ISSN: 2755-6468

Research Article

Open Access Journal of Clinical Pathology Research

The New 3rd Generation of Apex Locators

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Received: December 29, 2025; **Accepted:** January 05, 2026; **Published:** January 12, 2026

ABSTRACT

A much-discussed topic, which perhaps will always be disputed, is where to end the preparation – and thus, the obturation – of the root canal; in other words, what point to choose to determine the instrument's working length.

The correct determination of the working length (WL) is crucial for the success of the root canal treatment. WL is the distance from a coronal reference point to the point at which canal preparation and filling should terminate [1]. Thus, WL defines the deepest point within the root canal that the instruments may reach during the canal cleaning and shaping procedures, debris removing and sealing. A shorter WL may not provide a complete cleaning, leading to post-treatment inflammation and disease recurrence. On the other hand, if a longer WL is used to perform the root canal treatment the apical periodontal tissues can be damaged [2].

Several methods have been described to determine the working length in endodontic therapy: tactile, radiographic, electronic and the consistent drying point.

Tactile Method

In a recently published article, Ricucci and Langeland actually state that seeing that the anatomical location of the apical constriction cannot be clinically determined with accuracy and that it has been recorded as far as 3.8 mm from the anatomical apex, then one should mainly rely on tactile sensation to determine its location and not on the use of apex locators [3]. The Author of the present article agrees with the last sentence, since the apex locators, as it will be described soon, are not designed to locate the apical constriction, but rather the "end of the canal", which means the apical foramen. On the other hand, the Author is completely in disagreement with the concept of relying on tactile sensitivity, because this can be extremely misleading. Hani Ounsi et al [4]. In their study conclude that the tactile determination is highly inaccurate.

The tactile "constriction" encountered by the instruments can infact be due to a calcification or a narrowing of the canal space which can be close to or far from the real endodontic terminus (Figure 1), therefore the tactile sensation used to determine the working length can definitely be considered unreliable [4]. On the other hand, it is well known that at the origin of all endodontic failures there is a short preparation and therefore a short obturation [5]. Therefore, the arbitrary rule that canal preparation should terminate 1 or more millimeters short, is unacceptable in modern endodontic therapy because it increases the likelihood of failure! [6-7].

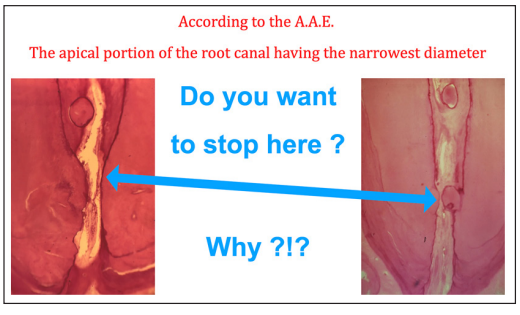

Figure 1: The "narrowest diameter" of the root canal could have nothing to do with the "narrowest diameter" described by Yuri Kuttler in 1955 and correspondent to the cemento-dentinal junction

Citation: Arnaldo Castellucci. The New 3rd Generation of Apex Locators. Open Access J Clin Path Res. 2026. 2(1): 1-10.
DOI: doi.org/10.61440/OAJCPR.2026.v2.31

Figure 2 illustrates the major landmarks of the tooth root-terminal, which are of interest when determining the WL, i.e., the anatomic apex/radiographic apex (A-A/R-A), the apical foramen (A-F) and the apical constriction (A-C) [8]. The AC is also known as minor foramen. Dummer et al [9]. studied 270 human teeth and observed that the mean distance between the tooth apex and the AF is 0.38 mm, within a range of 0 to 1.93 mm, and the mean distance between the tooth apex and the AC is 0.89 mm, within a range of 0.07 to 2.69 mm. Some authors suggest that the best conditions to periodontal tissues regeneration are obtained when the root canal is shaped, cleaned and sealed till the apical constriction, but the AC position cannot be accurately located by both the electronic and radiographic techniques [3,10-15].

