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ORIGINAL RESEARCH

Comparison of post-operative pain in relation to working length assessment by electronic apex locator and digital radiography in permanent teeth among pediatric patients

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Abstract

Background: Effective measurement of working length is essential for successful endodontic treatment. Electronic Apex Locators (EAL) and Digital Radiography (DR) are commonly used methods, yet their comparative impact on post-operative pain remains unclear. This study aimed to compare post-operative pain intensity and pain dissipation duration following working length determination using EAL and DR in pediatric endodontic patients. **Methods**: A total of 130 patients aged 10–15 years were randomly assigned to the EAL group (n = 65) or the DR group (n = 65). Pain intensity was assessed using the Visual Analogue Scale (VAS) at pre-operative, and at 6, 12, 24, 48 hours, and 7 days post-operatively. Pain scores were further analyzed by age and gender. Independent and paired *t*-tests and Analysis of Variance were applied for statistical analysis. **Results**: No statistically significant difference was observed between the EAL and DR groups in VAS scores at any time point ($p > 0.05$). Female participants consistently reported higher mean pre- and post-operative pain scores compared with males, with significant differences observed in both groups (EAL: $p = 0.031$; DR: $p < 0.001$ for pre-op scores). Overall, while both groups showed comparable pain reduction trends over time, gender influenced pain perception and pain relief duration significantly in both treatment modalities. **Conclusions**: Both EAL and DR are effective for working length determination, showing no significant difference in post-operative pain. Pain perception and relief duration, however, vary with gender and age and should be considered during endodontic treatment planning. **Clinical Trial Registration**: The trial was retrospectively registered with ClinicalTrials.gov (Identifier: NCT07181252, Retrospective registration).

Keywords

Post-operative pain; Working length; Radiography

1. Introduction

Successful root canal therapy is based on multiple factors, among which the accurate determination of working length is paramount. Working length is defined as the distance from a coronal reference point to the point at which canal preparation and obturation should terminate, typically at the apical constriction—an anatomical landmark that corresponds to the minor diameter where the pulp tissue transitions to periodontal tissue. Accurate working length determination is essential for successful endodontic therapy, as it ensures thorough canal cleaning and obturation while minimizing the risk of over- or under-instrumentation—key factors associated with treatment failure and postoperative complications [1–5].

Traditionally, periapical radiography has been the standard approach for working length determination, providing valuable information on canal anatomy and periapical tissues. However, as a two-dimensional imaging method, it is subject to distortion and superimposition, which may compromise accuracy [6–8]. Digital radiography (DR), while offering improvements in image quality and reduced radiation exposure compared to conventional film, still shares many of these limitations and does not eliminate diagnostic inaccuracies arising from root curvature or radiographic misinterpretation [8]. Although advanced imaging modalities like cone-beam computed tomography have been explored for working length estimation, their routine clinical use remains limited due to higher radiation doses, cost, and accessibility concerns [7].

To overcome these limitations, electronic apex locators

(EALs) were introduced by Custer in 1918 [9]. These devices measure electrical impedance between the periodontium and oral mucosa to identify the apical constriction. Modern third-generation EALs remain accurate even in the presence of fluids and varying pulp conditions, providing a reliable alternative or adjunct to radiographic methods [10, 11].

Despite technological advancements, post-operative pain remains a frequent complication following root canal treatment, with reported incidence rates ranging from 3% to 58% [12]. Several patient- and treatment-related factors influence post-operative pain, including pre-operative pain intensity, patient age and gender, microbial status of the canal, periapical inflammation, irrigation protocols, instrumentation techniques, and obturation methods [13–15].

While many studies have investigated the impact of instrumentation or irrigation techniques on pain outcomes, there is a paucity of research evaluating how the choice of working length determination method affects post-operative pain, particularly in pediatric patients with permanent teeth. Understanding this relationship is crucial, as children may exhibit different pain perceptions and clinical responses compared with adults, which may be attributed to developmental and emotional factors influencing both the perception and reporting accuracy of pain [16, 17].

