ORIGINAL RESEARCH PAPER

Dentistry

IN VITRO COMPARATIVE STUDY OF FOUR ELECTRONIC APEX LOCATORS IN DETECTING APICAL CONSTRICTION

KEY WORDS: Root apex; accuracy; minor constriction; electronic apex locator

Ahana Chakraborty*	Third Year Post Graduate Trainee, Department of Conservative Dentistry and Endodontics, Haldia Institute of Dental Sciences & Research, Haldia, West Bengal *Corresponding Author
Anirban Bhattacharyya	MDS, Professor & Head of the Department, Department of Conservative Dentistry and Endodontics, Haldia Institute of Dental Sciences & Research, Haldia, West Bengal
Asim Bikash Maity	MDS, Professor, Department of Conservative Dentistry and Endodontics, Haldia Institute of Dental Sciences & Research, Haldia, West Bengal.
Gayatri Majumder	MDS, Assistant Professor, Department of Conservative Dentistry and Endodontics, Haldia Institute of Dental Sciences & Research, Haldia, West Bengal

ABSTRACT

Objective: Minor constriction which is the narrowest diameter is considered to be the appropriate apical limit of endodontic treatment. Apex locators provide greater precision, fewer procedural errors, less discomfort to the patient during measurement of working length. The aim of this article is to compare the accuracy of four electronic apex locators in detecting the apical constriction using histological sections as the gold standard. **Materials and Methods:** 80 extracted single-rooted permanent teeth were selected and coronally flattened for stable reference point. Access cavity was prepared and canal patency was checked. Samples were embedded in alginate upto cemento-enamel junction. Working length was determined with the apex locators. A 15 K file adjusted to that reading was placed in the root canal and stabilized with flowable composite. Apical 4 mm of root was longitudinally sectioned and the position of the file in relation to the minor constriction was recorded for each tooth under stereomicroscope at 40X magnification. Chi-square test was carried out to test the difference in accuracy at various levels from the minor foramen. Kruskal Wallis Test was carried out to compare the differences between the study groups for the distance from the tip of the file relative to the minor foramen ($P<0.05$). **Results:** Measurements of mean working lengths within ±0.5 mm of minor diameter were 85% acceptable for CanalPro followed by Root ZX Mini (80%) and Propex Pixi (80%) and the least by DPEX V (65%). **Conclusion:** Accuracy of these instruments for detecting the minor diameter is acceptable for clinical practice

INTRODUCTION

The removal of all pulp tissue, necrotic material and microorganisms from the root canal is essential for endodontic success which can only be achieved through accurate determination the length of the tooth and the root canals. The outcome of treatment of roots with necrotic pulps and the associated periapical lesions is influenced significantly by the apical level of the root filling[1]. According to Glossary of Endodontic terms, working length is defined as 'the distance from a coronal reference point to the point at which canal preparation and obturation should terminate'[2]. Grove [3] (1930) stated that 'the proper point to which root canals should be filled is the junction of the dentin and the cementum and that the pulp should be severed at the point of its union with the periodontal membrane' but locating the appropriate apical position always has been a challenge in clinical endodontics. Cemento-dentinal junction is the anatomical and histological landmark where the periodontal ligament begins and the pulp ends and is also is referred to as the minor diameter or the apical constriction[4]. However, the cemento-dentinal junction and apical constriction do not always coincide, particularly in senile teeth as a result of cementum deposition, which alters the position of the minor diameter. Therefore, it is recommended that the apical constriction which is the narrowest part of the root canal with the smallest diameter of blood supply[5], should be considered as the apical limit of the working length, where it is easy to clean and shape or obturate the canal[6,7].

Various methods of determining the working length include using radiographic and non-radiographic methods like tactile sensation, apical sensitivity and paper point measurement technique. Electronic apex locators (EAL) are one of the breakthroughs that brought electronic science into the traditionally empirical endodontic practice. EALs are specifically useful when the apical portion of the canal system is obscured by anatomic structures, such as impacted teeth, tori, the zygomatic arch, excessive bone density, overlapping roots, or shallow palatal vaults[8]. Currently apex locators are being used to determine the working length as an important adjunct to radiography. EALs help to reduce the treatment time and the radiation dose, which may be higher with conventional radiographic measurements[8,9].