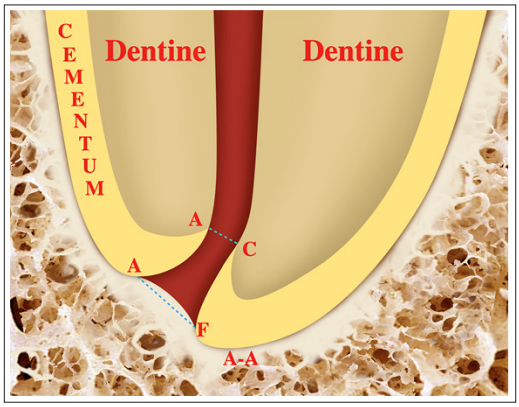

Figure 2: Schematic representation of the root apex, according to Kuttler [8]. A-A. Anatomic Apex, geometric apex or vertex of the root and Radiographic Apex on the radiograph. A-F. Apical Foramen. A-C. Dentocemental junction, also called "minor foramen" or "Apical Constriction". (adapted from Kuttler)

Radiographic Method

Traditionally, the WL could be obtained using radiographic images. However, this technique has some deficiencies and may induce to wrong WL determination, mainly when treating molars and premolars [11-13]. The main disadvantages of this technique are: 1) superimposition of tissue images in the radiographic image, for example, the zygomatic process of the maxillary bone and the root apex, does not allow an accurate identification of the apical limit of the root canal; 2) the radiography provides to the operator an estimative of the WL, since it is based on mean distances among the cementum-dentine-canal junction, apical foramen (AF) and root apex; 3) X Ray gives a two dimensional image from a three dimensional object; 4) it exposes the patient to ionizing radiation; 5) it requires more time than the electronic method to be executed; 6) stimulating the gag reflex; and 7) it is difficulty to be used in disabled patients. These limitations frequently induce to wrong WL determination, particularly when the foramen is located on the palatal or lingual aspect of the root (Figures 3, 4).

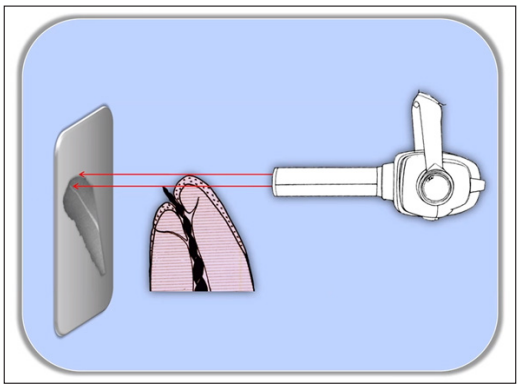

Figure 3: When the foramen is on the lingual or palatal aspect of the root surface it will be erroneous to establish the working length based of the radiographic examination (Courtesy of Dr. C. R. Spironelli)

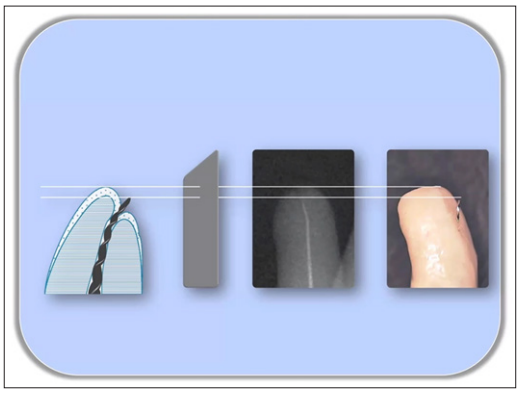

Figure 4: The instrument is at the "radiographic apex" but actually it is several millimeters through the foramen (Courtesy of Dr. C. R. Spironelli)

Electronic Method

Currently the use of the electronic apex locator represents a very valid and reliable method of measuring the working length for our instruments which, take the electronic apex as their reference point.