This study aims to bridge this gap by comparing post-operative pain intensity and its dissipation between two commonly used working length determination methods: EAL and DR. The null hypothesis (H_0) stated that there would be no significant difference in post-operative pain between the two methods of working length determination in pediatric patients. The alternative hypothesis (H_1) proposed that there would be a significant difference in post-operative pain between the two methods.

2. Materials and methods

2.1 Study design and duration

This randomized, single-blind clinical trial was conducted at the College of Dentistry, Jouf University, Kingdom of Saudi Arabia, between August 2024 and February 2025. A total of 130 pediatric patients were recruited from the outpatient department. Ethical approval was obtained from the Local Committee of Bioethics (approval number: 24-03/41), and all procedures adhered to the ethical standards of the Declaration of Helsinki. The trial was retrospectively registered with ClinicalTrials.gov (Identifier: NCT07181252). Written informed consent was obtained from parents and verbal assent from all children before participation.

2.2 Sample size and participants

The sample size was calculated using a medium effect size (0.30), based on a previous study by Guzel *et al.* [18], which evaluated postoperative pain in relation to different working length determination methods. To detect a 10% difference in mean pain scores with 95% confidence and 80% power, a minimum sample of 124 participants was required. Accounting for a 5–10% attrition rate, the final sample size was increased to 130 (65 in each group).

Fig. 1 shows Consolidated Standards of Reporting Trials (CONSORT) flow diagram of participant recruitment, allocation, and follow-up.

2.3 Inclusion criteria

- Children aged 10–15 years.
- Clinical and radiographic diagnosis of irreversible pulpitis.
- Absence of systemic disease.
- Permanent first molars with mature apices.
- No radiographic evidence of root resorption or periodontal bone loss.
- Written consent from a parent or legal guardian.

2.4 Exclusion criteria

- Medically compromised or psychologically unfit children.
- Teeth with periapical lesions on radiographs.
- Teeth with severely curved or calcified canals.
- Presence of acute or chronic systemic inflammatory conditions.

2.5 Randomization and blinding

Participants were randomly allocated into two groups using a computer-generated random sequence (block size = 4) and allocation was concealed using sequentially numbered, sealed, opaque envelopes prepared by the same independent statistician. Envelopes were stored by a study coordinator and opened immediately before treatment by a research assistant who did not participate in outcome assessment.

- EAL group: Working length determination using EAL.
- DR group: Working length determination using DR.

This study followed a single-blind design as in both the participants (children and parents) and the investigator responsible for post-operative pain assessment were blinded to the assigned working length determination method. Since both procedures (EAL and DR) were performed under rubber dam isolation and appeared similar to the patients, participant blinding was effectively maintained. The pain assessor and data analyst received anonymized data without group identifiers, ensuring unbiased outcome evaluation and statistical analysis. All clinical procedures were performed by a single well-experienced endodontist to maintain methodological consistency and the operator was not involved in pain assessment.

2.6 Clinical procedure

Diagnosis for irreversible pulpitis was based on lingering pain to cold testing, absence of periapical radiolucency, and positive vitality test. All root canal treatments were completed in a single visit under local anesthesia using 2% lignocaine with 1:80,000 epinephrine. Caries excavation and access cavity preparation were performed using sterilized high- and low-speed burs. Patency was confirmed using a #10 K-file.

• EAL Group: The working length was determined using the Root ZX electronic apex locator (J. Morita Corp., Kyoto, Japan) in accordance with the manufacturer's instructions. A #15 K-file was attached to the device and gently advanced into the canal until the digital display indicated "APEX", signifying the apical foramen. The final working length was

