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CanalPro EAL Accuracy compared to the Root ZX EAL

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The Canalpro EAL Accuracy Compared to the Root ZX EAL

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

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Abstract

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Objectives: Electronic apex locators (EAL) are an effective instrument in measuring the working length of a canal. The Root ZX is considered the gold standard by many. The aim of this research is to compare the accuracy of the CanalPro EAL to the Root ZX.

Methods: The actual length of 43 single rooted extracted teeth were measured with a #10 hand file when the tip was visualized at the foramen under a microscope. The EAL was then hooked up to a jig, with the tooth in saline, and a #10 hand file was placed in the canal. The working length was determined by using the 0.5 mm mark on both the CanalPro and Root ZX EAL.

Results: With the Root ZX, 74% of the teeth were within 0.5mm of the actual length (32/43). For the CanalPro, 65% were within 0.5mm (28/43). Neither the CanalPro nor the RootZX were deemed equivalent based on the preset equivalence bounds of +/- 0.5mm.

Conclusions: According to this study, both the Root ZX and the CanalPro are clinically acceptable for determining the apical limit for root canal therapy when using the ‘0.5’ mark, however it is advised that a MAF or MAC radiograph to confirm that instrumentation and obturation are within the confines of the canal. If using the ‘Apex’ mark on the EAL, then 1 mm should be subtracted from this length to ensure the limit of cleaning, shaping, and obturation are within the confines of the AC.

Introduction

Periapical health is influenced by the health status of the pulp. If the pulp becomes inflamed or infected this will spread to the adjacent periapical tissues. It is essential to debride, disinfect, and subsequently obturate the canal so that the body can heal the periapical region of the tooth**.** The length at which debridement and obturation is terminated will significantly affect the outcome (1). Swartz et al. looked at over 1007 endodontically treated teeth with a minimum of a 1 year follow up and reported that overfilled canals had a failure rate nearly four times higher than canals filled short of the radiographic apex(2). Schaeffer et al performed a meta-analysis to determine the optimal obturation length and concluded that filling 0-1 mm short of the apex had a 26% better success rate than filling long (3). The pre-op diagnosis of the pulp and periapical tissue affect the outcomes significantly as well. In 2003 Chugal et al. concluded that the success for necrotic cases with apical periodontitis is increased when the instrumentation and fill is closer to the radiographic apex. They found that teeth with normal pulps and periapical tissues had the highest success rate when instrumented about 1 mm from the radiographic apex. Teeth with pulp necrosis and apical periodontitis had the highest success when obturated 0.5 mm to the apex (4).

Outcomes are improved when cleaning, shaping, and obturation are short of the radiographic apex. Understanding the apical anatomy is crucial to achieve higher outcomes in endodontics. In 1955 Kuttler looked at the apical anatomy of 268 extracted teeth, approximately 8 of each type. They were stained with ink, sectioned, and measurements were made at the apices with a stereomicroscope. He made the following conclusions: 1. The center of the foramen was at the radiographic apex in 32% of the younger group (18-25) and 20% of the older group (55 and older). 2. There was a major foramen (apical foramen) and minor foramen (minor constriction). The minor constriction, also known as apical constriction, is found in the dentin right before the canal reaches the cementum and from that point widens to the major foramen as a funnel shape. Due to irregularities this funnel is very difficult to fill. 3. The minor constriction was located on average 0.52mm (younger pts) and 0.66mm (older pts) inside the canal from major foramen (4).

Based on Kuttler's conclusions when looking at obturation radiographically, if the fill appears to be flush it very well may be long. The major foramen is at the center of the apex 50% of the time and can be up to 2mm away from the apex (5). If the gutta percha fill is flush with the major foramen it may appear short radiographically. If the goal was to limit the gutta percha fill to the minor constriction, which is another 0.5-0.6 mm away from the major foramen (6), the fill will appear rather short radiographically. In 2014 ElAyouti did a study on the minor constriction in molars using CBCT. According to this study the mean distance from the apical constriction to the apical foramen was 0.2mm and the apical constriction to the apex was 0.9mm. The foramen was short of the apex in 88% of molars, and more than 2mm short in 5%, showing that fillings extending to the radiographic apex are actually overfilled (7).

Kuttler recommended that the fill terminate at the minor constriction because it would be difficult to fill the funnel with sealer and gutta percha (6), and Ricucci would agree. In Ricucci's study 29 roots were filled either long or short of the apex. The roots were resected and evaluated histologically. He found that cases that were filled beyond the apical constriction had severe inflammatory reactions in the periapical tissues. Cases with healed lesions exhibited a “stump” of vital tissue co-existing with the periradicular lesion. He concluded filling short of the constriction allows a vital pulp stump to remain in this area (8).

