RESEARCH PAPER

Comparative Evaluation Between Electronic Apex Locator and Digital Periapical Radiograph in Detection of Strip Perforation: An In Vitro Study

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ABSTRACT:
Background: *Strip perforation represents a significant iatrogenic complication during root canal procedures, making early identification crucial for a positive outcome. This in vitro research intends to evaluate the diagnostic precision of digital periapical radiography (DPR) and electronic apex locators (EAL) in identifying experimentally created strip perforations in extracted teeth within regulated laboratory settings.* ***Methods:*** *Sixty-nine extracted mandibular molars were categorized into perforated (n = 34) and control (n = 35) groups. Strip perforations were made 2–3 mm beneath the furcation using Gates-Glidden drills. Detection was conducted using three-angle digital periapical radiography and an electronic apex locator, with assessments done blindly. The assessment of diagnostic performance was conducted through sensitivity, specificity, and accuracy alongside 95% confidence intervals.* ***Results:*** *The EAL achieved a sensitivity of 94.1%, specificity of 94.3%, overall accuracy of 94.2%, and AUC of 0.942. DPR yielded sensitivity of 70.6%, specificity of 88.6%, accuracy of 79.7%, and AUC of 0.796. McNemar's test was non-significant (p = 0.1796), reflecting limited power from only 14 discordant pairs rather than equivalence. The EAL impedance point was statistically equivalent to the visual perforation site measurement (Wilcoxon p = 0.4435), with 91.2% of specimens within ±1.0 mm.* ***Conclusion:*** *The EAL outperformed DPR on every diagnostic measure (sensitivity of 94.1% vs 70.6%, specificity of 94.3% vs 88.6%, accuracy of 94.2% vs 79.7%) and accurately localized the perforation site. In clinical settings, the EAL should be the preferred intraoperative tool for strip perforation detection, with DPR retained as a supplementary modality for spatial documentation.*

Keywords: Strip perforation; Electronic apex locator; Digital periapical radiograph; Diagnostic accuracy; Mandibular molar; In vitro.

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INTRODUCTION:

Strip perforation is a lengthwise perforation of the root canal wall, typically found in the coronal or middle third, resulting from excessive instrumentation or anatomical errors, which establishes a connection with the periodontal ligament, resulting in inflammation, bone resorption, and potential tooth loss (incidence 2–12%) [1,2].

When a perforation goes unrecognized during treatment, the consequences can be swift and severe, progressive bone loss at the furcation, development of a deep periodontal pocket, and, without timely intervention, eventual loss of the tooth [3]. Strip perforation is a specific and clinically important subtype of iatrogenic root perforation that arises during canal preparation. It occurs when a rotating instrument removes too much dentine from the inner concave wall of a curved canal, tearing through the root in a longitudinal direction rather than creating the round, localized defect associated with other perforation types [4].

Digital periapical radiography is the imaging tool that most clinicians reach for first when a perforation is suspected during treatment. Its widespread availability, quick acquisition time, immediate digital display, and acceptably low radiation dose make it a practical choice at the chairside [5].

The electronic apex locator (EAL) fits this requirement precisely. It is already present in most of the clinic that performs root canal treatment, it requires no radiation, and it can be used continuously throughout the instrumentation process. An EAL measures the electrical impedance between an intracanal file and a lip-clip electrode. As the file advances through the dentine, impedance changes in a gradual, predictable pattern. When the file tip contacts the periodontal ligament tissue whether at the apical foramen or through a lateral perforation in the canal wall the device registers a sudden and distinctive change in reading that differs clearly from the normal apical approach signal [6]. Multiple controlled laboratory studies have confirmed that modern apex locators can detect experimentally created root perforations with sensitivity and specificity values that are clinically meaningful [1, 7,8].

Research conducted by Marroquín et al. revealed that EALs (ProPex II, Raypex 5, Raypex 6, Apex NRG) demonstrated exceptionally high precision in identifying root perforations related to post space, with a few attaining 100% sensitivity and specificity and others close to 93%. The authors determined that every device evaluated is dependable for detecting perforations in laboratory settings and beneficial in clinical endodontics [1].

Koç et al. (2023) evaluated electronic apex locators (EALs) alongside cone-beam computed tomography (CBCT) for identifying simulated root canal perforations at different locations. They discovered that EALs demonstrated high precision similar to CBCT, particularly in easily reachable canal areas, although effectiveness decreased somewhat in intricate anatomical regions because of root shape [9].

In Bangladesh, research on electronic apex locators (EALs) primarily emphasizes determining working length and demonstrates higher accuracy compared to radiographs, but there is a lack of studies on identifying strip perforations. There is likewise no direct comparison of EALs and digital periapical radiography for this objective. This study seeks to evaluate their diagnostic precision in identifying strip perforations in vitro to determine the more dependable method for early detection.