Several clinical studies demonstrated that modern electronic devices, also known as electronic apex locators or electronic foramen locators (EFL), present a high success rate, being capable to locate the apical foramen (AF) within an accuracy of ± 0.5 mm in up to 96.2% of cases [16-20]. EFLs may also be combined with radiographs in order to increase the reliability of the WL determination [21].

Even though these commercial electronic devices indicate the distance between the endodontic file tip and the AF, the only reliable read out is when the endodontic file tip is located at the AF. The length of the endodontic file within the canal is equal to the root canal length (RL), when its tip is positioned at the AF.

First Generation of Apex Locators

These instruments were based on the principle that the electrical resistance between one electrode in the root canal and another applied to the oral mucosa registered consistent values. This was demonstrated in studies by Suzuki in 1942, but had already been suggested by Custer in 1918 [22,23].

Sunada was the first to take advantage of this principle to measure the length of root canals. He established an electric circuit between the oral mucosa and the periodontal ligament, and with the help of an ohmmeter found that the resistance of this circuit was consistent [24]. He concluded that when an endodontic instrument was inserted in the canal and the ohmmeter registered 40 mA, the instrument tip was exactly in contact with the periodontal ligament at the apical foramen of the root canal.

Through the years, a variety of electronic apparatuses have been placed on the market with the aim of measuring the root canals by applying the findings of Suzuki and Sunada.

Cash has reported favorable results with the use of the Endometer [25]. Inoue has obtained identical results with the Sono-explorer [26]. Before isolating the tooth with the rubber dam, both these instruments must be calibrated by inserting the file connected at the insertion into the gingivalal sulcus of the patient's tooth.

The principle on which these instruments were based dictates that the tissue resistance of the periodontal membrane that surrounds the tooth is constant and is therefore the same at the gingival sulcus and at the apical foramen.

More recently, new devices such as the Neosono D (Figure 5) and Analytic Technology's Apex Finder (Figure 6) have been introduced. Because they did not require individual calibration in the gingival sulcus of each patient (differently from the previous two), they were easier and faster to use. A digital scale was used in these instruments to inform the user that the foramen has been reached.

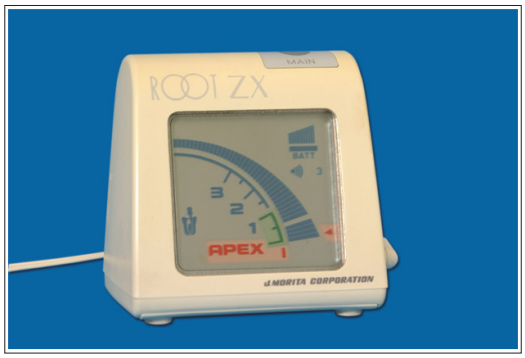

Figure 5: Neosono-D electronic apex locator (Amadent)

Figure 6: Apex-Finder electronic apex locator (Analytic Technology)

All the instruments mentioned above belong to the old generation of electronic apex locators and their use had several disadvantages.

For the correct use of these old generation apex locators, the canal had to be free of pulp tissue, exudate, pus, blood, electrolytes, and sodium hypochlorite; in other words, any substance that could act as a conductor [27].

If these rules are not observed, false readings will occur, just as there are inaccurate responses if the file comes into contact with another metal, including gold, amalgam, or the metal of a silver cone or another instrument present in another canal of the same tooth.

From all of this we can understand that in the past these instruments were not successful since, to be able to use them it was absolutely necessary to have a dry and empty canal, when perhaps it wasn't yet ready to receive a # 10 file!

Second Generation of Apex Locators

The applications and possible uses of electronic apex locators have evolved significantly in recent years as new, completely revolutionary instruments have become available to the dental profession. Their use is not influenced by the contraindications and disadvantages that were true limitations to the use of the instruments previously discussed.