Because the tooth is a 3-dimensional object, to ascertain the location of the apical constriction (AC) using 2-dimensional radiographs alone is difficult. Olson et al did a study that looked at the ability of intraoral radiographs to determine the location of the apical foramen. The tip of an endodontic file was positioned at the apical foramen of each canal in 117 extracted human teeth. Parallel radiographs in the bucco-lingual plane were taken. The tip of the instrument appeared to be at the apical foramen (AF) in 82% of canals (9). Unfortunately, radiographs do not show the AC (See figure 1.). The pre-op radiograph is vital to visualize anatomy of the root canal system, assess curvatures, and note other important findings that will affect treatment outcomes. However, to achieve much greater accuracy in working length determination (instrumenting and obturating to the AC), the use of an electronic apex locator is necessary (10).

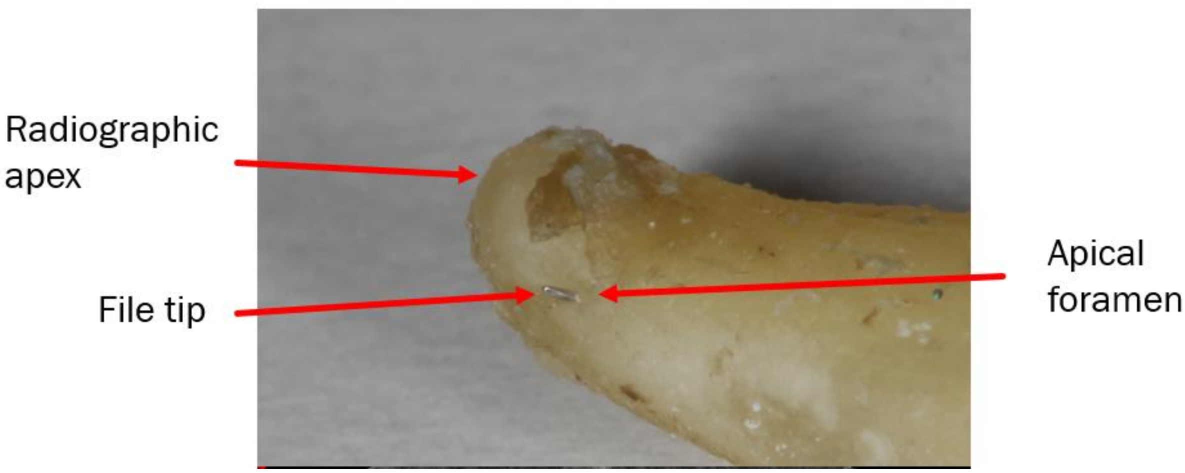

Figure 1: Extracted tooth showing a file tip exiting at the AF.

The origin of electronic apex locators (EAL) goes back to 1918. Dr. Levitt Ellsworth Custer published an article titled "Exact Methods of Locating the Apical Foramen" (11). Custer said in his article that locating the apex is just as important as any other step. "Pulp canals have been half filled and over filled for want of accurate knowledge of root length. The exact location of the apical foramen is not an easy matter even in straight roots. Heretofore the sense of touch has been relied upon and in some cases the x-ray of a root with a bent wire contained therein has been the most reliable but even this method is good only for the tooth rayed"(11). Custer proceeds to give an account of how to make the device and the methods of measuring the canal. He said, "The electrical method is based upon the difference in electrical conductivity of a dry pulp canal or one filled with a non-conducting liquid, and the conductivity of the tissues just beyond the apical foramen. That is, the pulp canal and contents being either a nonconductor or a poor conductor will contrast very sharply with the normal conductivity of the tissues surrounding apex of the root so that under proper electrical arrangement we can detect the instant a broach for instance passes thru the apical foramen, even much more quickly and accurately than can be told by the patient" (11). It took another 22 years before Suzuki took these ideas and put it to use and another 27 years before the first manufactured EAL(12)(13).

