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Accuracy of the integrated electronic apex locator in locating simulated perforation under various irrigating solutions in an in vitro study

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Aim: This study's objective was to assess the accuracy of the integrated apex locator in identifying artificial root canal perforations in the presence of saline, chlorhexidine, sodium hypochlorite, QMix, and MTAD. **Methods:** The root canals of 60 single-rooted extracted human teeth were perforated artificially at a point 10 mm away from the root apex. After measuring the actual lengths up to the perforation point, the teeth were then put within an alginate mould for measurements using an integrated apex locator. Using a #20 K-file in the presence of NaCl, CHX, MTAD, NaOCl, and QMix, an electronic apex locator was used to measure the perforations electronically in accordance with the manufacturer's instructions. Between the measurements, each canal was dried with paper points after being irrigated with distilled water. The accuracy of all the readings was calculated at ± 0.5 mm. Statistical analyses were performed using the Z-test. **Results:** In comparison to the MTAD, NaOCl, and Qmix, saline and chlorhexidine scored more readings in the ± 0.5 mm range of the perforation site, and the difference was statistically significant. **Conclusion:** The most precise electronic measurements of artificial perforation were obtained in the presence of chlorhexidine or saline.

Keywords: Endodontics. MTAD (intracanal irrigant). QMix root canal irrigant. Sodium hypochlorite. Tooth apex.

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Introduction

Since root canal perforation causes a new artificial route to emerge between the root canal and periodontal tissues, it is an unfavourable condition for clinicians. Iatrogenic perforations or those brought on by the resorptive process are more common. The size and location of the hole, its timing, whether it can be repaired, and how well the perforation material is placed all affect the perforated tooth's prognosis[1]. Therefore, early detection of root perforation and prompt management are essential components for a successful treatment outcome[2].

The presence of root perforation must be determined since root canal filling materials and irrigating solutions may leak and harm periradicular tissues[3]. Because of its wide range of antibacterial properties and capacity to break down organic tissue, sodium hypochlorite (NaOCl) is advised as the primary irrigant in root canal therapy[3]. However, a significant problem could be its cytotoxic impact on periapical tissues[4]. Another irrigation solution, chlorhexidine (CHX) (Werax, Tunadent, Izmir, Turkey), due to its biocompatibility and antibacterial properties, is mostly used in patients who are allergic to NaOCl and in teeth with open apices[5,6]. The presence of the smear layer impedes the antimicrobial efficacy and intratubular diffusion of NaOCl within the dentinal tubules. To address this challenge, ethylenediaminetetraacetic acid (EDTA) has emerged as a preferred final irrigant due to its ability to effectively solubilize and remove the inorganic components of the smear layer and associated debris[7].

Recent years have seen a rise in mixed irrigation solutions such as MTAD or QMix (Dentsply Tulsa, Maillefer, Ballaigues, Switzerland). The EDTA, CHX, and detergent-based QMix have antibacterial action and are successful in removing the smear layer[8]. Tetracycline, citric acid, and polysorbate 80 detergent are combined to create the MTAD (Dentsply Tulsa, OK, USA) solution used to provide an antibacterial effect during root canal therapy[9]. Multiple in vitro[10,11] and vivo[12,13] studies have been conducted to evaluate the effects of the irrigants as mentioned above, which are considered very effective disinfectants.

Various methods, including apex locators, radiographic analyses, and the staining of paper points with blood, are employed to identify root perforations[14]. Identifying root perforations requires radiographic inspection, yet 2-dimensional radiographic images of a 3-dimensional object typically do not give enough details regarding the perforation site. Cone-beam computed tomography (CBCT) can be used for 3D imaging, however, its usage in vivo perforation identification is constrained by excessive radiation exposure[15]. In this regard, it is thought to be more practical and trustworthy to determine root perforation using an electronic apex locator (EAL)[14,16]. The electroconductivity of the irrigant in the root canal, however, has an impact on these devices' in vivo accuracy[17].

When instrumenting a root canal, concurrently determining the WL is a great boon, integrated apex locators can be used in conjunction with endomotors to do the same[18]. One such example is the E-Connect S Endomotor (Eighteeth, Jiangsu Province, Changzhou City, China) coupled with an E-Pex Pro Apex Locator (Eighteeth, Jiangsu Province, Changzhou City, China). For quick and simple root canal preparation, endodontic motors with integrated EALs were created. Along with controlling torque and speed, these hybrid devices make sure to keep an eye on the apical limit while mechanically preparing the canals[19].