There has been a flooding of various apex locators in the today's market, each with its own set of advantages and disadvantages. Keeping in mind their various claims, four currently popular EALs based on different working principles were chosen in this study. A literature search revealed that there are limited number of articles evaluating the accuracy of apex locators like CanalPro (Coltene Whaldent, Switzerland) and DPEX V (Woodpecker DTE, Guilin, China) but no published study was found that compared the accuracy of CanalPro, Root ZX Mini (J. Morita Corp., Tokyo, Japan), Propex Pixi (Dentsply Sirona, USA) and DPEX V using histological sectioning as the gold standard.

Therefore, the purpose of this in vitro study was to compare the accuracy of four different electronic apex locators based on different operating principles in detecting apical constriction in human permanent single-rooted teeth using histological sectioning as gold standard. The four EALs tested were CanalPro, Root ZX Mini, Propex Pixi and DPEX V. The null hypothesis was that there is no difference between canal length determination by CanalPro, Root ZX Mini, Propex Pixi and DPEX V when compared to the length determined using histological sectioning.

MATERIALS AND METHODS

This study was approved by the Ethics Committee of Haldia

Institute of Dental Sciences and Research. Eighty freshly extracted human permanent single-rooted teeth with mature apices were selected for the study. Before use the teeth were stored in distilled water (IndPet, India) containing 10% formalin (Fisher Scientific, USA). The teeth were decontaminated by immersion in 5.25% sodium hypochlorite (Coltene Whaldent, Switzerland) for 2 hours. The teeth were then cleaned to remove the stain and calculus with the help of ultrasonic scaler using G2 scaler tip (Woodpecker, China) and were stored in normal saline solution (0.9% w/v Kunal Remedies Private Limited, India) until use in order to maintain the physiological characteristics of the teeth. Type I canal configuration with canal curvatures less than 20° were confirmed using digital radiograph from the buccolingual and mesiodistal directions (Acteon X-Mind) with exposures of 70 kV, 8 mA, for 0.125 sec and the images were analyzed using EzDent-i 2D software (VATECH, India). Teeth with resorption, curvatures, open apices or radiographically invisible canals were excluded. The occlusal and/or incisal surfaces were flattened using flat end tapered fissure diamond point, TF 13 (Mani, Japan) in an airotor handpiece (Dentmark Ornage, R&D Impex International, India) with water spray to serve as a stable and unequivocal reference for all measurements for working length and allow easy access to pulp chamber. Standard access preparations were made for all the sample teeth. The access cavity was prepared with Endo Access bur (Dentsply-Maillefer, Switzerland) followed by Endo Z bur (Dentsply-Maillefer, Switzerland) under water spray coolants using airotor handpiece (Dentmark Ornage, R&D Impex International, India). The orifices were explored with a DG 16 explorer (GDC, India) following which the coronal and middle portions were shaped using #4 and #3 Gates-Glidden burs (Mani, Japan) using contra-angled handpiece (NSK EC, Japan) and micromotor (Strong 90, India). The remaining pulp tissue was removed with a barbed broach (Mani, Japan), without any attempted to enlarge the canal. After irrigation with 5 mL of 3% sodium hypochlorite (Septodont, India) using luer lock disposable syringe (Becton, Dickinson and Company, Singapore) and 30G side vented needle (Orikam, France) the canals were negotiated using size #8 stainless steel K-file (Mani, Japan). An ISO #10 stainless steel K-file (Mani, japan) was inserted inside the canal to check apical patency. To simulate the periodontium, this study used in vitro alginate model. as described by Higa et al.[10] Two and a half scoops of alginate powder (Neoalgin, Orikam, France) was measured using alginate measuring scoop (Major Dental, India) and mixed with appropriate amount of water in a rubber mixing bowl (EiTi Dental, India) using alginate plastic spatula (API Dental, India) following the manufacturer's instructions. Freshly mixed alginate was poured from the rubber mixing bowl (EiTi Dental, India) onto a plastic container (Signoraware, India) of volume 40 ml and diameter of 60 mm and height 30 mm. The teeth were embedded up to the cemento-enamel junction into freshly mixed alginate in the plastic container (Signoraware, India). Subsequently, the metal lip clip of the EAL evaluated was embedded alongside the root of each tooth. (Figure 1) shows the experimental set-up.