Electronic apex locators were first manufactured in Japan in the 1960's. Suzuki is credited for his early work on electronic apex locators back in 1942. He found that by placing an instrument in the root canal of dogs and a probe in the mucosa that he could measure resistance consistently (12). Sunada took this research from Suzuki and expounded upon it. Using direct current Sunada came up with a device that measured the resistance from the periapical tissue to the mucous membranes consistently at 6.0 kΩ. He found that when his device measured 37, 40, and 43 μA, the mean values of the distances from the tip of the reamer to the apex were -1.1 ± 1.31 mm, -0.1

± 0.37 mm, and 0.72 ± 0.72 mm, respectively. Sunada concluded that reading this measurement on his device was an accurate, quicker way of measuring the working length of the root canal, rather than using the wire measuring method and taking radiographs, or trying to locate the apical constriction based off of tactile feel (13). This research kicked off the beginning of manufacturing EAL's in Japan starting with the first mass produced EAL in 1969, the Root Canal Meter (Onuki Medical Co., Tokyo,Japan) (14).

Much like everything in dentistry, new products that come to market are self-proclaimed to be the "new" or "latest generation" to set themselves apart from what has come before them. Instead of categorizing EAL's based on what generation (1st, 2nd, 3rd, etc.), they will be categorized here based on 4 fundamental categories of EAL. 1. Resistance (direct current) 2. Impedance (alternating current), single frequency. 3. Impedance, two frequencies. 4. Impedance, multi-frequencies.

Resistance type EALs measure the resistance to flow of direct current. There was only one of this type and it was Sunada's. The problem with Sunada's apex locator was polarization effects at the surface of the electrodes that occurred with the application of direct current giving inconsistent readings (15). Onuki Medical Co. expanded upon the work of Sunada and produced The Root Canal Meter. This was an impedance type as it measured the resistance of flow of an alternating current instead of a direct current. Utilizing alternating current overcame the polarization effects, but also gave additional information about the conduction properties of the media (15). However, there were issues that prevented the Root Canal Meter and subsequent impedance type EALs from becoming common place in the practice. The first issue that the Root Canal Meter had was that it caused pain because of the high amperage alternating current with a frequency of 150 hz sine wave. The Endodontic Meter and the Endodontic Meter II (Onuki Medical Co.) came out afterwards and lowered the current to 5μA to address the pain issue and increased the frequency to 400 hz (15). The second issue that these first few EALs had was that they operated on a single frequency. The surrounding media and its electrolytes would alter the readings of the EAL because it was relying on a single frequency (13). If strong electrolytes are in the canal it will give a short reading (16). It was suggested that the canal be dry between measurements which ultimately made using the device more cumbersome (15).

The next generation of impedance type locators utilized two frequencies. Saito and Yamashita suggested using two frequencies, 1 KHz and 5 KHz, and by measuring the difference between the two frequencies the major apical foramen could be measured (17) (15). Strong electrolytes influence the readings within the canal of a particular single frequency, depending on the strength of the electrolyte and the frequency being used. By utilizing two different frequencies the average influence of the electrolyte is reduced (18). The Apit (Osada Electric Co.) took advantage of this method of using a 1 KHz and 5 Khz frequencies, however it must be calibrated in each canal (14). The accuracy of the Apit had an average of 81% within ± 0.5 mm of the apical foramen (14).

Now that it was understood that two frequencies were necessary to negate the effects of electrolytes in the canal, this idea was taken further to improve the accuracy. Kobayashi in 1994 discovered if the two impedances were measured simultaneously and the ratio (not the difference) was calculated, it would determine the location of the apex (19). The method of finding the ratio instead of the difference of two different impedances lead to the development of the Root ZX (J. Morita, Tokyo, Japan)(19). The Root ZX is the 3rd generation or impedance type using two frequencies. Today's EALs work off the basic principles of using at least two frequencies and finding the ratio. Their differences lie in signal conversion, using more than two frequencies, algorithms, and hardware components (15,20). However they are always compared against the Root ZX which is considered the gold standard (14,21).

The Root ZX is the most studied of all EALs and only a few notable studies will be given here. Shabahang et al in their in vivo study concluded that the Root ZX has 96% accuracy within ± 0.5mm (21). Pagavino et al. did an in vivo study with SEM and found the Root ZX to be 83% (± 0.5 mm) and 100% (± 1.0 mm) accurate (22). Gordan and Chandler averaged multiple studies claiming the Root ZX has an overall average accuracy of 90% within ± 0.5mm (14).

