. (3) Absence

of baseline or follow-up panoramic radiographs. (4) Apical lesion at the initial radiograph. (5) Teeth found to be missing or extracted during the follow-up period.

Sixty-eight radiographs (before/after), including 191 teeth treated endodontically two years previously, were examined by two undergraduate students (STD), two endodontics residency students (ERS), two endodontists, and an AI application (Fig. 1). Panoramic device images were saved onto a disk in Digital Imaging and Communications in Medicine (DICOM) format. The STD, ERS, and experienced endodontist evaluations were performed in this format.

A final decision based on the consensus of two independent and experienced endodontists with over 10 years of clinical experience was considered the gold standard for diagnosis (Fig. 1). If the two experienced endodontists

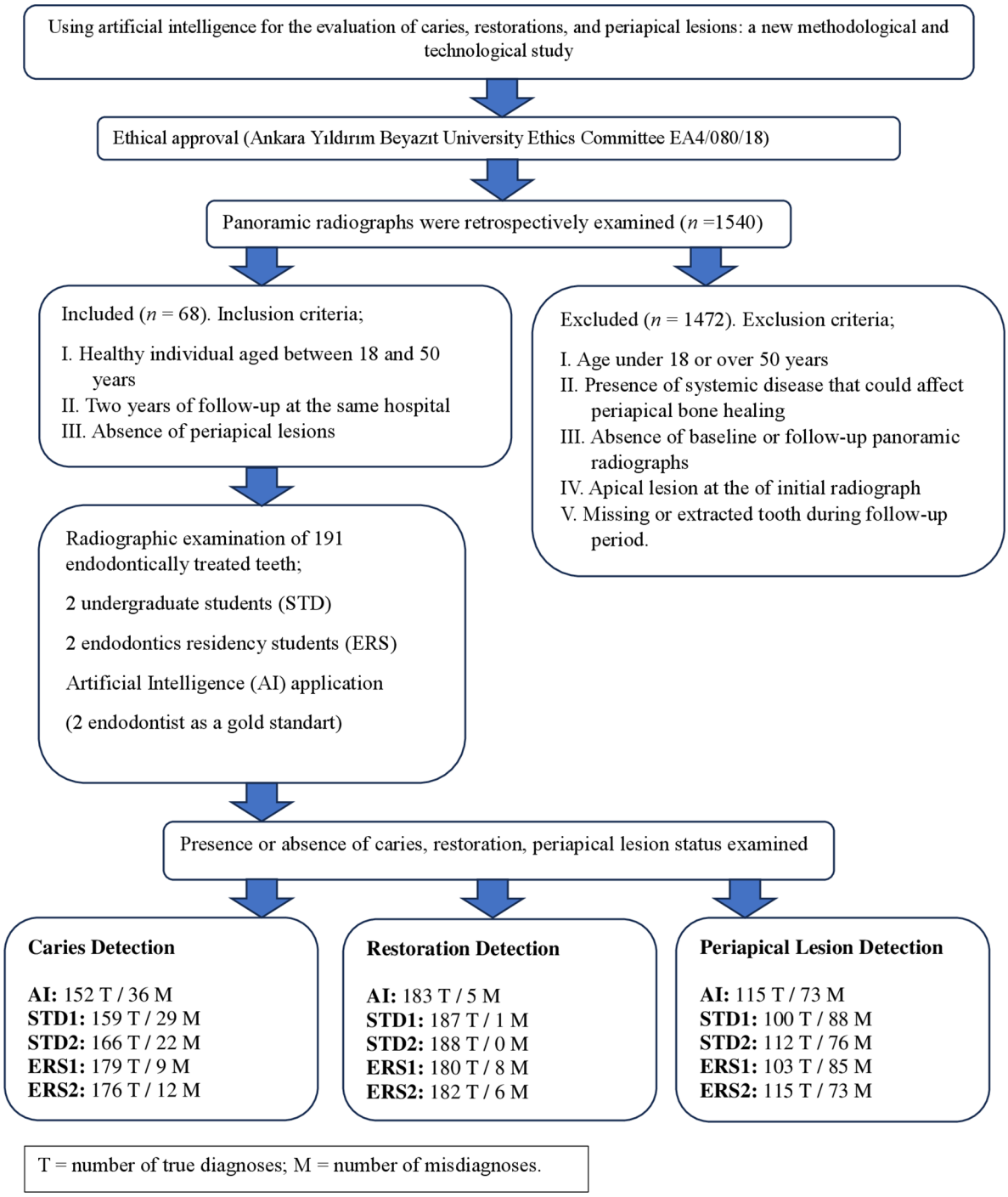


Fig. 1 Study design as a flowchart

were unable to reach a consensus, the image was considered ambiguous and removed. The conditions examined in panoramic images were the presence or absence of caries and restorations, and the periapical status.