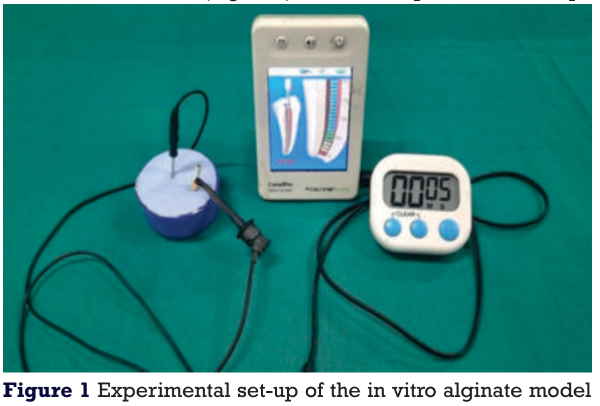

Figure 1 Experimental set-up of the in vitro alginate model for electronic working length measurement

All measurements were made using size 15K file (Mani, Japan) within 2 hours after model preparation to ensure sufficient alginate humidity. Electronic working length measurement was done after irrigation with 3% Sodium hypochorite (Septodont, India). The metal lip clip embedded into the alginate was stabilized with a transparent adhesive tape (Prime, India). The pulp chamber was gently dried with air and sterile cotton pellets (Oro, India) to eliminate the excess irrigants, with no attempt to dry the canals. Each EAL was used according to the manufacturers' instructions.

For each measurement, the file was slowly advanced slow clockwise turn into the canal. After reaching the apex, as indicated by audio and/or visual signals by each of the apex locators, the file was retracted 0.5 mm from the mark of apex indication. This was also verified by audio visual information from each of the apex locators. The silicon stopper was adjusted at the coronal reference point at this length and the file was withdrawn from the canal. Figure 2 and 3 showing the respective images should be placed after this paragraph. Measurements were deemed valid if the instrument remained stable for at least 5 seconds which was recorded by a stopwatch (Trexee Enterprises, India). The file length from the silicon stopper till the end point of the file was measured using vernier caliper (Zhart, India) till the nearest hundredth of a millimetre.

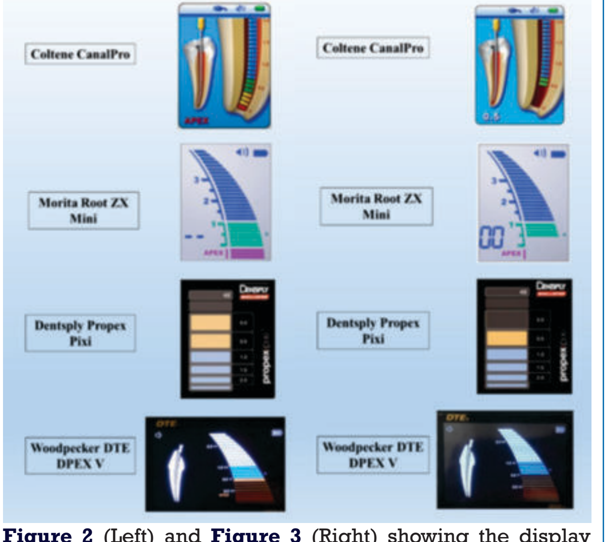

Figure 2 (Left) and **Figure 3** (Right) showing the display conditions on the apex locator screens for the position of the major and minor foramen respectively

The file was again placed back into the canal till the previous measurement and locked in place using A2/B2 Shade Synergy D6 Flow light-curing composite (Coltene, Whaldent, Switzerland) and cured with LED curing unit (BEECOOL LED with cord) using wavelength: 440~490nm (light output: 1000-1200 mW/cm^2) for 20 secs in full curing mode. The file handle was then cut using a flat end tapered fissure diamond point; TF 11 diamond bur (Mani, Japan) with the cemented file in the root canal. The cemented file position was reconfirmed by adapting the electrode to the cemented file, to make sure that composite placement did not disturb the recording.