Today there are numerous EALs on the market that use the same underlying principles of measuring the ratio of multiple frequencies to determine the canal length. It's important to assess the accuracy of these new devices against the Root ZX. Piasecky et al evaluated the accuracy of the Root ZX Mini, CanalPro (Coltene- Endo, Cuyahoga Falls, OH), and Apex ID (SybronEndo, Glen- dora, CA) in vitro utilizing a CBCT(23). According to the manufacturer the CanalPro measures the mean square root values for 2 different, alternating frequencies(23). The Apex ID also uses the same impedance principles as the Root ZX but operates at frequencies of 0.5 and 5.0 kHz instead of 0.4 and 8 kHz(23). These subtle differences in the operating mechanism can impact the accuracy of the EAL in different conditions. Piasecky et al found that the Root ZX Mini was 81% accurate within ± 0.5mm for locating the AC(23). The CanalPro was 72.4% accurate within ± 0.5mm for locating the AC(23). Finally, the Apex ID was 81% accurate within ± 0.5mm for locating the AC(23). However, when looking at the precision of measuring the AF both the Root ZX and CanalPro outperformed the Apex ID(23). In conclusion the Root ZX Mini and CanalPro were precise for both root canal length and working length determination whereas the Apex ID was accurate for the working length when using the 0.5 mark (23).

In 2018 Connert et al studied the accuracy of 9 different EALs. Extracted teeth were scanned with micro-CT preoperatively to localize the apical constriction, and the length measurements of 91 root canals were made using the EALs in question. They found there was no significant difference in the accuracy of determining the AC and AF between the nine EALs within a tolerance of ±0.5 mm and 1 mm(24). In a recent study published in the Journal of Endodontics, Serna-Pena et al evaluated the accuracy of the Root ZX Mini, Apex ID, and the Propex Pixi (Dentsply Maillefer, Ballaigues, Switzerland)(25). They found there was no significant difference in the accuracy between all three EALs. The accuracy of the Root ZX Mini, Apex ID, and Propex Pixi was 83%,83%, and 80% (± 0.5mm) respectively (25).

Given the high accuracy of the Root ZX EAL and many of today's EALs it has been established that they accurately and precisely locate the AC, but they are not without limitations (14,15,18,21-25). Lack of patency, obstructions, metal restorations, lateral canals, and unique canal anatomy can lead to inaccurate readings or sometimes no reading at all (14,15,17,22,23,26). Ebrahim et al conducted a study that looked at the effects of file size, blood, and NaOCL on the accuracy of the Root ZX. They found that as the diameter of the root canal increased the measured length became shorter with smaller file sizes. In the presence of blood a file size in close approximation to the size of the canal should also be used as it will affect the accuracy, while NaOCL did not affect the accuracy of the Root ZX (27). In the presence of other fluids such as 2% lidocaine with 1:100,000 epinephrine, 5.25% sodium hypochlorite, RC Prep, liquid EDTA, 3% hydrogen peroxide, and Peridex, the accuracy of the Root ZX is not affected (28). The question of whether necrotic tissue affected the accuracy of EALs was answered by Dunlap et al. They concluded there was no statistical difference in measuring the AC in vital versus non-vital cases with the Root ZX (29). The previously mentioned article by Piasecki et al looked at possible anatomical variations that could affect the accuracy of the Root ZX Mini, CanalPro, and Apex ID in molars. They found that when a lateral foramen was present it negatively affected the accuracy of the Apex ID (68.8% accuracy)(23).

To this point the accuracy and limitations of EALs have been discussed. It is also important to address the consistency of EALs. ElAyouti and Lost wanted to know the consistency of accuracy and the repeatably of measuring the length of canals. In this study they determined the working length in 507 patients using Root ZX and Raypex5 EAL. An estimated working length was measured from the diagnostic radiograph and the electronic working length was taken. A working length radiograph was then taken to see where the file was in relation to the radiographic apex. When the file tip was 0-2mm from the radiographic apex it was considered "acceptable". When the file tip was beyond the radiographic apex it was considered "Long". When the file tip was more than 2mm short of the radiographic apex it was considered "short". This was measured to allocate extreme measurements related to the dysfunction of apex locators (e.g. over instrumentation). They defined a "consistent" reading when the scale bars on the apex locator were stable and moved in relation to file movement in the tooth. An "inconsistent" reading was when the scale bars intermittently flashed, rapid movement from one position to another, and when no bars displayed at all. They found that both EAls in question functioned properly 85% of the time. The number one factor for inconsistent readings were obliterated canals from retreatment cases, calcifications, and other filling materials. When this factor was removed consistency jumped to 96%. They also found that metallic restorations and the vitality of the teeth did not affect the consistency as long as the files were not in contact with the metal restoration and the canals were dry so that fluids did not act as a conductor (30).