The radiographic periapical status of teeth was evaluated using Periapical Index Scoring (PAI) to compare results. PAI scoring is a reliable way to evaluate treatment results and detect changes in periapical inflammation after root canal therapy [15].

Artificial intelligence process

The uploaded panoramic X-ray images first underwent a preprocessing stage, transforming them from DICOM to JPEG format. A comprehensive dataset of panoramic dental X-ray images was constructed to facilitate the diagnosis of a wide range of dental conditions. The dataset initially consisted of 9,573 radiographs collected from both adult and paediatric patients. At this stage, image sizing, contrast enhancement, and noise reduction algorithms were applied. To enhance diversity and improve the robustness of potential models, data augmentation techniques were employed, expanding the dataset to a total of 14,407 images. Each image was systematically annotated to identify and classify 19 distinct dental pathologies. The processed data was analysed by a deep learning model specially trained for segmentation and classification. The applied augmentation procedures included automatic orientation correction to ensure consistent image alignment and horizontal flipping to increase variability. During the training of the model, data augmentation techniques were applied; the diversity of the data was increased using methods such as rotation, scaling, brightness adjustment, and elastic transformation.

The AI model detected dental lesions and anatomical structures with high accuracy. For model development and evaluation, the dataset was divided into three subsets: 82% for training (11,848 images), 12% for validation (1,699 images), and 6% for testing (860 images). This stratified partitioning, combined with balanced class distributions, provides a strong foundation for building models with reliable generalisation capability. Overall, the dataset encompassed 135,559 annotations, consisting of bounding boxes and labels across 19 categories, representing the most extensive coverage of dental problems reported in publicly available datasets to date.

Artificial intelligence application

The AI application used is an online, mobile, free software platform. First, we downloaded the free programme (DentisToday; https://apps.apple.com/tr/app/dentistoday/id6482289821?l=tr and https://play.google.com/store/search?q=dentistoday%26c=apps%26hl=en; available on the Apple Store and Google Play). Radiography images were then uploaded to the AI programme, and the algorithmically analysed diagnosis results saved in Microsoft Excel format. The program diagnosed lesions and caries as present or absent on each X-ray (Fig. 2). The AI data and reference tests scoring periapical status as present or absent were recorded in an Excel sheet.

The mobile application was developed with the Flutter framework and optimised to run on both iOS and Android platforms. Provider structure was used for state management, and interface designs were prepared in accordance with Material Design principles in order to provide a user-friendly experience. The application performs data transfer to the AI system and retrieval of results via the RESTful API.

Statistical analysis

Statistical analyses were conducted using SPSS 25.0 (IBM, Chicago, IL, USA). To assess consistency between examiners, Fleiss's kappa was used. In order to assess the effectiveness of our approach, we utilised sensitivity (SEN), specificity (SPEC), positive predictive value (PPV), and negative predictive value (NPV) as metrics.

Results

Agreement between evaluators

Agreement between all raters and the gold standard was assessed for caries, dislodged coronal restorations, and periapical status. These results, with Kappa values, are listed in Table 1.

For caries detection, agreement with the gold standard for STD, ERS, and AI was moderate to substantial (Kappa values of 0.694 and 0.759), almost perfect (Kappa values of 0.904 and 0.874), and moderate (Kappa value of 0.653), respectively.

For dislodged coronal restoration detection, agreement for STD, ERS, and AI was near perfect (Kappa values of 0.974 and 1.000), substantial (0.888 and 0.914), and moderate (Kappa value of 0.879), respectively.

For periapical status assessment, agreement for STD, ERS, and AI was fair to moderate (Kappa values of 0.295 and 0.411), moderate (Kappa values of 0.523 and 0.606), and slight (Kappa value of 0.155), respectively.