After drying, apical 4 mm was shaved for each sample with a low speed diamond disk (Horico, Japan) mounted on a straight handpiece (Sprint, IDS Denmed Private Limited) along the long axis of the tooth in a plane that was determined to show the best representation of the minor diameter in relation to the file, until the file tip was seen through a very thin layer of dentin. This layer was then carefully removed using a no. 15 stainless steel Bard Parker blade (Kehr Surgical Private Limited) after which all the samples were ready for stereomicroscopic evaluation. Figure 4A, 4B and 4C showing the respective images should be placed after this paragraph.

The position of the apical constriction for each sample was viewed by means of a stereomicroscope (Amscope, USA) at 40X power. Two evaluators who were blinded about the type of EALs used were consulted about the position of the apical constriction for each sample. Evaluations that differed between the 2 evaluators were discussed until they reached a consensus. Subsequently, the position of the file tip in relation to the apical constriction was viewed and measurements were taken using software Portable Capture Pro by Winmax (a third party software) and averaged to the nearest hundredth of a millimetre.

Figure 4 A (left), 4B (middle) and 4C (right) shows the procedure for longitudinal histological sectioning. Figure 4A shows longitudinal sectioning of apical 4 mm along the long axis of the tooth in a plane that was determined to show the best representation of the minor diameter in relation to the file. Figure 4B shows the file tip can be seen through a very thin layer of dentin. Figure 4C shows the removal of the thin remaining layer of dentin a no. 15 stainless steel Bard Parker blade.

Data was recorded as zero if the file tip was found to be at apical constriction. Positive values were recorded when the tip was detected beyond the apical constriction while negative values were recorded when the tip was detected short of the apical constriction. Figure 5A, 5B, 5C showing the respective images should be placed at the end of this paragraph. The differences between the study groups for the distance from the tip of the file relative to the minor foramen using Kruskal Wallis Test. Chi-square test was carried out to test the difference in accuracy at various levels from the minor foramen. The analysis was performed with GraphPad Prism for Windows, Version 9.0 (GraphPad Software, La Jolla California USA). A *P* value of less than 0.05 was considered to be statistically significant.

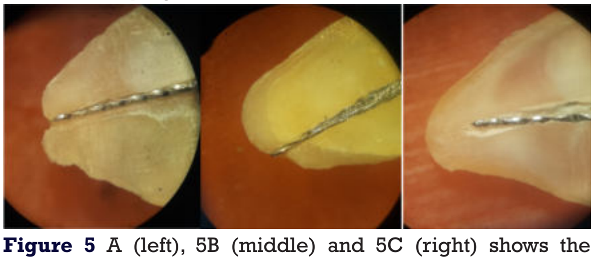

Figure 5 A (left), 5B (middle) and 5C (right) shows the position of the file tips in relation to the apical constriction. File tip was found to be at apical constriction for 5A. Positive values were recorded when the tip was detected beyond the apical constriction as in 5B while negative values were recorded when the tip was detected short of the apical constriction as shown in 5C

RESULTS

Distances from the tip of the file relative to the minor foramen for the four apex locators are shown in (Table 1). Number of cases showing accuracy at distances from the tip of the file relative to the minor foramen for the four EALs are in (Table 2). The results from (Table 1) indicates that Root ZX Mini had the shortest distance (Mean ± S.D. = -0.07 ± 0.67) mm relative to the minor foramen, followed by Propex Pixi (Mean ± S.D = -0.21 ± 0.54), then CanalPro (Mean ± S.D. = - 0.24 ± 0.58) and the maximum distance was recorded by DPEX V (Mean ± S.D. = -0.32 ± 0.69). However, the Kruskal Wallis test showed that difference between the four EALs were not statistically significant [H(3) = 3.2, *P* = 0.36], with a Median (IQR) of 0(0), 0(-0.36-0), 0(-0.35-0) and 0(-0.86-0) for Root ZX Mini, Propex Pixi, CanalPro and DPEX V respectively. Box Plot showing the distances from the tip of the file relative to the minor foramen for the four apex locators is in Figure 6.

Table 1: Distances from the tip of the file relative to the minor foramen for the four EALs.