Experience reading and interpreting radiographs, knowledge of apical anatomy, and understanding the limitations of electronic apex locators will provide predictable results. With today's advances in micro processing technology and software advances, it has become more difficult to gain understanding of how modern electronic apex locators operate. Despite this, when comparing different EALs the most important finding is how accurately they measure the AC. It has been shown that instrumentation and obturation to the AC will have favorable outcomes. At this point in time there are only a few peer reviewed articles assessing the accuracy of one of the latest EALs, the Coltene CanalPro. The goal of the present study is to assess the accuracy of the CanalPro compared to the gold standard Root ZX.

Methods

Extracted single rooted maxillary and mandibular pre-molars were included in this in vitro study (n=43). Periapical radiographs of the teeth were taken to ensure the canal was visible, no lateral canals, and that there were no resorptions that could alter the readings of the EALs. The teeth were examined under a Global microscope at 5x magnification. Teeth with open apices, root caries, perforations, and fractures were excluded. After the teeth were screened, the coronal segments were sectioned at the CEJ using a diamond disc to have a reliable and repeatable reference point to rest the rubber stoppers. Once the crowns have been cut off and access to the canals have been made a 10 file was inserted to verify patency.

The gold standard in measuring the actual length of the canal is direct visualization of the file passing through the AF under magnification (23). All teeth were measured in this manner by manually inserting a size 10 hand file until the tip was visualized exiting the apical foramen. The rubber stopper was placed flush against the flattened surface where the crown was sectioned. Locking cotton pliers were then placed on the file against the rubber stopper to keep it in the exact location. The file was gently removed from the tooth and measured under magnification using a Mitutoyo Digimatic Caliper (Misumi Corporation Tokyo, Japan) to 100^{th} of a mm. There were some teeth where the canals were calcified to a point in which a size 10 hand file would not pass through the AF. In these more calcified teeth, a smaller size 6 hand file was used with sodium hypochlorite as lubrication to achieve patency followed by a size 8 hand file. The canals were enlarged enough until a size 10 hand file could achieve patency and direct measurements recorded.

After the actual length of the tooth was measured the tooth was then mounted in a Castillo Endo Training Model (Roydent Dental products Johnson City, TN). The well where the tooth was placed was filled with saline, according to the manufacturer's instructions, and held in place with a plastic screw to ensure the tooth would not move. In this well there is a metal post that is in contact with the saline and where the end of the lip clip of the EAL is directly placed. The saline simulates the conductivity of the oral soft tissues and provides the resistance to which the EALs take the measurements from. Even if the conductivity of the of the saline is not the same as the oral soft tissues of a live patient the EAL is measuring the electrical resistance at the metal post in the saline, and this is the reference it uses to gauge where the file tip is. Once the file tip electric resistance equals the resistance at the metal post then the EAL will show that the file tip is out of the apex. A size 10 hand file was than inserted into the canal and clipped to the EAL. If a size 10 hand file fit loosely a size 15 hand file was used to achieve a tight fit at the apex of the tooth. This ensures a reliable reading by the EAL and that errors are minimized by movement (31). Measurements were read at the 0.5 mm mark on the EAL unit. Values were deemed reliable if the bars on the EAL moved in correspondence to file movement and were solid for 5 seconds (31). The rubber stopper was put in place and the file was removed from the tooth using locking cotton pliers. The length of the file was then measured using a Mitutoyo Digimatic Caliper under the microscope to the 100^{th} of a mm. After the measurement was recorded for one EAL, the file was reinstated in the canal without the locking plier and the rubber stopper reset against the handle. The lip clip of the other EAL was then attached to the metal post and the same methods as before were used to take the measurement. All measurements were taken by a single operator that is trained in using the EALs. The measurements were tabulated and subjected to statistical analysis.