Diagnostic performance for caries detection

Diagnostic performance for caries detection was evaluated for STD, ERS, and AI, as summarised in Table 2. A comparison of the performance of AI with other evaluators is illustrated in Fig. 3. The AI system achieved 152 true positive diagnoses, with a sensitivity of 65.3% and a high specificity of 96.8%. The PPV was 95.4%, and the NPV was 73.2%.

The students STD1 and STD2 achieved 159 and 166 true positive diagnoses, respectively. Sensitivity was 81.1% for STD2 and 73.7% for STD1, while both had

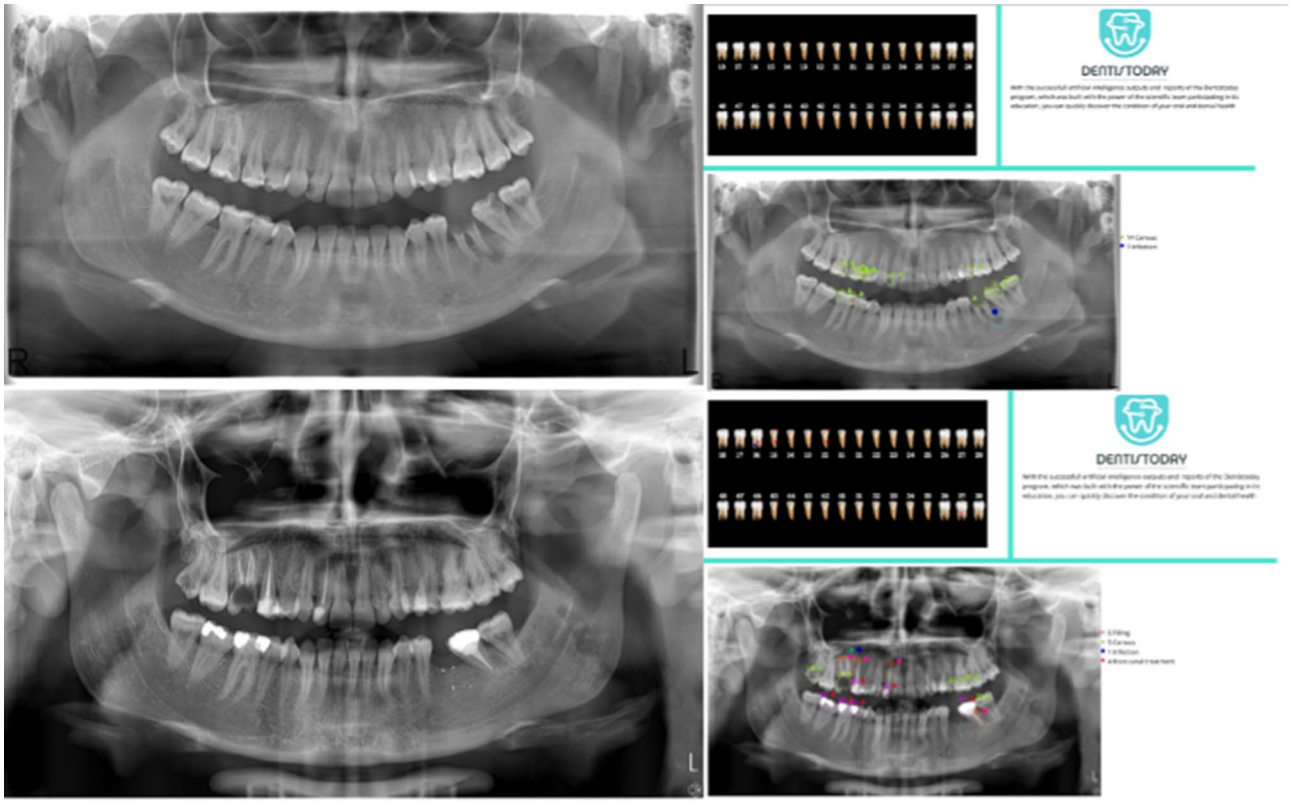


Fig. 2 Image of the artificial intelligence program used to detect the presence of periapical lesions, caries and restorations

Table 1 Interrater agreement values (Kappa) according to the detection of periapical status, caries, and dislodged coronal restoration

Groups	Caries	Dislodged Coronal Restoration	Periapical Status
SDT1	0.694	0.974	0.295
SDT2	0.759	1.000	0.411
ERS1	0.904	0.888	0.523
ERS2	0.874	0.914	0.606
AI	0.653	0.879	0.155

similar specificity (95.7%). PPV values ranged from 94.6% to 95.1%, and NPV values were 78.1% for STD1 and 83.2% for STD2.