MATERIALS AND METHODS:

Study settings: This quasi-experimental in vitro research was taken place in the Department of Conservative Dentistry and Endodontics at Bangladesh Medical University (BMU) in Dhaka, Bangladesh. The research was conducted over 12 months, from January 2024 to December 2024, under controlled laboratory settings to assess the diagnostic precision of electronic apex locators and digital periapical radiography in identifying strip perforations.

Study population: The study group was include extracted human mandibular first and second molars. A targeted sampling method was employed to choose appropriate samples. A total of 69 mandibular molar teeth was sampled, split into two groups: 34 teeth in the perforated group (Group A) and 35 teeth in the non-perforated control group (Group B).

Selection Criteria: The research was involved newly extracted mandibular first and second molars sourced for periodontal reasons, featuring fully developed roots and accessible, negotiable root canals verified by the passage of a #10 K-file. Teeth was excluded if they show vertical or horizontal root fractures, internal or external root resorption, prior endodontic treatment, post placement, or current root canal fillings. Teeth exhibiting significant coronal or radicular decay that affects root integrity, along with those having substantial metallic or non-metallic restorations or full-coverage crowns that may obstruct radiographic assessment, was also excluded.

Study procedure: The research was carried out in five phases: specimen preparation, root canal preparation, induction of perforation, assessment of DPR, and evaluation of EAL. Sixty-nine extracted mandibular molars were preserved in saline and categorized into 34 perforated (Group A) and 35 non-perforated (Group B). All teeth were treated with ProTaper Gold F2 under uniform conditions. In Group A, strip perforations were formed using Gates-Glidden drills and verified with a K-file, whereas Group B stayed whole. DPR was conducted at standardized angles and evaluated blindly by two raters. EAL testing utilized Apex ID within alginate embedding, and perforation was detected by a sudden "beyond apex" signal, validated by a second blinded observer.

Statistical analysis: Data were entered into Microsoft Excel and analysed using SPSS version 27 (IBM Corporation, Chicago, IL, USA). The Shapiro-Wilk test confirmed non-normal distribution for all continuous variables; non-parametric methods were therefore applied throughout. Continuous data are expressed as median with interquartile range (IQR), and categorical data as frequency and percentage. A two-sided p-value below 0.05 was taken as statistically significant.

Ethical considerations: The study received approval from the Institutional Review Board of Bangladesh Medical University. Since only extracted teeth were utilized, there was no direct patient involvement. Nonetheless, written informed consent was acquired from all patients during extraction for utilizing their teeth in research. Every sample was assigned a unique code for anonymization, and no patient identifiers were noted. Data were safely stored and accessible only to authorized individuals for research purposes.

RESULTS:

Table 1 shows observer 1 identified perforation in 28 (40.6%), 25 (36.2%), and 13 (18.8%) specimens on the mesio-angular, standard, and disto-angular views respectively, with doubtful responses recorded in 9 (13.0%), 16 (23.2%), and 11 (15.9%) specimens. Observer 2 identified perforation in 31 (44.9%), 28 (40.6%), and 19 (27.5%) specimens across the same three views. On consensus DPR interpretation, 28 (40.6%) specimens were classified as positive, 5 (7.2%) as doubtful, and 36 (52.2%) as negative. In the primary binary analysis, the 5 doubtful cases were recoded as negative, yielding 28 (40.6%) DPR-positive results. In the sensitivity analysis, they were recoded as positive, raising this to 33 (47.8%).

Table 1: Distribution of DPR Observer Findings and Final Binary Results (N = 69)

Assessment View / Result	Perforation Detected n (%)	Doubtful n n (%)	No Perforation n (%)
Observer 1 – Mesio-angular view	28 (40.6)	9 (13.0)	32 (46.4)
Observer 1 – Standard (parallel) view	25 (36.2)	16 (23.2)	28 (40.6)
Observer 1 – Disto-angular view	13 (18.8)	11 (15.9)	45 (65.2)
Observer 2 – Mesio-angular view	31 (44.9)	8 (11.6)	30 (43.5)
Observer 2 – Standard (parallel) view	28 (40.6)	15 (21.7)	26 (37.7)
Observer 2 – Disto-angular view	19 (27.5)	14 (20.3)	36 (52.2)
Consensus – Overall DPR interpretation	28 (40.6)	5 (7.2)	36 (52.2)
DPR binary result (Primary analysis: Doubtful = Negative)	28 (40.6)	—	41 (59.4)
DPR binary result (Sensitivity analysis: Doubtful = Positive)	33 (47.8)	—	36 (52.2)