The first new instruments available have been the Apit/Endex (Figure 7) and Root ZX (Figure 8) locators, which were respectively produced by the Japanese manufacturers Osada Electronics and J. Morita Co. They have overcome almost totally all the disadvantages previously discussed. Recently others have appeared on the market and nowadays there is a truly wide range of the second generation of locators available.

Figure 7: The Root ZX apex locator (J. Morita)

Figure 8: The Endex/Apit apex locator (Osada)

These instruments make use of a different principle and are not at all affected by the contents of the root canal, whether blood, vital or necrotic pulp, pus, RC Prep, or (most of all) sodium hypochlorite [28,17,29]. In other words, the instruments can perform accurately even in moist conditions and in the presence of mineral salts; moreover, they may be used with small size files immersed in sodium hypochlorite and in contact with organic fluids. It is thus possible to obtain an accurate measurement of the working length from the first probing of the root canal [30].

The instruments yield inaccurate responses only if the shaft of the file used for the measurement comes into contact with the metal of a coronal restoration or if there is a previous obturation within the canal that impedes contact of the endodontic file with the surrounding dentin. The reading is inaccurate also if the file used is of a too small size compared to the size of the apical foramen or if the conductive liquid is in contact with the metallic restoration: in the first situation an accurate reading can be obtained using an endodontic instrument of a proper size (the readings are more accurate the more the size of the instrument is close to the size of the foramen), while in the second case the length of the root canal can be accurately measured by simply removing the electrolyte from the access cavity with a suction tip and, if necessary, from the root canal with a paper point (Table. 1).

Table 1: Causes of Incorrect Measurement by the Apex Locator

1	Incorrect use of the rubber dam: the dam does not completely isolate and there is salivary contamination
2	Presence of hypochlorite in pulp chamber (especially in multirooted teeth)
3	Contact between the instrument and a metallic restoration [28]
4	Contact between the hypochlorite of the chamber and a metallic restoration
5	Instrument diameter too thin compared to the diameter of the apical foramen (the digital scale oscillates frenetically between the zero value and beyond the apex value) [24]
6	The canal still contains traces of the old canal obturation
7	The file has entered into a lateral canal
8	The file has entered into a perforation

The physical principle on which their function is based differs from that of the above instruments, inasmuch as they do not give the impedance measurement value for the periodontium and the measuring needle, but rather the difference in the impedance responses for two different frequencies (1 kHz and 5 kHz) in the Apit/Endex ("the relative values of frequency response method"), and the ratio in the impedance for two different frequencies (400 Hz and 8 kHz) in the Root ZX ("the ratio method") at differing points in the root canal [28,24,31].

The so called "ratio method" was introduced by Kobayashi and Suda [32]. It computes the ratio of the measured impedance at two frequencies. This quotient is then correlated with the endodontic file tip distance from the AF. This method is implemented in the commercial Root ZX (J. Morita Co., USA) EFL, and is considered as one of the most reliable techniques for locating the AF [15-20].

This ratio gives a very precise value, that represents the position of the electrode inside the canal independently of the type of electrolyte contained in it [33]. This value diminishes as the file nears the foramen, until it becomes zero upon reaching it. This principle therefore not being influenced by the canal contents, reduces to a minimum the error caused by the conditions of the canal itself and of the measuring instrument.

A recent study has shown that the instrument is 96.5% accurate with a clinically acceptable default margin of error that is less than 0.5 mm [34].

Because the Apit/Endex cannot be accurately calibrated when the inside of the root canal is dry, it is unable to make an accurate measurement of a dry root canal [29,35,36].

The Root ZX is Based on a Slightly Different Method (the "ratio method") and the Measurement is Even Easier to Make, Since:

- The instrument needs no calibration and no reset
- It is accurate even in dry canals
- The root canal cleaning and shaping can easily be performed while the length of the root canal is simultaneously monitored
- It works on replaceable long-lasting batteries and therefore does not have to be continuously recharged [32,37]. Once the device has been activated, the clip is applied to the patient's lip, and the other is connected to the instrument introduced within the root canal.