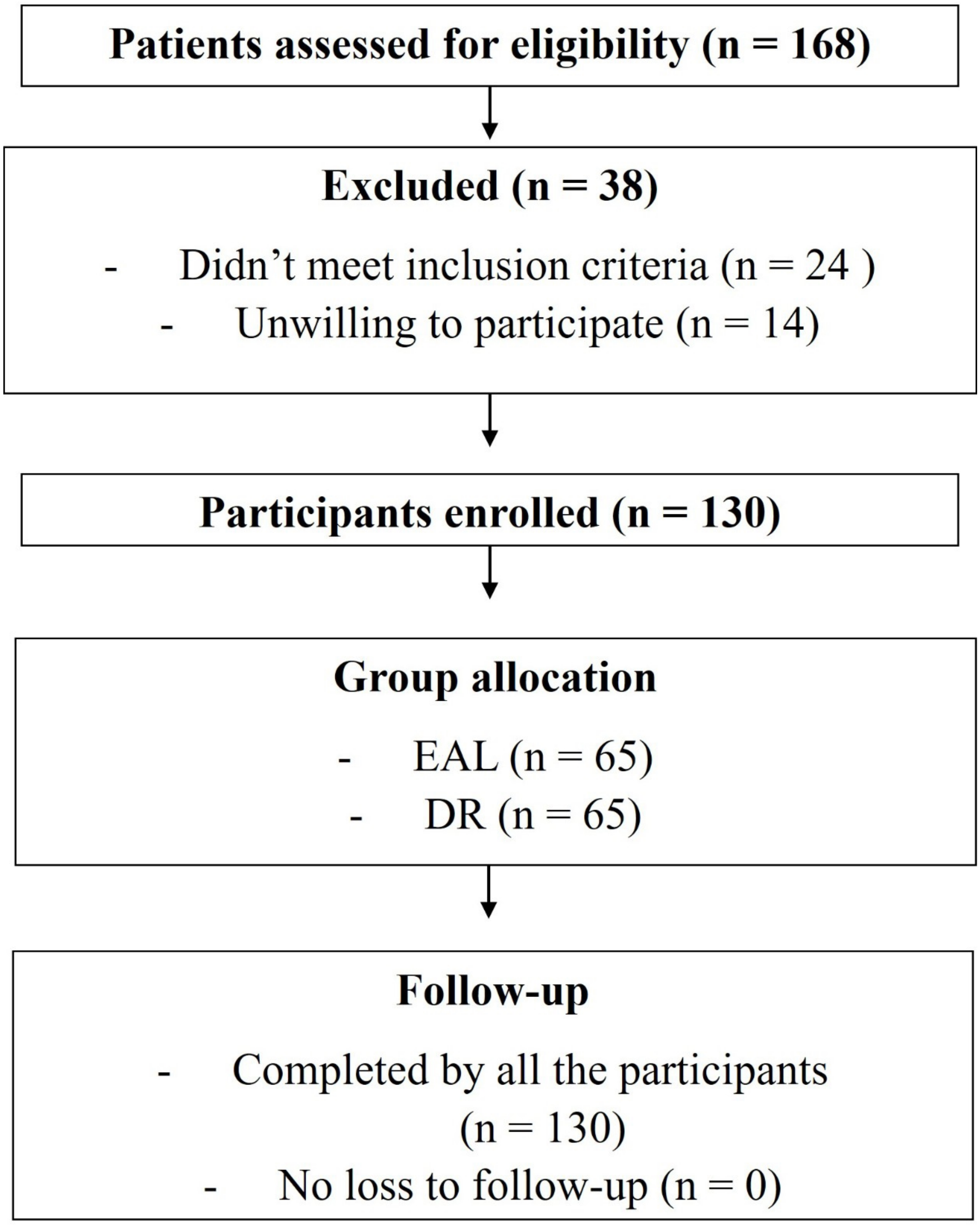

FIGURE 1. CONSORT flow diagram of participant recruitment, allocation, and follow-up. EAL: Electronic Apex Locators; DR: Digital Radiography.

then established as 1 mm short of this reading to correspond with the apical constriction.

• DR Group: Working length was determined using a #15 K-file inserted 1 mm short of the estimated radiographic apex. A digital periapical radiograph was taken, and the working length was adjusted accordingly. Repeated radiographs were obtained until the file tip was 1 mm short of the radiographic apex. On average, two digital radiographs were obtained per tooth. Appointment durations were kept short, with brief intervals provided as needed to prevent child fatigue and maintain cooperation.