The highest diagnostic accuracy was observed with ERS. ERS1 detected 179 and ERS2 detected 176 true positive diagnoses. Sensitivity, specificity, PPV and NPV were also very high, ranging from 91.6% to 95.7%.

Diagnostic performance for dislodged coronal restoration

For dislodged coronal restoration, diagnostic performances were evaluated for STD, ERS, and AI, and are summarised in Table 3. The AI system performed well, with 82.1% sensitivity and 100% specificity. It yielded high PPV and NPV (100% and 97%). Students demonstrated excellent sensitivity (100%) and very high specificity (99.4% and 100%). PPV and NPV were also 100% for STD2. ERS had excellent sensitivity (100%) and slightly lower specificity (95% and 96.3%). NPVs 100%, while PPVs were slightly lower (77.8% and 82.4%).

Diagnostic performance for periapical status

Diagnostic performances for periapical status were evaluated and are presented in Table 4; Fig. 4. AI yielded high sensitivity (92.9%) and NPV (99%), with 115 true

Table 2 Comparison of the detection of caries

	True Diagnosis	Mis Diagnosis	Sensitivity %	Specificity %	PPV %	NPV %
AI	152	36	65.3	96.8	95.4	73.2
STD1	159	29	73.7	95.7	94.6	78.1
STD2	166	22	81.1	95.7	95.1	83.2
ERS1	179	9	94.7	95.7	95.7	94.7
ERS2	176	12	91.6	95.7	95.6	91.8