An acoustic signal, as well as the digital scale at the zero value while the "Apex" sign is flashing, inform the dentist that the apical foramen has been reached (Figure 7). After about ten minutes, the instrument automatically turns itself off.

Recent studies have shown that the Root ZX gives readings that are 100% accurate with a clinically acceptable margin of error ±0,5mm: the average distance of the file tip from the apical foramen was 0,2 mm. The same authors, have also emphasized the fact that the Root ZX can be used with confidence to localize the apical foramen, not the apical constriction, referred to by other authors, and thus it is obvious if we take into account the physical principle of which it is based and on the role the instrument has in diagnosing the site of the radicular perforation [27,38,39]. Therefore, contrary to what its manufacturers say, the Root ZX must not be utilized to determine the site of the point that is 0,5 mm from the foramen, but to locate the actual foramen, that is reached when the digital scale is on the "Apex" sign and when the wording flashes [40]. Only then, if desired, one can measure 0.5 mm from the foramen on the scale.

Recently, an in vivo study has been published, showing an electronic device that generates a constant electric current composed by summing six sine waves of different frequencies and calculates the impedance ratio among these frequencies, and the results confirmed the ability of "ratio method" to accurately locate the AF [41]. From the results it is also possible to understand the reason that this method is only suitable to locate the AF and for sure

is not capable to locate the “apical constriction”, as other authors have insisted and erroneously maintained for years [42,43].

The 3rd Generation of Apex Locators. The Ai Pex. (Figure 9)
The third-generation apex locators are also based on the “ratio” method and its work is based on two fundamental principles of the electronic signal: "impedance" and "capacitance [44]."

Figure 9: The Ai Pex electronic apex locator of 3rd generation by Woodpecker

Let us first discuss impedance using the example of a central incisor. The thickness of dentin in the root canal is the same until the most apical 4 mm when it decreases. Dentin is an excellent thermal and electrical insulator, so when a file is inserted into the root canal and sparks an electronic signal, the signal will try to pass through the dentin and reach the periodontal ligament and bone. However, where the dentin is thick, only half or less of the signal (50% of those "ohms") will likely pass through. An apex locator can detect the electronic signal that the dentin impedes from passing through. In the most apical millimeters, the thickness of the dentin will also impede the passage of some electronic signals. Still, some of it will go back to the lip clip and the device, informing the dentist about the related distance from the end of the root canal.

As the instrument penetrates deeper into the root canal, the thickness of the dentin reduces. This allows more electronic signals to pass through and reach the device, which informs the dentist that the instrument is closer to the end of the root canal. Thus, the deeper the instrument goes, the lower the impedance will be. At the final part of any dentin wall, the foramen equator, the thickness of dentin and impedance will be almost "zero" because there is little insolation. This is why the "00" point is the most accurate measurement point, as it is the most apical part of the root canal.

On the other hand, when the instrument is introduced inside the root canal, the electronic signal will go into the metal and stop at the very end. It will not be available in the whole metal. Still, it will accumulate and increase at the tip of the instrument, becoming a reservoir of electronic signal or a genuine capacitor until, being complete, there will be several sparks, one after the other, one to five thousand sparks per second, which is the frequency component of the equation. The most critical part of the endodontic instrument is its tip, which must be in contact with the dentin. This explains why sometimes the signal is not stable on the device's reading because the instrument is too thin and is losing contact with the dentin wall. If the instrument's body touches the dentin, no signal will arrive at the device until the tip touches the dentin wall because the tip will only give the “spark” of the electronic signal, trying to pass through the dentin. The tip of the file will start to receive a lot of electrons more and more (input signal), until the accumulated electrons will cause a “spark” and will try to pass dentin and they will do it. When they arrive to the periodontal ligament and bone, and mucosa and gengiva, then the electrons will be received again very fast by the lip clip and will go back to the machine (output signal). But there will be a difference between the number of electrons arrived to the tip of the file and the amount received by the lip clip, because the dentin is an insulator and some of them will be lost into the thickness of dentin (Figure 10). The more the tip of the file will progresss apically, the less electrons will be lost because the thickness of dentin is decreasing (less impedance) and we know that we are getting closer and closer to the end of the root canal. It doesn’t mean that we are .5 or 1 or 1.5 mm from the foramen, but that we are closer and closer. In other words, the closer the file is to the foramen, the thinner is the dentin layer, the more precise and accurate will be the reading.