In both groups, #15 K-files with 2% taper were used to standardize measurements. Working length was maintained using rubber stoppers on files and a fixed coronal reference point. Canal instrumentation was performed using ProTaper Universal NiTi rotary endodontic file system (Dentsply Maillefer, Ballaigues, Switzerland) in a crown-down technique. After initial coronal flaring with an SX file, canals were shaped using S1 and S2 files, followed by F1–F3 files up to 1 mm short of the working length. Irrigation was performed with 2.5% sodium hypochlorite throughout the procedure, with an approximate total volume of 10 mL per canal. Final obturation was carried out using the lateral compaction technique with gutta-percha cones and a resin-based sealer, followed by restoration with composite resin. No intracanal medicament was placed prior to obturation. Rubber dam isolation was maintained throughout all procedures to ensure asepsis and patient comfort. Child behavior was managed using the Tell-Show-Do approach and positive reinforcement to minimize anxiety and pain perception.

2.7 Pain assessment

Pain was evaluated using a 10-point Visual Analog Scale (VAS), where 0 indicated "no pain" and 10 denoted "worst possible pain". Participants were trained to use the scale pre-operatively and were provided with printed forms to record pain at specific post-operative intervals: 6 hours, 12 hours, 24 hours, 48 hours, and 7 days. Pre-operative pain scores were recorded before starting the procedure. This method has been widely used in pediatric endodontic research for subjective pain evaluation [12]. Children recorded pain under parental supervision after training with the VAS scale. If pain exceeded VAS >5, participants were prescribed ibuprofen (10 mg/kg).

2.8 Statistical analysis

Data was analyzed using Statistical Package for Social Sciences version 22.0 (IBM Corp., Armonk, NY, USA). Normality was verified using Shapiro-Wilk test prior to parametric analyses. Descriptive statistics were computed for demographic variables. The Chi-square test was used to compare categorical variables such as incidence of post-operative pain between groups. Independent samples *t*-test was used to compare mean VAS scores between groups, while paired *t*-test was used to compare pre- and post-operative scores within each group. One-way analysis of variance (ANOVA) was employed to assess mean VAS scores across different post-operative time intervals. A *p*-value $\leq$ 0.05 was considered statistically significant.

3. Results

A total of 130 participants were included in the study, equally distributed into the EAL group (n = 65) and the DR group (n = 65). The age distribution was similar between the groups, with 48.46% of participants aged 10–12 years and 51.53% aged 13–15 years. There was a higher proportion of male participants in both groups (65.38%), with no significant difference in gender distribution between groups (*p* = 0.648) (Table 1).

Table 2 presents the comparison of mean (±standard deviation (SD)) pre-operative and post-operative pain (6 hours) according to gender and age. In the EAL group, the mean pre-operative pain scores were 6.2 ± 1.2 in males and 9.6 ± 2.8 in females, showing a statistically significant difference (*p* = 0.031). Post-operative pain scores in the EAL group were not significantly different between genders (*p* = 0.548). However, in the DR group, female participants had significantly higher pre-operative ($p < 0.001$) and post-operative pain scores (*p* = 0.014) compared with males. Across age groups, there were no significant differences in mean pre- and post-operative pain scores in either treatment group.

TABLE 1. Characteristics of included cases (N = 130).

Variables		EAL group (n = 65)	DR group (n = 65)	Total N (%)	*p*-value (Chi square test)
Age (yr)					
	10–12	32 (49.23)	31 (47.69)	63 (48.46)	0.321
	13–15	33 (50.76)	34 (52.30)	67 (51.53)	
Gender					
	Male	43 (66.15)	42 (64.61)	85 (65.38)	0.648
	Female	22 (33.84)	23 (35.38)	45 (34.61)	

EAL: Electronic Apex Locators; DR: Digital Radiography.

TABLE 2. Comparison of mean (±SD) pre-operative and post-operative pain (6 hours) with gender and age of the participants.