Figure 2: Castilli Endo Training Model

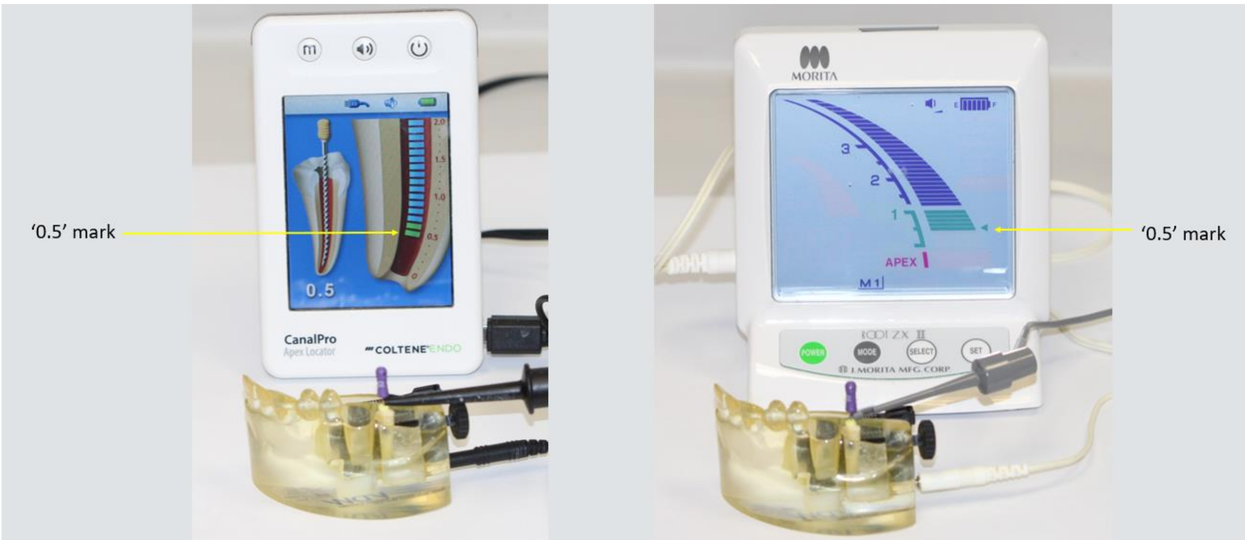

Figure 3: Taking working length measurements using both EALS

Two one-sided t-tests were used to test for equivalence between the Root ZX and the CanalPro and the actual length as measured by the Mitutoyo Digimatic Caliper. The equivalence bounds were preset at +/- 0.5mm. The discrepancies with the actual length were compared between the two apex locators using paired t-test. Significance level was set at 0.05. SAS EG 8.2.4 (SAS Institute, Cary, NC) was used for all analyses.

Results

For the Root ZX, 74% of the teeth were within 0.5mm of the actual length (32/43). For the CanalPro, 65% were within 0.5mm (28/43). The average difference between the CanalPro and the actual length was 0.51mm (SD=1.33) and ranged from +0.70mm to -8.50mm. For the Root ZX, the average difference was 0.38mm (SD=0.83) and ranged from +0.81 to -4.68mm. Neither the CanalPro nor the Root ZX were deemed equivalent based on the preset equivalence bounds of +/- 0.5mm. The equivalence bounds for the CanalPro were (0.17, 0.85) and (0.17, 0.60) for the Root ZX. The equivalence bounds are the range within which the two measures are equivalent. As noted by the range of the lengths, there was one tooth that was measured by both apex locators much shorter than the actual (tooth noted 'CC') when this tooth was removed from the analysis, both were deemed equivalent within the 0.5mm level. These instances are denoted in red on the Bland Altman plots in Figures 1 and 2. After removing this sample, the equivalence bounds for the CanalPro were (0.20, 0.44) and (0.16, 0.41) for the Root ZX.

The discrepancies between the actual length and the CanalPro and Root ZX were not significantly different (p-value=0.2272). The CanalPro had an average error 0.12mm higher than the Root ZX (95% CI: -0.08-0.33). After removing tooth 'CC' the average difference was 0.036 (95% CI: 0.7-0.14).