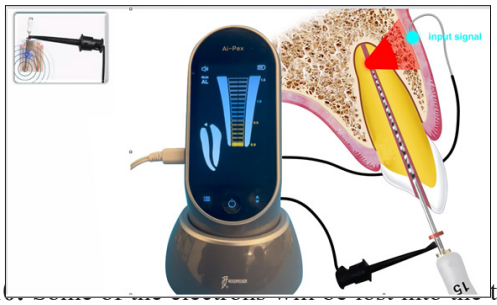

Figure 10: Some of the electrons will be lost into the thickness of dentin which is an insulator

When the file will be very close to the foramen, the output signal and the input signal will be “almost” the same but not exactly the same yet, because there is still some impedance on the bone, gengiva etc. (Figure 11).

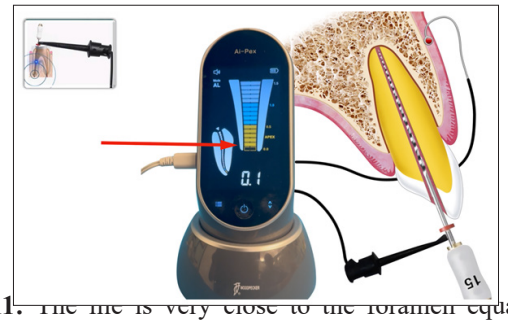

Figure11: The file is very close to the foramen equator, the output signal and the input signal are “almost” the same, but not yet the same

Very accurate the reading will be when the file is at the foramen equator and we move from the position of having dentin to not having dentin anymore, which will corresponid to a big drop of impedance: this is where the apex locator is more precise and

accurate and the reading is 0.0 (Figure 12).

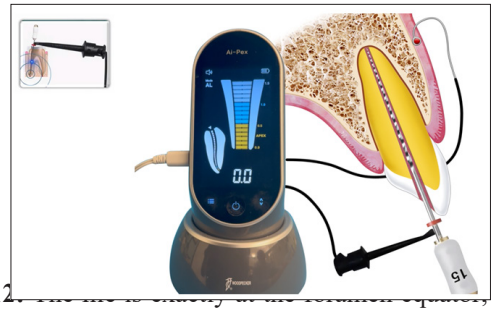

Figure12: The file is exactly at the foramen equator, there is a big drop if impedance and the reading is very precise: 0.0

Outside of the foramen, it doesn't matter if .5 or 10 mm, the impedance will drop in any of the cases and the reading will be always the same: out! After saying all this, it is obvious that the apex locator "cannot" localize the "constriction" as well as there is nothing to do with the contact with the periodontal ligament. In case of inflammatory apical resorption, for example, there is no periodontal ligament but we still have a drop of impedance.

In conclusion, the tip of the instrument has to touch two-thirds of the dentin wall, and there must be some irrigation inside the root canal because this will facilitate the passage of the electronic signal. From a clinical point of view, it is imperative to perform some coronal pre-flaring in the cervical and middle thirds to ensure that the instrument's body is free and only the tip touches the dentinal walls. One crucial aspect to remember is to turn on the apex locator and insert the file into the canal first, based on the pre-operative measurement, which may be approximately four millimeters short. Then, attach the lip clip to the patient and the file clip to the file, and gradually negotiate the canal deeper. This sequence is vital as the apex locator is programmed to start working when the thickness of dentin is less and less in the last four or five millimeters. By following this procedure diligently, you ensure accurate readings and effective use of the apex locator.