Variables		EAL group (n = 65)		DR group (n = 65)	
		Pre-operative (Mean ± SD)	Post-operative (Mean ± SD)	Pre-operative (Mean ± SD)	Post-operative (Mean ± SD)
Age (yr)					
	10–12	8.1 ± 1.4	4.7 ± 0.9	8.6 ± 1.6	4.3 ± 1.4
	13–15	7.8 ± 1.1	3.9 ± 1.0	7.8 ± 1.3	3.9 ± 0.8
p-value (Independent samples "*t*" test)		0.484	0.688	0.092	0.246
Gender					
	Male	6.2 ± 1.2	3.8 ± 1.4	7.1 ± 1.5	3.3 ± 1.6
	Female	9.6 ± 2.8	4.8 ± 1.3	9.3 ± 3.2	4.9 ± 2.3
p-value (Independent samples "*t*" test)		0.031*	0.548	<0.001	0.014*

*SD: Standard Deviation; EAL: Electronic Apex Locators; DR: Digital Radiography. *Statistically Significant.*

When comparing mean pain scores (VAS) at different time intervals between the two groups (Table 3), no statistically significant differences were observed. Both groups showed a gradual decrease in pain scores over time. At 6 hours post-operatively, mean VAS scores were 4.3 ± 0.9 in the EAL group and 4.1 ± 1.2 in the DR group (p = 0.086). At 7 days post-operatively, pain scores further reduced to 0.4 ± 0.2 in the EAL group and 0.4 ± 0.1 in the DR group (p = 0.461). No significant differences were noted in pain relief patterns between the groups ($p > 0.05$ at all-time intervals).

Overall, while both groups showed comparable pain reduction trends over time, gender influenced pain perception and pain relief duration significantly in both treatment modalities.

4. Discussion

Accurate determination of working length is a fundamental step in endodontic therapy, directly influencing both the clinical success of treatment and the patient's post-operative comfort. The apical constriction, generally regarded as the ideal endpoint for canal instrumentation and obturation, lies at the histological junction between pulpal and periodontal tissues and serves as a physiological barrier that should not be breached [2, 4].

Traditionally, periapical radiography has been widely used to determine working length, providing useful anatomical information regarding canal morphology and periapical tissues. However, its limitations include two-dimensional imaging, distortion, and superimposition of anatomical structures, which may compromise accuracy [6, 7]. In contrast, EALs have gained prominence due to their ability to determine working length with high precision, even in the presence of electrolytic fluids within the canal [10, 11].

Our findings revealed that there was no statistically significant difference in post-operative pain scores between the two groups at any follow-up interval. Both groups showed a progressive reduction in pain over time, with mean post-operative pain dissipation duration of 17.12 ± 10.40 hours in the EAL group and 20.52 ± 15.40 hours in the DR group. These results align with previous findings, such as those by Paradiso *et al.* [4], Topçuoğlu *et al.* [19], and Rawat *et al.* [20], who also observed similar trends in pain reduction following different instrumentation techniques. While the use of rotary systems in their study may not directly compare to our working length determination methods, the pattern of pain reduction is consistent. One plausible explanation for absence of significant differences in postoperative pain between groups may be due to standardization of techniques and controlled procedural variables.

Multiple studies have demonstrated that post-operative pain tends to subside significantly within the first 24 to 72 hours, reaching minimal levels by the seventh day [12, 21]. In our study, VAS scores followed a similar pattern of decline, with minimal differences between the groups. These findings support the null hypothesis, indicating that the method of working length determination does not significantly influence the patient's post-operative pain experience. The observed reduction in post-operative pain within the first six hours may be attributed to the gradual resolution of transient inflammatory responses and the waning effect of local anesthesia. Immediately after endodontic instrumentation, periapical tissues may release inflammatory mediators, such as prostaglandins, bradykinin, and substance P, contributing to early discomfort. As these mediators begin to dissipate and tissue pressure normalizes, pain intensity typically decreases. Concurrently, as the effect of local anesthesia wears off, patients experience a brief transitional phase of mild discomfort that subsides as inflammatory activity declines and tissue healing begins [12, 19].