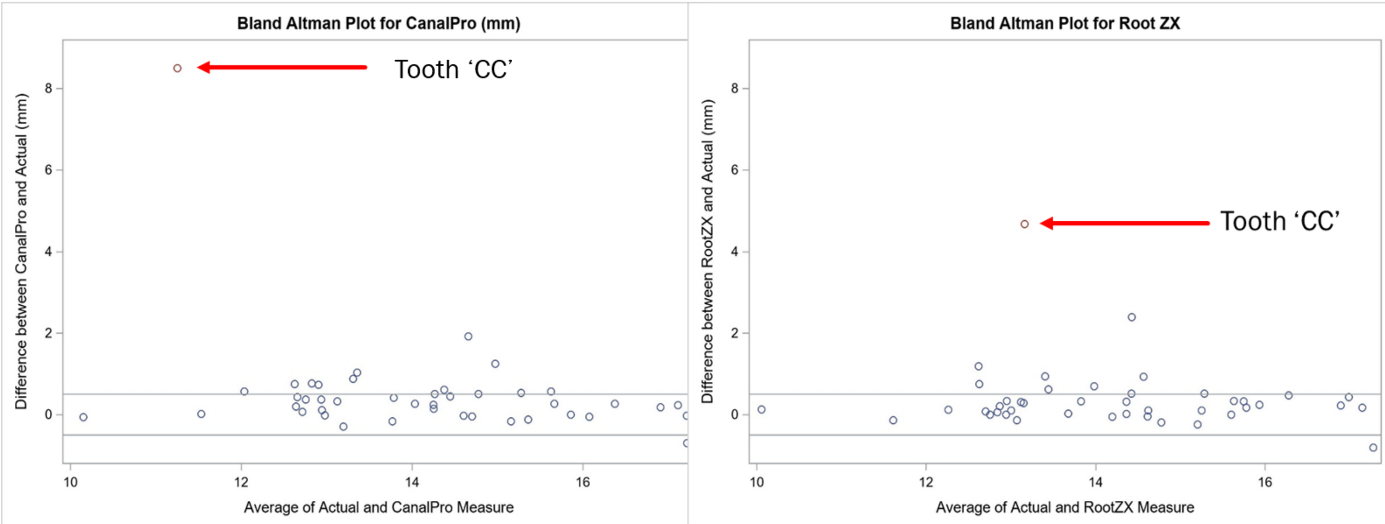

Figure 4: Bland Altman Plot for CanalPro and Root ZX. Note: Tooth 'CC' anomaly

Discussion

The accuracy of the RootZX versus the accuracy of the CanalPro were 75% and 65% respectively. On average the difference between the actual length and the measurement from the CanalPro was 0.51 mm. The Root ZX averaged 0.38 mm from the AF. It has been shown the apical limit of instrumentation and obturation should be the apical constriction(8). According to Kuttler the average distance of the apical constriction is 0.52mm (younger pts) and 0.66mm (older pts) inside the canal from major foramen (4). Piasecki found the average distance of the AC-AF to be 0.46 mm using micro CT (23). Comparing the average measurements of both the RootZX and the CanalPro this would be clinically acceptable given the average distance of the AC to the AF found in these studies. There was one anomaly (tooth labeled ‘CC’), if included, deemed both apex locators non-equivalent to the actual measurement. However, if this tooth was not included in the analysis the CanalPro and the Root ZX would both be considered equivalent within the bounds of +/-0.5mm. The CanalPro measured the canal in tooth ‘CC’ to be 8.50 mm shorter than the actual length of the canal. The RootZX measured tooth ‘CC’ to be 4.68 mm short of the actual length. This tooth was not originally excluded from the study because there were no apparent fractures or restorations that would have altered the readings of the EAL. This tooth was measured several times and ultimately included because on occasion teeth in live patients can measure this way. The reasons for this could be lateral or accessory canals that communicate with the PDL higher up the canal giving a false reading. These are the cases that need to be verified by radiographs to estimate proper working lengths. Eliminating tooth 'CC' from analysis decreases the higher error average of the CanalPro from 0.12mm to 0.036 mm compared to the RootZX.

Compared to other similar studies that looked at the Root ZX, Shabahang et al found the Root ZX to be 96% accurate (21). Shabahang et al was an in vivo/ex vivo study that measured the working length on the Root ZX at the '0.5' mark, the same as this study. Shabahang had 25/26 teeth that were within +/- 0.5 mm of the actual length measured with direct vision under a microscope. The one tooth that didn't measure to within 0.5mm was 3mm short of the AC, much like tooth 'CC', and there was no apparent explanation for this according to the examiners in the Shabahang study. They had 8/26 teeth that measured at the AC, 9/26 teeth that measured between the AC and the AF, and 8/26 teeth that measured beyond the AF. In the present study the Root ZX measured 8/43 teeth that overextended passed the AF. It is worthy to note that only 1 tooth measured more than 0.5 mm past the AF. The CanalPro had 8/43 teeth measure long, and only one of these teeth measured more than 0.5 mm past the AF (See Table 1.). Studies show that if cleaning, shaping, and obturation are short of the AF, at the AC, that healing rates are higher (3). This would suggest teeth that measured passed the AF would have a lower chance of healing. When considering the rest of the teeth that measured short with the Root ZX, only 10/43 teeth were more than 0.5 mm from the AC. One of those teeth was tooth 'CC' and the other one measured just 2.39 mm from the AC. The CanalPro had 14/43 teeth that measured more than 0.5 mm short of the AC and all but one was less than 2 mm short of the AC (See Table 1.). Perhaps the bounds should be set from 0-2mm short of the AF as this would fall in line with Schaefer et al's meta-analysis and other studies that promote higher success rates for healing. The bounds of +/- 0.5 mm is considered clinically acceptable and measurements that fall in this range are labeled precise by many studies (21–24,29). However, considering a measurement that is up to 0.5 mm passed the AF as precise needs to be further evaluated given the lower chances of success.