Descriptive statistics	Group I: CanalPro	Group II: Propex Pixi	Group III: DPEX V	Group IV: Root ZX Mini	P value
Mean ± S.D.	-0.24 ±0.58	-0.21±0.54	-0.32±0.69	-0.07±0.67	0.36
Median (IQR)	0(-0.35-0)	0(-0.36-0)	0(-0.86-0)	0(0)	

SD, standard deviation IQR, interquartile range

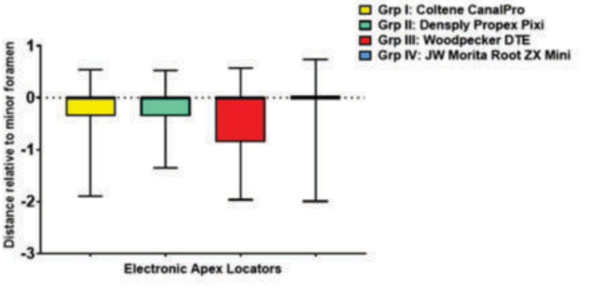

Figure 6 Box Plot showing the Distances from the tip of the file relative to the minor foramen for the four EAL

According to (Table 2), accuracy of Root ZX Mini (70%, *n*=14) and CanalPro (70%, *n*=14) was found to be the highest followed by Propex Pixi (65%, *n*=13) and the least by Woodpecker DTE (60%, *n*=12) in determining the working length at the minor foramen. However, the Pearson's Chi-square test showed that difference between the four EALs were not statistically significant [$\chi^2(3)=0.21$, $P = 0.98$]. Accuracy of CanalPro (85%, *n*=17) was found to be the highest followed by Root ZX Mini (80%, *n*=16) and Propex Pixi (80%, *n*=16) and the least by DPEX V (65%, *n*=13) in determining the working length 0.5 mm short or over-instrumented from minor foramen. However, the Pearson's Chi-square test showed that difference between the four EALs were not statistically significant [$\chi^2(3)=0.58$, $P = 0.9$]. Accuracy of CanalPro (90%, *n*=18) was found to be the highest followed by Root ZX Mini (85%, *n*=17) and Propex Pixi (85%, *n*=17) and the least by DPEX V (80%, *n*=16) in determining the working length 1 mm short or over-instrumented from minor foramen. However, the Pearson's Chi-square test showed that difference between the four EALs were not statistically significant [$\chi^2(3)=0.12$, $P = 0.99$]. Bar Graph showing the accuracy of the four EALs for the distances from the tip of the file relative to the minor foramen is in (Figure 7).

Table 2: Number of cases showing accuracy at distances from the tip of the file relative to the minor foramen for the four EALs

Descriptive statistics	Group I: CanalPro	Group II: Propex Pixi	Group III: DPEX V	Group IV: Root ZX Mini	χ2 value	P value
At minor foramen	14 (70%)	13 (65%)	12 (60%)	14 (70%)	0.21	0.98
0.5 mm short/ over-instrumented from minor foramen	17 (85%)	16 (80%)	13 (65%)	16 (80%)	0.58	0.9
1 mm short/ over-instrumented from minor foramen	18 (90%)	17 (85%)	16 (80%)	17 (85%)	0.12	0.99

DISCUSSION

The goal of this in vitro study was to compare the accuracy of four electronic apex locators in detecting the apical constriction using histological sections as the gold standard.

An electronic method for root length determination was first investigated by Custer (1918)[11]. The idea was revisited by Suzuki in 1942 who studied the flow of direct current through the teeth of dogs. He registered consistent values in electrical resistance between an instrument in a root canal and an electrode on the oral mucous membrane and speculated that this would measure the canal length[12]. Sunada took these principles and constructed a simple device that used direct current to measure the canal length. It worked on the principle that the electrical resistance of the mucous membrane and the periodontium registered 6.5 kΩ in any part of the periodontium regardless of the persons age or the shape and type of teeth. However, using direct current caused instability with measurement, and polarization of the file tip altered the measurement[13]. Present electronic apex locators are based on alternating current.

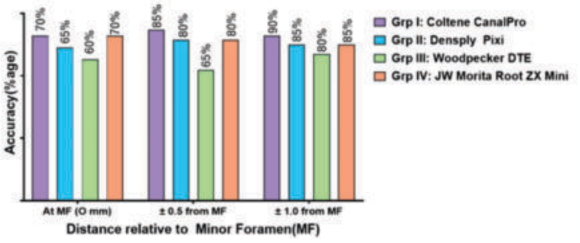

Figure 7 Bar Graph showing the accuracy of the four EALs for the distances from the tip of the file relative to the minor foramen

EALs functions by using the human body to complete an electrical circuit as shown by (Figure 8). One side of the apex locator's circuit subsequently connected to the oral mucosa through a lip clip and the other side to a file. When the file is placed into the root canal and advanced apically until its tip touches periodontal tissue at the apex, the electrical circuit is completed. The electrical resistance of the electronic apex locators and the resistance between the file and oral mucosa are now equal, which results in the device indicating that the apex has been reached[14].