Several studies[20-23] have been done on the detection of perforation by electronic apex locators, but to the best of our knowledge, there are no studies that have studied the ability of an integrated apex locator to locate perforation under the influence of various commonly used irrigation solutions. Hence, this study aimed to evaluate the same, and to study this phenomenon our study design used artificially created perforations on the tooth to check the accuracy of the integrated apex locator.

Materials and Methods

This study used de-identified samples of human teeth from the Tooth Bank. This study was reviewed and deemed exempt by our institutional ethical committee review board due to the in vitro design of the study. The protocols for the Tooth Bank adhere to our institution's ethical standards, the 1964 Helsinki Declaration and its later amendments, as well as any other relevant ethical norms.

60 recently extracted, uncurved, single-rooted human anterior teeth with a single canal were used in the investigation. The sample size calculation was done on power analysis using software G*Power considering the effect size and statistical power. This sample size ensured sufficient sensitivity and struck a balance between statistical significance and practical feasibility.

The teeth that were slated to be removed due to periodontal disease or orthodontic issues were chosen. The teeth were selected through a direct clinical assessment. Exclusion criteria for the study were teeth with caries, fractured or broken teeth, treated teeth, immature apices, root resorption, and multiple canals. The periodontal ligament was removed from the teeth by soaking them in a 0.5% sodium hypochlorite solution for two hours before the test. Using an ultrasonic scaler, all leftover organic residues were eliminated from the external root surfaces. Thereafter, all the teeth were rinsed with distilled water, and then the teeth were transferred to a 0.9% saline solution. Sample preparation and actual length determination were done by one operator, while the determination of length by the integrated apex locator was done by another operator for the teeth.

Sample Preparation

For the study to be carried out effectively, a proper step-by-step chronological order was planned (Figure 1). To begin with, to obtain a consistent reference point for all measurements, all the teeth were decoronated at the cementoenamel junction. Thereafter, access cavity preparation was done in all the decoronated teeth. Following that, each sample was taken up one by one for further preparation. After identifying the root canal orifice, the canal was disinfected and cleaned of debris with 5 ml of 5.25% sodium hypochlorite before evaluating canal patency with a 10 or 15 K-File (Dentsply Maillefer, Ballaigues, Switzerland). Any teeth with canal obstructions were discarded. The pulp tissue was removed with barbed broaches (Dentsply Maillefer, Ballaigues, Switzerland) without attempting to enlarge the canal with root canal instruments. To remove the organic contents of the root canal space, the root canals were thoroughly irrigated with 5 ml of sodium hypochlorite.

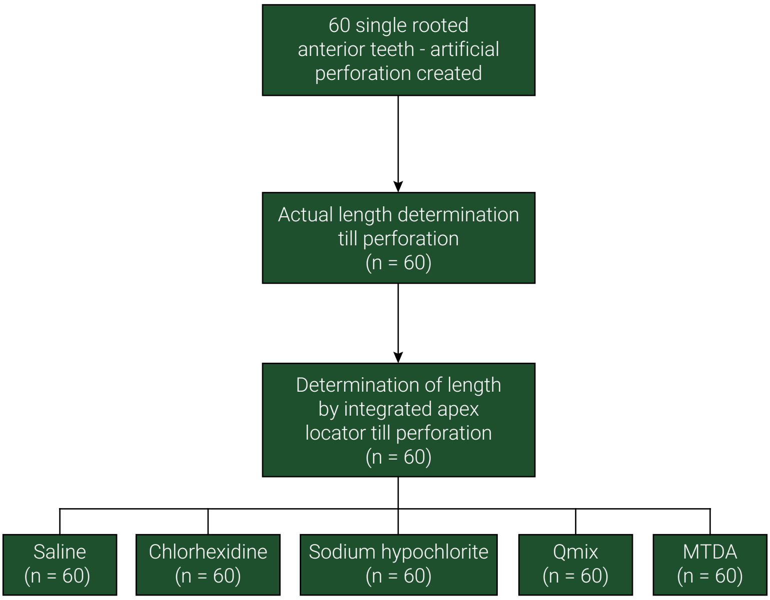

Figure 1. Flowchart of the experimental design.