Table 1: Teeth measuring short and long of AF compared to Shabahang's findings.

	>0.5mm longer than AF	Overextended Passed AF	>0.5mm Short of AF
CanalPro	1	8	14
Root ZX	1	5	10
Shabahang$_{RootZX}$	0	8	1

Changing the reference point by which measurements are taken from an EAL can affect the overall working length. Pagavino et al found that the Root ZX was 82.75% accurate with bounds set at +/- 0.5mm. According to this study the error with the Root ZX was always overextension of the file tip (22) (See Table 2.). The main difference with this study was that they measured the Root ZX at the 'Apex' reading which is also the 0-mark depending on what EAL is being used. This may be the reason for the overextension of the file tip as they were taking the reading of the Root ZX at a longer length. Only one tooth measured the AF exactly. They suggested if measuring from the 'Apex' that subtracting 1 mm from this length would place the tip of the file at the AC or short of it. The findings of Pagavino et al suggest the Root ZX is more accurate than the current study. It is possible that if the 'Apex' or 0-mark was used on the EALs in this study that some of the overextended measurements would exceed the bounds of +/- 0.5 mm and decrease the accuracy.

Table 2: Teeth measuring short and long compared to Pagavino's findings.

	> 0.5mm longer than AF	Overextended Passed AF	> 0.5 mm Short of AF
CanalPro	1	8	14
Root ZX	1	5	10
Pagavino$_{RootZX}$	5	24	0

In a more recent study by Piasecki, they evaluated that accuracy of the Root ZX, CanalPro, and Apex ID. They utilized the gold standard for measuring the actual length of the canal by direct visualization under magnification using a size 10 hand file. A micro-CT scan of each tooth was used to identify the AC. This is the most accurate method to study the AC location and size (23). They took two measurements from the EALs, the 'Apex' and the '0.5' marks to measure the AF and the AC respectively. The measurements from the EALs were compared against the measurements of the AC from the micro-ct and direct measurements. They found that each device was precise in finding the AF and AC over 70% of the time when the parameters were +/- 0.5 mm. Their findings agree with the results of this study. They concluded that using the '0.5' mark is acceptable for locating the apical limit for the root canal procedure.

Conclusion

According to this study, both the Root ZX and the CanalPro are clinically acceptable for determining the apical limit for root canal therapy when using the ‘0.5’ mark, however it is advised that a MAF or MAC radiograph to confirm that instrumentation and obturation are within the confines of the canal. If using the ‘Apex’ mark on the EAL, then 1 mm should be subtracted from this length to ensure the limit of cleaning, shaping, and obturation are within the confines of the AC.

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Tooth	Actual Length mm	Root ZX Length mm	CanalPro Length mm
A	15.08	15.32	15.24
B	14.17	14.22	13.9
C	14.67	14.57	14.22
D	15.03	14.1	14.52
E	15.62	13.23	13.7
F	15.8	15.46	15.53
G	12.87	12.81	12.44
H	13.69	13.66	13.85
I	13.29	13.01	12.96
J	15.6	15.6	14.35
K	12.94	12.94	12.57
L	14.33	13.63	14.18
M	13.87	12.93	12.84
N	13.27	12.96	12.54
O	14.37	14.35	14.13
P	13.21	12.02	12.44
Q	13.05	12.95	13.34
R	12.75	12.75	12.68
S	13.75	13.13	12.87
T	12.74	12.66	12.54
U	12.32	12.2	11.75
V	14.68	14.87	14.72
W	13	12.25	12.25
X	16.87	17.68	17.57
Y	14.68	14.16	14.07
Z	17.2	16.77	17.23
AA	15.91	15.58	15.34
BB	16.05	15.81	16.1
CC	15.5	10.82	7
DD	13.99	13.66	13.58
FF	15.54	15.02	15.01
GG	10.12	9.99	10.18
HH	14.52	14.2	14.01
II	15.86	15.69	15.86
JJ	11.54	11.68	11.52
KK	13.12	12.78	12.75
LL	13	13.14	12.89
MM	14.59	14.63	14.62
NN	16.51	16.04	16.24
OO	17.23	17.06	17
PP	12.97	12.76	12.99
QQ	15.3	15.2	15.42
RR	17	16.78	16.82