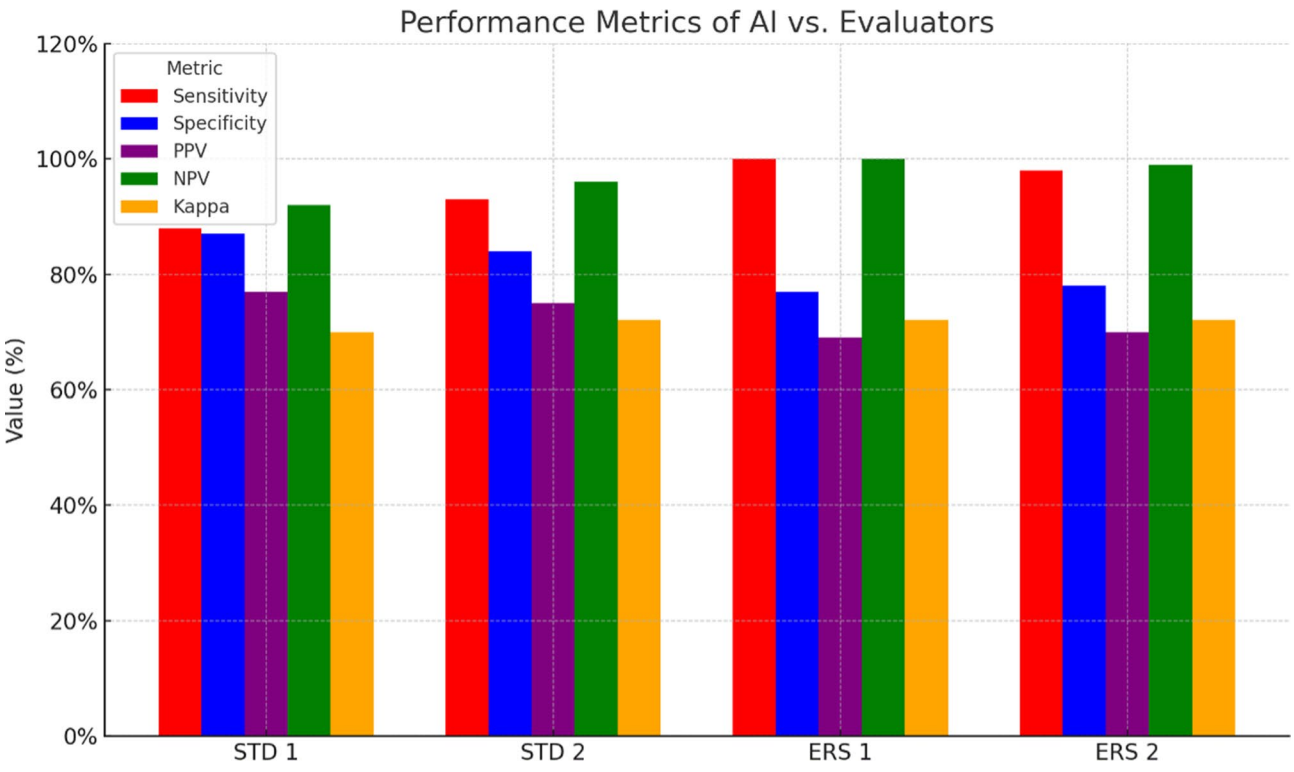


Fig. 3 Comparison of caries detection performance between AI and undergraduate students (STD1 and STD2) and endodontic residency students (ERS1 and ERS2) based on sensitivity, specificity, predictive values, and agreement

Table 3 Comparison of detection of dislodged coronal restoration

	True Diagnosis	Mis Diagnosis	Sensitivity %	Specificity %	PPV %	NPV %
AI	183	5	82.1	100.0	100.0	97.0
STD1	187	1	100.0	99.4	96.6	100.0
STD2	188	0	100.0	100.0	100.0	100.0
ERS1	180	8	100.0	95.0	77.8	100.0
ERS2	182	6	100.0	96.3	82.4	100.0

Table 4 Comparison of the detection of periapical status

	True Diagnosis	Mis Diagnosis	Sensitivity %	Specificity %	PPV %	NPV %
AI	115	73	92.9	58.6	15.3	99.0
STD1	100	88	57.1	72.1	62.3	67.6
STD2	112	76	71.4	70.2	65.9	75.3
ERS1	103	85	91.7	62.5	66.4	90.3
ERS2	115	73	95.2	67.3	70.2	94.6

diagnoses. However, specificity and PPV were quite low (58.6% and 15.3%, respectively), indicating a higher rate of false positives.

Students showed moderate sensitivity (57.1% and 71.4%) and specificity (72.1% and 70.2%). PPV and NPV ranged from 62.3% to 65.9% and 67.6% to 75.3%, respectively. ERS yielded high sensitivity (91.7% and 95.2%) and moderate specificity (62.5% and 67.3%). Their predictive values were higher than those of students (PPV, 66.4%–70.2%; NPV, 90.3%–94.6%).

Discussion

This study aimed to investigate the effectiveness of AI in assessing coronal deficiencies and periapical status in follow-up panoramic radiography images. While AI was successful in detecting caries and dislodged coronal