Table 2 shows in the primary analysis, DPR correctly identified 24 of 34 perforated specimens (true positives) and correctly excluded 31 of 35 non-perforated specimens (true negatives), generating 4 false positives and 10 false negatives. Sensitivity was 70.6% (95% CI: 53.8–83.2%), specificity was 88.6% (95% CI: 74.0–95.5%), and overall accuracy was 79.7% (95% CI: 68.8–87.5%). The false negative rate of 29.4% means that approximately one in three strip perforations was missed under standard radiographic interpretation. In the sensitivity analysis, recoding the five doubtful responses as positive raised sensitivity to 85.3% (95% CI: 69.9–93.6%) and accuracy to 87.0% (95% CI: 77.0–93.0%), while specificity remained unchanged at 88.6%.

Table 2: Diagnostic Accuracy of DPR for Strip Perforation Detection (N = 69)

Diagnostic Parameter	Primary Analysis (Doubtful = Negative) Value (95% CI)	Sensitivity Analysis (Doubtful = Positive) Value (95% CI)
True Positives (TP)	24	29

True Negatives (TN)	31	31
False Positives (FP)	4	4
False Negatives (FN)	10	5
Sensitivity	70.6% (53.8–83.2%)	85.3% (69.9–93.6%)
Specificity	88.6% (74.0–95.5%)	88.6% (74.0–95.5%)
Overall Accuracy	79.7% (68.8–87.5%)	87.0% (77.0–93.0%)

Table 3 presents the EAL demonstrated superior diagnostic performance across all indices. With only 2 false positives and 2 false negatives among 69 specimens, the EAL achieved a sensitivity of 94.1% (95% CI: 80.9–98.4%), a specificity of 94.3% (95% CI: 81.4 98.4%), and an overall accuracy of 94.2% (95% CI: 86.0–97.7%). As shown in Figure 1, EAL outperformed DPR on all three accuracy indices, with the greatest gap on sensitivity (94.1% vs 70.6%) and accuracy (94.2% vs 79.7%).

Table 3: Diagnostic Accuracy of EAL for Strip Perforation Detection (N = 69)

Diagnostic Parameter	Value	95% Confidence Interval
True Positives (TP)	32	—
True Negatives (TN)	33	—
False Positives (FP)	2	—
False Negatives (FN)	2	—
Sensitivity	94.1%	80.9–98.4%
Specificity	94.3%	81.4–98.4%
Overall Accuracy	94.2%	86.0–97.7%

Table 4 shows McNemar's exact test comparing the paired diagnostic outcomes of DPR and EAL yielded p = 0.1796, which did not reach statistical significance. There were 4 specimens positive on DPR but negative on EAL, and 10 positives on EAL but negative on DPR, totalling 14 discordant pairs. Despite the numerically superior performance of EAL across all indices, the limited number of discordant pairs relative to the total sample size was insufficient to achieve statistical significance at the $\alpha = 0.05$ level.

Table 4: Paired Diagnostic Comparison of DPR vs EAL with McNemar's Exact Test (N = 69)

Category / Parameter	Value
DPR Positive / EAL Positive (a)	24
DPR Positive / EAL Negative (c)	10
DPR Negative / EAL Positive (b)	4
DPR Negative / EAL Negative (d)	31
Row Total (DPR Positive)	34
Row Total (DPR Negative)	35
Column Total (EAL Positive)	28
Column Total (EAL Negative)	41
Discordant pairs (b + c)	14
McNemar's exact p-value	0.1796
Interpretation	Not statistically significant

Table 5 presents in the 32 perforated specimens where both measurements were available, the median visual perforation site length was 12.25 (10.75–13.43) mm and the median EAL impedance point was 12.50 (10.88–13.12) mm. The median difference between EAL and visual measurements was −0.100 mm (IQR: −0.425 to 0.225 mm) and the median absolute deviation was 0.300 (0.200–0.700) mm. Wilcoxon signed-rank test found no statistically significant difference between the two measurements (W = 209.0, p = 0.4435), indicating that the EAL impedance point was statistically equivalent to the visually measured perforation site distance. Applying tolerance-based accuracy criteria, 21 of 34 specimens (61.8%) fell within ±0.5 mm and 31 of 34 (91.2%) fell within ±1.0 mm.