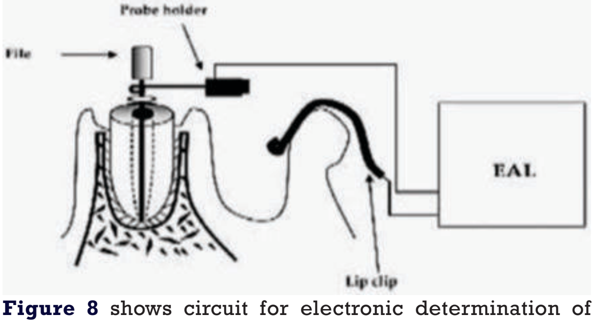

Figure 8 shows circuit for electronic determination of working length

Classification of apex locators was given by Mc Donald (1992) based on the type of current flow (operating principle), opposition to the current flow, number of current frequencies involved giving rise to apex locators based on resistance, impedance and frequencies[15].

First Generation Electronic Apex Locators (Resistance Type) are also known as Resistance Based Apex Locator. Basically these instruments measured the opposition to the flow of direct current (resistance) and hence the name[16]. Second Generation Electronic Apex Locators (Impedance Type) were of the single-frequency impedance type which used impedance measurements instead of resistance to measure location within the canal. These operated on the principle that there is electrical impedance across the wall of the root canal due to the presence of transparent dentin. Impedance is comprised of resistance and capacitance and has a sinusoidal amplitude trace. The property is utilized to measure distance in different canal conditions by using different frequencies [17].

Third Generation Electronic Apex Locators (Frequency dependent comparative impedance Type) are similar to the second generation except that they use multiple frequencies to determine the distance from the end of the canal. These units have more powerful microprocessors and are able to process the mathematical quotient and algorithm calculations required to give accurate readings[18]. Since the impedance of given circuit may be substantially influenced by the frequency and the current flow, these devices have been called Frequency Dependent[2]. The main shortcoming of early apex locators (erroneous readings with electrolytes) was overcome by Kobayashi et al. (1991) with the introduction of the ratio method and the subsequent development of the self-calibrating Root ZX (J. Morita, Tokyo, Japan)[19]. The electronic method employed was the ratio method. The radio method works on the principle that two electric currents with different sine wave frequencies will have measurable impedances that can be measured and compared as a ratio regardless of the type of electrolyte in the canal. The capacitance of a root canal increases significantly at the apical constriction, and the quotient of the impedances reduces rapidly as the apical constriction is reached. Kobayashi & Suda (1994) showed that the ratio of different frequencies have definitive values , and that the ratio rate of change did not change with different electrolytes in the canal[19]. Root ZX simultaneously measures two impedances at two frequencies (8 kHz and 0.4 kHz) inside the canal. The Root ZX mainly detects the change in electrical capacitance that occurs near the apical constriction[2]. Root ZX Mini belongs to the third generation of apex locators.

Fourth Generation Electronic Apex Locators are Ratio Type apex locators which determine the impedance at five frequencies. These devices do not process the impedance information as a mathematical algorithm, but instead take the resistance and capacitance measurement and compare them with a database to determine the distance to the apex of the root canal[2]. CanalPro apex locator belongs to this category. The measurements in CanalPro apex locator are performed using AC signals at two frequencies. The frequencies are alternated rather than mixed, as it is done in other apex locators, thus cancelling the need for signal filtering and eliminating the noise caused by non- ideal electronic apex locator filters. The Root Mean Square (RMS) level of the signal is measured, rather than its amplitude or phase. The RMS value is much more immune to various kinds of noises than other parameters of the measured signal[20].