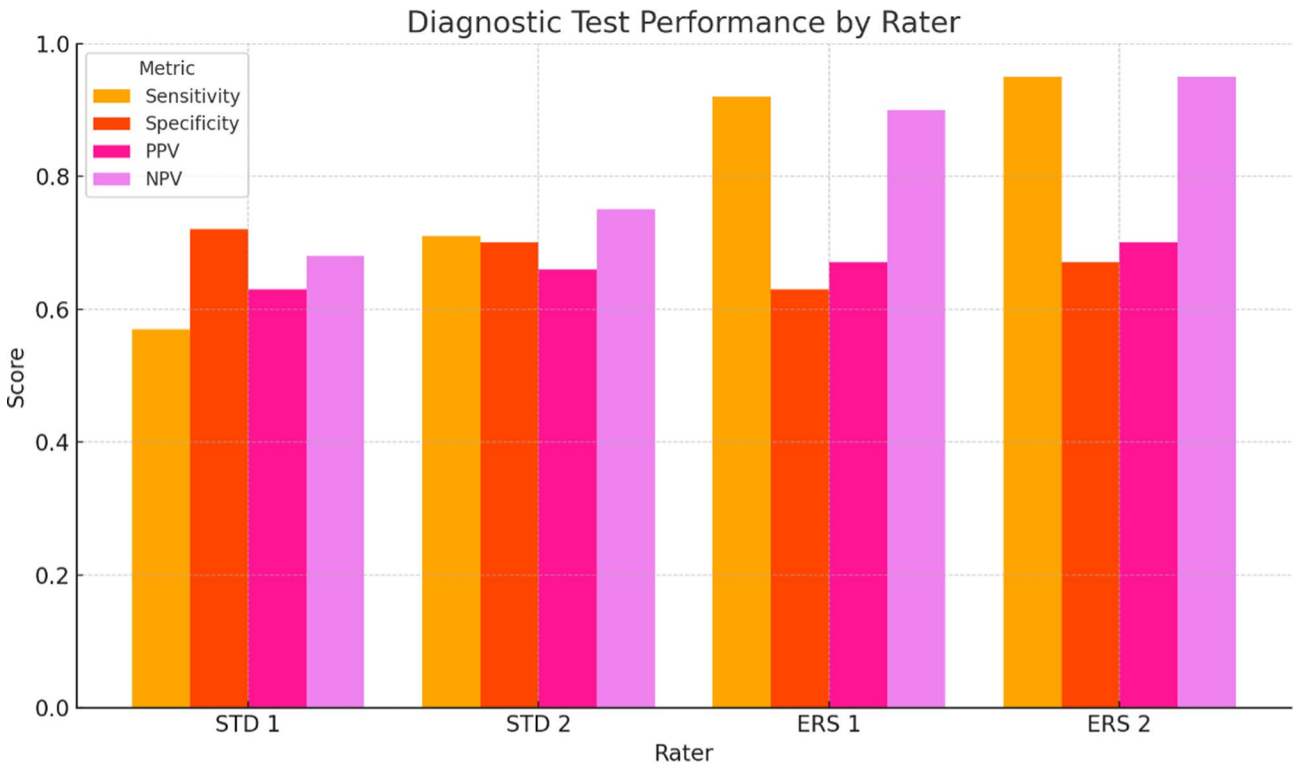


Fig. 4 Performance of undergraduate students (STD1 and STD2) and endodontic residency students (ERS1 and ERS2) in PAI Index evaluation

restorations in the coronal region, it was inadequate in assessing periapical status.

The performance of undergraduate and postgraduate dental students in detecting caries and periapical lesions was compared with that of AI, using expert opinion as reference values. The findings indicate that AI is not yet suitable to replace the gold standard in diagnosing caries and periapical lesions; however, it may be capable of serving as an auxiliary diagnostic tool. In caries detection, especially for educational purposes, a combination of AI and student assessment may yield effective results. Nevertheless, supervision by an expert is essential in such cases. From the perspective of specialists, AI could be utilised as a clinical decision support system, but it should not be relied upon as a sole decision-maker in high-risk cases. In the detection of dislodged coronal restorations, AI demonstrated high clinical reliability. Accordingly, it could be integrated into clinical workflows as a pre-assessment tool or a source of second opinion. However, due to the low kappa values observed, the overall reliability of the AI system remains limited. Further validation studies and model training are necessary to improve accuracy and consistency.

Promising reports have been published on the use of AI for monitoring dental caries and dislodged coronal restorations, using various diagnostic modalities. Das et al. [16] reported that AI algorithms provided higher accuracy than human interpretation in detecting caries from intraoral radiographs. Zhang et al. [17] reported on the integration of AI with an intraoral camera, with relatively high sensitivity for caries detection (81.31%), and even higher specificity for identifying sound teeth (95.65%). The authors emphasised, however, that diagnostic performance varied depending on tooth location.

The literature presents varying results regarding the detection of periapical lesions. Allihaibi et al. [18] compared the analysis of periapical radiographs using the Diagnocat software (Diagnocat Ltd., San Francisco, CA, USA) with expert assessments based on CBCT data. In contrast to our findings, they found the software to be more successful than experts in ruling out disease (95.4% specificity). In another study using the same software, periapical radiographs were compared with the outcomes of endodontic treatment, with AI-based diagnosis outperforming expert evaluation [19]. Liu et al. [20] stated that AI-assisted detection of lesions on periapical films could aid inexperienced clinicians during the diagnostic process. The variability in results regarding periapical lesion and disease detection may stem from methodological differences between studies.