Interestingly, earlier studies, such as those by Solanki *et al.* [22] and Jeevanandan *et al.* [23], reported faster pain resolution compared with our findings. One plausible explanation may be the variation in operator experience, irrigation protocols, and individual pain perception in pediatric patients. Additionally, pediatric patients may report pain differently due to variations in emotional maturity, anxiety levels, or communication abilities [16].

Several randomized clinical trials and systematic reviews on permanent teeth have compared EALs with radiographic methods for working length determination and reported largely concordant findings with respect to short-term post-operative pain. Kara *et al.* [24] reported no significant difference in postoperative pain between EAL and radiographic groups in a randomized clinical trial, highlighting that both methods produce comparable short-term clinical outcomes when stan-

TABLE 3. Comparison of mean VAS score at various time intervals between two groups.

Time intervals	EAL group (n = 65)	DR group (n = 65)	p-value (Independent samples "t" test)
Pre-operative VAS	7.9 ± 1.8	8.2 ± 1.3	0.344
Post-operative (6 h)	4.3 ± 0.9	4.1 ± 1.2	0.086
p value (paired "t" test)	0.88	0.24	-
Post-operative (12 h)	3.2 ± 0.7	3.0 ± 0.8	0.268
Post-operative (24 h)	2.4 ± 0.6	2.6 ± 0.9	0.765
Post-operative (48 h)	1.6 ± 0.4	1.3 ± 0.3	0.069
Post-operative (7 d)	0.4 ± 0.2	0.4 ± 0.1	0.461
p-value (One-way ANOVA)	0.764	0.092	-

VAS: Visual Analogue Scale; EAL: Electronic Apex Locators; DR: Digital Radiography; ANOVA: Analysis of Variance.

dard protocols are followed. More recent randomized trials have produced similar results while exploring different devices and tooth types, suggesting that technique standardization and careful instrumentation may be more important determinants of pain than the specific method of working length measurement [18]. Systematic reviews and meta-analyses pooling randomized data likewise find no clinically meaningful difference in short-term pain between EAL and radiographic modalities, although authors note heterogeneity in study designs and call for larger, standardized trials [25]. Taken together, these data support the conclusion that EALs and digital radiography offer similar short-term patient comfort in permanent teeth; however, differences in accuracy, radiation exposure, and clinical logistics remain important when choosing the method in practice.

The clinical efficacy of EALs is due to their ability to bypass limitations related to the presence of conductive fluids and to localize the apical foramen without requiring multiple radiographs. Suzuki's foundational work in 1942 demonstrated the constancy of electrical resistance between periodontal ligament and oral mucosa, laying the groundwork for modern EALs [26]. Subsequent improvements have enabled accurate measurements even in complex anatomical situations or fluid-filled canals [27].

An important finding of our study was that female participants reported higher pre- and early post-operative VAS scores than males in both EAL and DR groups. This result is consistent with previous studies showing that females, on average, report greater pain sensitivity and higher pain intensity across many acute and chronic pain conditions [28, 29]. Similarly, the International Association for the Study of Pain note that women typically display lower pain thresholds and tolerance and a greater prevalence of many pain conditions than men [30]. Gender differences in pain are multifactorial and likely reflect an interplay of biological, hormonal, genetic, and psychosocial factors [28, 31]. Sex hormones, such as estrogens, progesterone, and testosterone, modulate nociceptive processing and endogenous pain inhibitory systems, and hormonal fluctuations—particularly those related to the menstrual cycle—can alter pain sensitivity [32, 33]. Recent studies have demonstrated sex-dependent differences in nociceptor function, immune cell involvement, and central pain processing, while psychosocial factors, including pain expectation, coping strategies, and anxiety levels, can further influence reported pain intensity and pain behavior [29, 34, 35]. These mechanisms provide plausible explanations for our observation of higher pain reports among female participants. Sex differences in pain perception often emerge or become more pronounced during adolescence, when pubertal hormonal changes interact with neurodevelopmental and psychosocial processes [36]. Therefore, in our 10–15-year age group, these developmental factors may have contributed to the observed gender differences. Studies in pediatric dental and endodontic populations report mixed findings—some showing higher post-operative pain among females and others finding no significant difference—which may be attributed to variations in sample size, age distribution, pain assessment methods, and consideration of menstrual, hormonal, or psychosocial confounders [37–39].