To cope with associated problems associated with previous generations of apex locators a new measuring method were developed based on comparison of the data taken from the electrical characteristic of the canal and additional mathematical processing and so the fifth generation apex locator (Dual Frequency Ratio Type) came to use[2]. Propex Pixi belongs to this category. The measurements in Propex Pixi apex locator are performed using multiple frequencies, in addition to calculating the root mean square (RMS) values of the electric signals. The RMS represents the energy of the electric signals, and therefore, it is claimed to be less affected by electrical noises affecting other physical parameters such as amplitude or phase of electrical signal that are used by other apex locators[21].

The efficacy of sixth Generation Electronic Apex Locators (Adaptive Apex Locators) in long term use yet to be established. Adaptive apex locators continuously define humidity of the canal and immediately adapts to dry or wet canal. This way it is possible to be used in dry or wet canals, canals with blood or exudates[2]. DPEX V apex locator (Woodpecker DTE) belongs to this category[22]. There is limited literature regarding the working principle of DPEX V apex locator.

Tang et al. [23] (2011) evaluated the effects of root canal anatomy, tooth type (tooth location), root curvature and canal calcification on the accuracy of the Root ZX apex locator. The results indicated that tooth anatomy obviously affected the accuracy of electronic apex locators and made canal preparation difficult[23]. Single-rooted teeth with straight and wide canals were used in this study to minimize problems presented by a more complicated canal anatomy.

Literature suggests that the reason for the lower accuracy of electronic apex locators in teeth with enlarged apical foramen diameters may be due to difficulty in identifying the narrowest diameter of the canal with these devices[24]. According to the study of Kolanu et al. [25] (2014), Propex Pixi apex locator is accurate under a diameter size of 0.6 mm irrespective of the file size used. So in the current study, samples were selected considering the apical diameters were much smaller than 0.6 mm and 15K file was chosen as they fit snugly into the canals.

Literature suggests that preflaring root canals before using the electronic apex locator led to an increased device accuracy[26], but it was also noted that preflaring could only result in better accuracy in some types of electronic apex locators[24]. It appears that after preflaring, electronic apex locators should be used more cautiously for length measurement Thus, in the present study the canals were carefully preflared with Gates-Glidden burs.

The antimicrobial activity and the removal of the organic remnants by irrigants are very important for the success of endodontic treatment. Root canal irrigation with 3% NaOCl was used in the present study to dissolve the necrotic pulp around the orifice and the coronal portion of the canals before determining the working lengths. The possible influence of NaOCl on electronic reading has been assessed by various authors like Welk et al. [27] (2003), Wrbas et al. [28] (2007), Baldi et al. [29] (2007) who observed no interference with the readings. Herrera et al. [30] (2007) stated that the use of hypochlorite prompted no deterioration of the alginate model as well.

In the current study, alginate was used as a medium because of its suitable electroconductive property, simulation of the periodontal ligament colloidal consistency, high degree of stability and low cost[29,30]. Due to its simplicity of preparation and availability, the alginate model allowed the testing of greater number of canals over a shorter period of time than could have been achieved by clinical means[29,30]. After the alginate setting, the roots embedded within are sufficiently firmly held to resist the force exerted by mechanical instruments[30].

Some authors in their literature measured working length from the minor diameter (apical constriction)[26,27,28,29,30] while others measured from the major diameter (apical foramen)[4]. The manufacturers of electronic apex locators should define the exact nature of their devices, how they operate electronically, and also should define the landmarks that their product is trying to locate (apical foramen versus minor foramen) which will help to understand and evaluate the effect of various newer files on the accuracy of newer electronic apex locators. Apical constriction was favoured as a reference point for working length by Ricucci and Langeland [5](1998) since they found that it provided the most favourable histological conditions when instrumentation and obturation remained short of the apical constriction since gutta-percha extruding beyond the same always caused a severe inflammatory reaction despite the absence of any pain. Hence in the current study, the apical constriction or minor diameter was considered as the apical limit of the working length.

Results from a study by Piasecki et al.[32] (2018) highlight the importance of evaluating both the 0.0 and 0.5 marks of the electronic apex locators because some devices may be differentially affected by anatomic variations. Most electronic apex locators present the Zero mark "0" (APEX or 0.0) to indicate the apical foramen and another to indicate the position of the apical constriction, which is usually displayed as the 0.5 mark even though the numbers in the display do not represent millimeters. However, there has been controversy as to whether electronic apex locators are able to determine the minor constriction or the major foramen. Diverse studies by D'Assunção et al. [26] (2007) and Plotino et al. [31] (2006) have usually considered the electronic measurements for the minor constriction to be between the 0.5 mm mark and the zero mark. Therefore this in vitro study employed the "0.5" reading on the display/LED of all electronic apex locators as apical constriction.