An SS white Endoguide EG 8 bur (SS White, New Jersey, US) was used to create the perforation area. All the perforations were prepared on a point on a line marked 10 mm away from the coronal reference point (Figure 2). The first operator placed it perpendicular to the tooth's long axis of the root in the mid-third of the proximal surface (Figure 3). The perforations were about 0.12 mm in diameter (Figure 4). The perforation area was then checked for standardisation using a digital caliper (Zhart, Jaipur, Rajasthan, India) under a dental operating microscope (DOM) at 16 X magnification (Labomed Prima, LA, USA).

Figure 2. Marking at a 10 mm distance from the coronal reference point.

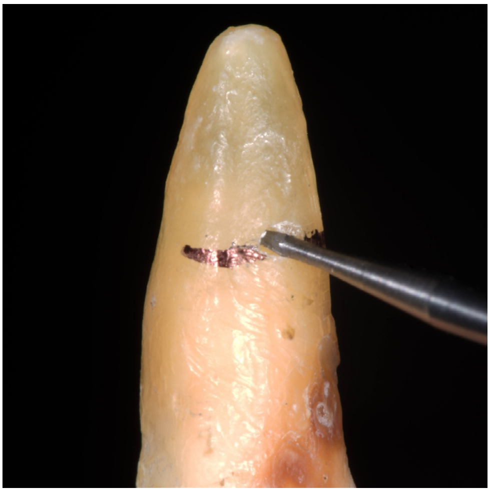

Figure 3. Perforation preparation.

Figure 4. Measurement of perforation size.

Measurement of length till perforation

Working length determination was done by two different operators to avoid bias. The exact working length was determined by the first operator up until the perforation, while the second operator performed the same task but using an integrated apex locator.

Actual length

Despite knowing the length of perforation, due to the slightest change in the angulation of the drilling bur, the actual length could be different. Therefore, the first operator took an actual length measurement till the upper border of the perforation. Under a DOM, a #20 K-file was used to measure the actual length (AL) till the perforation site to the coronal reference point (Figure 5). After visual confirmation, the file was retracted back to the coronal margin of the perforation hole. This distance was considered the actual length and the digital caliper was used to measure and record this distance, extending from the rubber stop to the file tip.

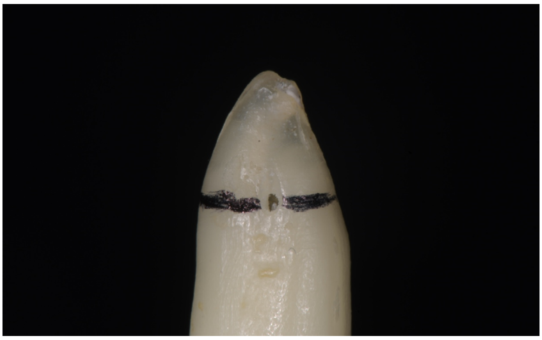

Figure 5. Actual length determination until perforation.

Length measurement by integrated apex locator

After determining AL, electronic measurements were made per the manufacturer's guidelines by the second operator (Figure 6). The teeth were embedded in the freshly prepared alginate model with dimensions of 2 x 2 x 1.5 inches. Each group was studied separately. The second operator took measurements of the working length with an integrated apex locator (IAL) after filling the root canal with the chosen irrigant. The root canals were irrigated with 5 ml of distilled water to prevent measurement errors, and they were dried with paper points in between each measurement of a different irrigant. Each tooth's root canal was filled with the irrigating solution, the surplus was removed from the chamber, and the tooth's exterior surface and pulp chamber were both dried with a cotton swab.

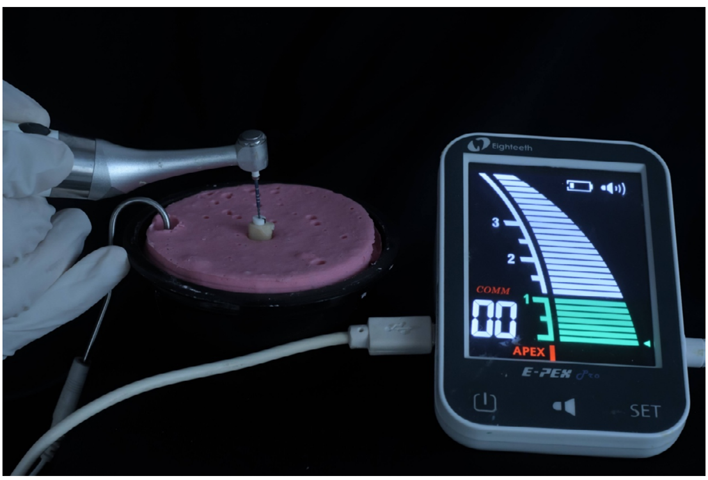

Figure 6. Determination of length by integrated apex locator.