Post-operative pain is a multifactorial phenomenon influenced by several procedural and patient-related variables. Factors such as operator technique, depth of anesthesia, patient anxiety, and tissue trauma can significantly affect pain perception in addition to the method used for working length determination. Pain perception may also have been influenced by injection discomfort or clamp pressure, which can transiently elevate pain scores immediately after treatment. These interrelated variables highlight the complex etiology of post-endodontic discomfort and underscore the need for careful procedural standardization and individualized patient management to minimize pain [12, 14]. Different methods for establishing working length may theoretically affect post-operative pain through their influence on apical instrumentation accuracy and the risk of apical extrusion. Over-instrumentation beyond the apical constriction can mechanically extrude debris, irrigants, or filling materials into periapical tissues, triggering inflammation and increasing pain; conversely, accurate working length limit minimizes such irritation [40, 41]. Experimental and clinical studies have, therefore, associated apical extrusion with higher incidence of post-operative discomfort. Nevertheless, randomized clinical trials specifically comparing EAL and radiographic methods generally report similar short-term pain outcomes, suggesting that when standard protocols and careful technique are used, both methods can produce comparable clinical results [24]. Taken together, these data indicate a plausible mechanistic link between working-length precision and pain (via control of apical extrusion), but the available clinical evidence shows no consistent superiority of one method over the other, in terms of short-term post-operative pain [18]. Future studies that directly quantify apical extrusion in parallel with pain scores may help clarify whether small differences in working length accuracy lead to clinically meaningful pain differences.

Although several procedural factors—such as preoperative pulp status, occlusal conditions, irrigation protocols, and use of intracanal medicaments—have been associated with postoperative pain, limited evidence exists regarding the specific influence of working length determination methods. The present study contributes to filling this gap by demonstrating that both EAL and DR techniques are equally effective in minimizing postoperative discomfort among pediatric patients. Given its ability to reduce radiation exposure, the use of EAL may be particularly advantageous in children.

This study has certain limitations worth acknowledging. It was conducted exclusively among pediatric patients aged 10–15 years, which may limit the generalizability of the findings to adults. Our sample contained a higher proportion of males, which may affect generalizability of gender-comparisons. The use of subjective self-reporting of pain through the VAS may also affect pain assessment accuracy in younger participants. Future studies with larger sample sizes, multiple operators, and long-term follow-up assessing parameters, such as periapical healing and tooth retention, are recommended to provide more comprehensive and generalizable insights. Incorporating radiographic follow-up and applying multivariate analyses to control for confounding variables would further enhance the robustness of future research.

5. Conclusions

Within the limitations of this study, both electronic apex locator and digital radiography methods for working length determination were equally effective in terms of post-operative pain outcomes. These findings suggest that clinicians may choose either method based on case-specific factors, equipment availability, and operator preference without compromising patient comfort.

ABBREVIATIONS

EAL, Electronic Apex Locator; DR, Digital Radiography; VAS, Visual Analog Scale; SD, Standard Deviation; CONSORT, Consolidated Standards of Reporting Trials; ANOVA, Analysis of Variance.

AVAILABILITY OF DATA AND MATERIALS

Data will be made available upon request to the corresponding author.

AUTHOR CONTRIBUTIONS

OK and DAA—designed the research study. OK, AE and SM—performed the research. TA and MFF—analyzed the data. FHK, AFA and RI—wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was reviewed and approved by the Local Committee of Bioethics, Jouf University, Kingdom of Saudi Arabia (approval number: 24-03/41). Written informed consent was obtained from a parent or legal guardian.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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