Some authors like Lee et al. [33] (2002) have suggested that taking the instruments slightly long when using electronic apex locators and then retracting them may increase the accuracy of readings of electronic apex locators. Thus, to confirm the measurement, in this study the file was advanced beyond "0.5" reading upto "APEX" reading to verify that warning signals indicated the foramen was reached and then retracted again to "0.5" reading as a detection of apical constriction.

The histological section of each canal is considered to be the gold standard for such studies. Sectioning of tooth provides an unobstructed view of the file tip in relation to the apical constriction and also allows direct exact measurement of the distance between major and minor diameter with aided magnification[24]. In the present study, the exact distance between the file tip and the minor diameter has been determined using histological sections which were viewed under a stereomicroscope at 40X magnification to obtain better viewing clarity and details. The electronic Portable Capture software was used for measurement to minimize human errors.

Electronic apex locators have traditionally afforded some latitude of acceptable error in locating the apex[5]. Most literature stated that measurements attained within within a ±0.5 mm range surrounding the evaluated landmark are considered highly accurate[26,27,28,29,31]. Other studies like those by Goldberg et al. [34] (2005) relied on a less strict clinical range of ±1.0 mm. One reason cited by Dummer et al.[5] (1984) for accepting a ±1.0 mm margin of error is the wide range seen in the shape of the apical third. As a result, the current study, used an error range of ±0.5 mm and ±1.0 mm to assess the accuracies of the electronic apex locators.

In the current study, for determination of the working length at the minor foramen, accuracy of CanalPro and Root ZX Mini was found to be the 70%, 65% for Propex Pixi and 60% by DPEX V. At a range of error of ±0.5 mm the order of accuracy of electronic apex locators was CanalPro (85%) > Root ZX Mini and Propex Pixi (80%) > DPEX V (65%) and for an error range of ±1.0 mm the order of accuracy of electronic apex locators was CanalPro (90%) > Root ZX Mini and Propex Pixi (85%) > DPEX V (80%) with statistically no significant difference between the electronic apex locators. This is in correlation with the studies by Singh et al. [35] (2020) where the results demonstrated that readings of CanalPro were more accurate than Propex Pixi and by Serna-Pena et al. [36] (2020) where the readings of Root ZX Mini and Propex Pixi were both 83.33% for ±0.5 mm and for ±1.0 mm, 100% and 89.99% respectively. A study by Taneja et al. [37] (2017) concluded the accuracy of CanalPro and Root ZX Mini in detecting apical constriction was 100% within ±0.5 mm.

The result of the current study is also in accordance with the study by Saxena et al. [38] (2017) and Pawar et al. [39] (2018) which revealed an 80% accuracy for Dentsply Propex Pixi within ± 0.5mm error range The study by Bonilla et al. [21] (2022) also concluded the accuracy of Propex Pixi to be 88% in ±0.5 mm range and 98% accurate within ±1.0 mm range. An in vitro study by Zahra et al. [40] (2019) concluded the accuracy of a Woodpecker electronic apex locator to be 90%

and 100% in the range of ±0. 5 mm and ±1.0 mm. However the study did not specify the exact brand of Woodpecker electronic apex locator used in their methodology.

An in vitro research is limited in its ability to simulate the in vivo conditions required for reproduction of the clinical environment. Therefore the results of the in vivo study are considered most reliable and/or relevant as compared to in vitro studies. Future studies should focus on the further evaluation of accuracies of the four electronic apex locators.

CONCLUSIONS

Within the limitations of this study, it can be concluded that CanalPro was most accurate in detecting the apical constriction followed by Root ZX Mini and Propex Pixi while DPEX V was least accurate considering an error margin of ±0.5 mm and ±1.0 mm, however the difference between the three devices were not statistically significant. Therefore, it may be concluded that accuracy of all the four electronic apex locators was acceptable for clinical practice in detection of the apical constriction and thus for the electronic working length determination.

Conflict Of Interest

No potential conflict of interest relevant to this article was reported.

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