The auto apical reverse (AAR) feature was kept on before taking all the readings. For the E-Pex Pro Apex Locator, the 16/02 glide path file (Proglider, Dentsply Sirona, California, USA) was slowly and steadily advanced until the LCD displayed the apex signal, and thereafter the file was retracted to the 0.5 mm mark in the green zone. The length was recorded with the help of the digital calliper. After completion of taking readings with each irrigating solution, the alginate model was repoured with freshly mixed alginate, and the whole process was repeated for the next tooth sample.

Statistical Analysis

All the reading data were tabulated according to two different levels of accuracy ranges using Microsoft Excel (Microsoft Office, Washington, USA). Thereafter, the percentage of accuracy was calculated using the formula -

$$\frac{\text{Readings in} \pm 0.5 \text{ mm range}}{\text{Total number of readings}} \%$$

The IBM SPSS Statistics software (version 20.0; IBMCorp., Armonk, NY, USA) was used for calculating statistical significance for the readings obtained in the ± 0.5 mm range. Intergroup comparison was done using the Z-test difference between two proportions.

The z-test was employed to validate whether observed differences in accuracies across variables arose from chance or revealed significant, non-random variations. This statistical assessment provided robust evidence, enabling conclusions about the true impact of each variable on accuracy measurements.

Results

The AL and range of working length obtained by IAL till the perforation site under different canal conditions are shown in Table 1. The readings in the range of ± 0.5 mm were considered the most accurate and were used for the calculation of accuracy under different solutions. The most accurate readings were recorded with chlorhexidine and saline, 96.66 % and 93.33 % respectively. (Table 1)

Table 1. Accuracy of perforation detection based on scoring criteria and Intergroup comparison based on the use of various irrigating solutions for determining working length till perforation, using the Z-test.

Accuracy Range	Saline (n=60)	Sodium hypochlorite (n=60)	Qmix (n=60)	Chlorhexidine (n=60)	MTAD (n=60)
±0.5 mm	56	44	46	58	48
> 0.5 mm - ≥1 mm	4	16	14	2	12
Accuracy (%)	93.33	73.33	76.66	96.66	80
Saline	-	0.00328**	0.01046*	0.40090$	0.03156*
Sodium hypochlorite	0.00328**	-	0.67448	0.00034**	0.38978
Qmix	0.01046*	0.67449$	-	0.00128**	0.65994$
Chlorhexidine	0.40090	0.00034**	0.00128**	-	0.00452**
MTAD	0.03156*	0.38978	0.65994	0.00452**	-

MTAD - Mineral trioxide aggregate and Detergent
P value: level of significance; $: P value>0.05-Not Significant, *: P value<0.05-Significant, **: P value<0.01-Highly Significant; MTAD - Mineral trioxide aggregate and Detergent

Intergroup comparison showed a highly statistically significant difference (HS) ($P < 0.01$) between readings obtained under chlorhexidine and all other irrigating solutions except for saline. Statistically significant differences ($P < 0.05$) were noted for saline and other irrigating media readings, while an HS difference was observed between saline and sodium hypochlorite. (Table 1)

Discussion

Perforations were made in this study with a mean diameter of 0.12 mm to simulate medium defects on the root surface, reflecting clinical conditions such as root surface resorption and perforations caused by coronal shapers or drills used during post-space preparation. The diameter of the perforations in this study was found to be similar to or larger than in the previous studies[16,24,25]. In previous studies, perforations of 1, 0.60, 0.40, 0.30, and 0.27 mm were used[24,26,27]. In one investigation, artificial perforations made using a spherical bur with a diameter of 1 mm were regarded as unrealistic[24]. Large defects on the root surface, on the other hand, can occur as a result of resorption and the use of coronal shapers or large files, as well as during various intracanal procedures for post placement.