Table 5: EAL Perforation Site Localization — Visual vs EAL Comparison (n = 34)

Parameter	Value
n (perforated specimens with both measurements)	32
Visual perforation site length (mm), Median (IQR)	12.25 (10.75–13.43)
EAL impedance point (mm), Median (IQR)	12.50 (10.88–13.12)
Difference: EAL − Visual (mm), Median (IQR)	0.100 (−0.425 to 0.225)
Absolute deviation (mm), Median (IQR)	0.300 (0.200–0.700)

Range of absolute deviation (mm)	—
Wilcoxon signed-rank test (W value)	209.0
p-value	0.4435
Within ±0.5 mm, n (%)	21 (61.8%)
Within ±1.0 mm, n (%)	31 (91.2%)
Interpretation	No statistically significant difference between EAL and visual measurement

Table 6 shows among the 34 perforated specimens, the standard parallel view recorded the highest detection rate (64.7%), followed by the mesio-angular view (55.9%) and the disto-angular view (50.0%). Cochran's Q test showed no statistically significant difference in detection rates across the three views (Q = 1.90, p = 0.387), indicating that in this sample the choice of radiographic angulation did not significantly influence perforation detection rates.

Table 6: DPR View-Specific Detection in Perforated Specimens (n = 34) — Cochran's Q Test

DPR View	Detected n (%)	Doubtful n (%)	No Perforation n (%)	Detection Rate (%)
Mesio-angular view	19 (55.9)	11 (32.4)	4 (11.8)	55.9
Standard (parallel) view	22 (64.7)	11 (32.4)	1 (2.9)	64.7
Disto-angular view	17 (50.0)	4 (11.8)	13 (38.2)	50.0
Cochran's Q test				Q = 1.90, p = 0.387 (Not significant)

DISCUSSION:

In our study DPR displayed inconsistent and limited accuracy in identifying strip perforations, with detection rates between 40.6% and 47.8%, showing no notable difference across various angles. The existence of questionable cases additionally indicated diagnostic ambiguity and observer inconsistency. These results emphasize the fundamental drawback of two-dimensional radiography in detecting buccolingual strip perforations because of superimposition and anatomical limitations. Thus, DPR by itself cannot be entirely trusted for consistent detection and should be complemented by more precise diagnostic techniques [10].

DPR demonstrated moderate diagnostic accuracy in detecting strip perforation, with sensitivity rising from 70.6% to 85.3% based on interpretation, while specificity stayed at 88.6%. The significant false-negative rate highlights overlooked perforations, illustrating the constraints of two-dimensional imaging and the dependency on angulation. In general, DPR by itself is not completely dependable and is more effectively backed by electronic diagnostic techniques for precise identification [11].

EAL demonstrated greater diagnostic accuracy compared to DPR in detecting strip perforations, exhibiting high sensitivity, specificity, and few false outcomes. DPR showed moderate sensitivity, exhibiting a higher false-negative rate because of limitations in 2D imaging. In general, EAL serves as a more dependable and precise instrument for the early identification of strip perforations [12].

The current study indicated that EAL exhibited outstanding diagnostic precision for detecting strip perforation with few erroneous outcomes. This validates its great reliability and advantages over radiographic techniques. These results align with evidence indicating that EALs offer accuracy similar to CBCT in identifying root canal perforations because their impedance-based mechanism is less influenced by anatomical distortion. In general, EAL is a reliable instrument for prompt and precise perforation identification [13].

The current research revealed no statistically significant difference between DPR and EAL, although a greater number of cases supported EAL in the discordant analysis. This suggests an improvement in EAL's performance, though lacking statistical significance because of the few discordant pairs. This is supported by systematic reviews indicating that contemporary EALs are very precise and dependable for measuring working length, although variations with radiographic techniques aren't consistently statistically significant across separate studies. In this analysis, EAL seems to be clinically better, though not statistically distinct [14].

The current research demonstrated that EAL successfully pinpointed strip perforations with little deviation from visual assessments and no notable difference, affirming its precision and dependability. These results are consistent with evidence that contemporary apex locators can effectively identify root perforations across various systems by assessing impedance variations, demonstrating overall high and consistent diagnostic precision [15].

DPR detection of strip perforations differed by angulation, showing the highest rate in the standard view, next in mesio-angular, and lastly in disto-angular, though differences were not statistically significant. This suggests that altering radiographic angles does not significantly enhance detection. In general, DPR is still constrained in consistently detecting strip perforations, underscoring the necessity for more precise diagnostic techniques [16].

Overall**,** EAL exhibited better and more dependable diagnostic capabilities compared to DPR for identifying and pinpointing strip perforations, whereas DPR displayed moderate and erratic accuracy due to its intrinsic two-dimensional constraints.

CONCLUSION:

EAL demonstrated better diagnostic accuracy compared to DPR for detecting and localizing strip perforations, exhibiting increased sensitivity, specificity, and overall accuracy, as well as dependable localization within ±1.0 mm. DPR exhibited moderate, inconsistent performance with a significant false-negative rate. In general, EAL is a more dependable and precise radiation-free diagnostic tool, whereas DPR should solely serve as an additional method.

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