Dentists may face difficulties and produce false positive errors in the detection of proximal radiolucency, resulting from issues like “cervical burnout” due to uneven exposure to X-rays, and variability of tooth thickness and density [21, 22]. Many studies have shown that AI can be beneficial for the detection (accuracy of 86% to

97%) of caries [23, 24]. In our study, the AI's results were largely consistent for the detection of caries on panoramic radiographs. Most previous studies have used bitewing [25, 26], periapical radiographs [27], or panoramic radiographs [28, 29] to assess caries detection. Panoramic radiographs are less sensitive than periapical and bitewing equivalents for the detection of caries and should not be the first choice alone. Although CBCT provides valuable information for the diagnosis of periapical lesions, it is not systematically used in the first stage of clinical examination or follow-up due to high radiation exposure and cost [29, 30]. Moreover, CBCT has a limited resolution that may lead to a higher rate of false positive findings in caries detection [31].

Evaluation of follow-up radiographs is an important factor for the success of endodontic treatment. It is important to keep in mind that the full outcome of an endodontic procedure may not be apparent during short-term follow-up periods [32, 33]. A two-year follow-up period is required to obtain a meaningful result from the relevant teeth [34]. Paredes-Vieyra and Jimenez Enriquez performed a two-year follow-up of teeth that had undergone root canal treatment [35]. They reported a 92.9% success rate according to PAI scoring. Song et al. examined 180 teeth with apical lesions using panoramic radiographs using a deep learning guided method, reporting high performance for the detection of periapical lesions [36]. Our results show that while AI had a high performance for detecting caries, it was inadequate in detecting periapical lesions. This may be because of interference from anatomical structures (such as the sinus floor, foramen mentale, and anterior nasal spine), which do not affect radiographs when detecting caries. Modern deep neural networks have a large number of parameters, and we aimed to increase data augmentation to improve generalisation by maximising the amount and variety of training data [37].

There are other limitations associated with integrating AI into diagnosis. Although standardised imaging methods are used in panoramic radiography, imaging techniques and the ability of AI to detect differences vary [38]. Patient-related anatomical differences, image distortions, and superimpositions of anatomical structures can affect the quality of the panoramic radiographs used for evaluation [39]. There are also patient-independent limitations arising from panoramic radiographs. In cases of early caries, in particular, panoramic radiographs have lower resolution compared to intraoral radiographs. Small or incipient caries or defective restorations may be overlooked. Magnification and distortion are also variable in panoramic radiographs. This makes it difficult to accurately determine the size and location of proximal caries, in particular. Furthermore, overlapping teeth in the posterior region can make small lesions difficult to detect [40, 41]. Contrast is more pronounced in intraoral and limited in panoramic radiographs.

In this study, a single AI program was assessed for diagnosis. It is important to note that different programs may yield different results. The results of AI-based lesion detection should be interpreted with caution, as the healing process of a lesion may take several years. Misinterpreting a visible lesion as a treatment failure may lead to unnecessary interventions and, in some cases, even tooth extraction due to complications [18].

Despite these limitations, AI-supported programs can aid clinicians in identifying certain defects and formations on panoramic radiographs, performing follow-up clinical examinations, objectively monitoring teeth, and interpreting prognoses. However, these programs require further development to ensure reliability in general use for clinical practice. It is recommended that AI algorithms be further developed, to provide more detailed analyses on the diagnosis of periapical lesions and increase the data supporting their acceptance as a practical clinical tool.

Conclusions

While the application of AI has produced promising results in the detection of defects in the coronal region, further development is required for its use in clinical practice for assessing the periapical status of endodontically treated teeth. As panoramic radiography provides a comprehensive view of the entire dentition and surrounding tissues, the integration of AI into the initial assessment of panoramic images may greatly assist in the diagnosis of coronal and periapical pathologies in future.

Abbreviations

AI	Artificial Intelligence
AL	Apical Lesion
CBCT	Cone Beam Computed Tomography
DICOM	Digital Imaging and Communications in Medicine
ERS	Endodontic Residency Students
PAI	Periapical Index
STD	Undergraduate Students

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12880-025-02019-y.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

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Author contributions

NBK: Conceptualisation, Methodology, Validation, Formal analysis, Resources, Writing-Original Draft. HGG: Conceptualisation, Methodology, Validation, Formal analysis, Investigation, Resources, Writing - Original Draft, Supervision.

GU: Methodology, Validation, Formal analysis, Investigation, Visualisation. EOT: Validation, Writing- Review & Editing, Visualisation.

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Data availability
The datasets generated or analysed during the study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by Ankara Yıldırım Beyazıt University Health Science Ethics Committee (EA4/080/18), which agreed to waive informed consent due to the retrospective nature of this study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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