In earlier in vitro studies, the teeth were placed in agar, gelatin, alginate, or floral sponge that had been saturated with NaCl to use an apex locator in perforated teeth. The most precise measurements, according to Baldi et al.[28], were made in cases that were immersed in alginate. Alginate replicates the electric impedance of the human periodontium well, making it a suitable medium for creating the requisite electric circuit for an accurate electronic apex locator measurement[29].

The accuracy achieved by IAL in our study under the conditions of saline and chlorhexidine was at an acceptable level of 90% (Table 1), which was similar to that of studies conducted by Cimilli et al.[30] and Cruz et al.[31]. However, it was not quite the same for other solutions, indicating that the Auto apical reverse (AAR) feature may have been a factor in decreased accuracy in certain conditions[32]. Most studies used a permissible range of ± 0.5 mm[33,34] to assess the accuracy of the EALs. Others used a ± 1.0 mm error range, which was more forgiving[30,35]. Therefore, another reason for the significant differences in accuracy under various conditions can be due to the consideration of ± 0.5 mm as the criteria for accuracy.

In this investigation, 2% chlorhexidine provided the greatest number of readings in the ± 0.5 mm range, followed by saline. Overall data showed that normal saline performed similarly well while 3% sodium hypochlorite was the least accurate, and was preceded by Qmix and MTAD.

According to Shin HS et al., the electrical conductivity of tap water ranges from 100 to 1,000 S/cm, whereas that of a 5% sodium chloride solution is 70,000 S/cm. Physiologic saline and 1% NaOCl solution have electrical conductivities of 44,940 S/cm and 172,420 S/cm, respectively[24]. It was hypothesised that a change in electroconductivity would cause a shift in the frequency quotient curve. When conductive solutions are present inside the canal, the changes in electrical properties as the foramen is approached and passed are negligible. This circumstance would make it more difficult to determine the foramen electrically. In fact, Meredith and Gulabiwala[36] found that the series resistance for dry canals (22.19-92.07 k) increased clearly as the distance from the radiographic apex increased, and these values were noticeably higher than those containing deionized water (9.32-12.10 k) and sodium hypochlorite (7.46-8.92 k). It was shown by Ikhar et al.[37] that the Dentaport ZX and Propex II apex locators provided the least accurate results in the perforated root canal with NaOCl, which was consistent with the findings of our study. In contrast, Duran-Sindreu et al.[38] reported that the accuracy of either the IPEX or Root Z EAL was not affected by the use of chlorhexidine and sodium hypochlorite.

In this study, as in many others, it was discovered that the irrigants used for the final rinses, such as 3% sodium hypochlorite, Qmix, and MTAD, were not as reliable for carrying out electronic canal measurements. Instead, 2% chlorhexidine, 17% EDTA, and 0.9% saline were found to be more reliable. As with the earlier solutions, there isn't much clinical data on their effects on measuring working length using an integrated apex locator in perforated root canals because the majority of studies focus on the effects of different irrigating solutions on electronic working length measurements of the entire root length. However, the evidence that is now available points towards the relative electroconductivity of different irrigation solutions and its variable impacts on the estimation of working length by an integrated apex locator.

To mention a few limitations of the studies. A comparative evaluation with other apex locators was avoided to focus on the accuracy of the integrated apex locator. The various sizes of perforation, location of the perforation, size of the file, and various other influencing factors could not be analysed. Nonetheless, additional research can aid in our understanding.

In conclusion, with different degrees of accuracy, the integrated apex locator could determine the working length till perforation under all irrigating solutions.

In comparison to Qmix, MTAD, and sodium hypochlorite, chlorhexidine and saline proved to be better suitable for precise working length assessment in the perforated root canal.

Acknowledgement

None.

Conflict of Interest

None.

Data availability

All the datasets related to this article will be available upon request to the corresponding author.

Author Contribution

Chintan Joshi: concepts, design, definition of intellectual content, literature search, experimental studies, manuscript preparation, editing & review, guarator

Surabhi Joshi: design, literature search, clinical studies, experimental studies, data acquisition, manuscript editing & review, guarator

Urooj Desai: data analysis, statistical analysis, manuscript editing & review, guarator

Sweety Thumar: literature search, data acquisition, manuscript review, guarator

Aashray Patel: experimental studies, manuscript editing & review, guarator

Ankita Khunt: manuscript editing & review, guarator

All the authors actively participated in the manuscript's findings and have revised and approved the final version of the manuscript.

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