Another common mistake is introducing the file into the canal, connecting the lip clip to the patient, and "then" turning on the apex locator. Every time the apex locator is turned on, it disregards the impedance of the entire cable, but if the patient is connected to the cable, the apex locator disregards everything, including the patient.

The other component of the apex locators is the "capacitance." While the impedance can be defined as the opposition to the passage of the electronic signal, the capacitance is the opposite. It can be defined as the ability of a conductive body to accumulate and flow the electronic signals. Let's assume the file is a few millimeters from the end of the root canal. The equipment will be able to calculate the impedance value, but at the same time, it will be able to calculate the value of the capacitance as well, which will be low because the file has to travel through the canal to the foramen. When the file arrives at the foramen equator, it will not have any more dentin around, and the impedance will be "zero", while the capacitance will be the maximum. When this happens, the reading of the apex locator corresponds to "00". This is the ideal situation represented by a root canal, which becomes narrower and narrower to the end, the foramen equator. In the case of root resorption due to a chronic apical lesion, for example, the limit between the real end of the root canal and the foramen equator is very limited, and the reading can vary just by moving the file a fraction of a millimeter inside the root canal. In such a situation, it is advisable to take the working length at the "00" reading and subtract 0.5 – 1.00 millimeters to ensure the obturation inside the root canal walls and avoid any overfilling (Figure 13).

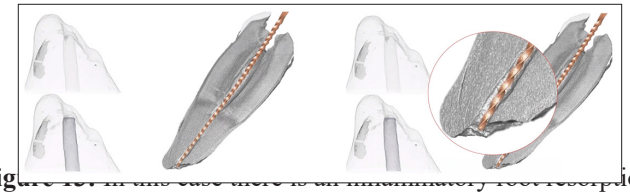

Figure 13: In this case there is an inflammatory root resorption, therefore the file on one side is inside the canal and may be in 0.01 mm off, the file is not touching the dentin at all. The presence of dentin is extremely important for any electronic measurement, which are based on impedance of dentin. In such a case it will be impossible to have an accurate reading, and the working length will be confirmed soon after the shaping, just using the paper points and looking for the "consistent drying point"

The last thing not to forget is that the reading must be very stable and in order to be stable, it is important that the size of the file which is used to determine the working length should be as close as possible to the size of the foramen. For this reason, especially in case of large foramen like in a central incisor of a young patient, the first stable reading can be obtained and confirmed not with a .10 or .15 K File, but rather with a .30, .35 or .40 K File.

In conclusion as has already been emphasized, even if today one cannot imagine an endodontic practice that doesn't use one of the apex locators, and if determining the working length without the use of a locator has been compared to piloting an airplane without a radar, nevertheless, not even these latest generation of electronic apical locators can be considered radiographic substitute since radiographs provide the operator with other information that the electronic measuring equipment is unable to provide: canal width, degree and direction of curve, position of the foramen, dentine thickness, relationship between canals which might be in the same root [45,46]. Furthermore, these instruments are able not only to inform the operator about the location of the foramen, but they can also reveal the opening of any other foramen, such as that of a lateral canal (Figure 14) or that of a perforation (Figure 15).

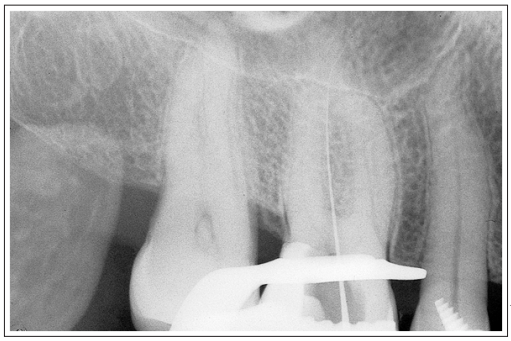

Figure that the

instrument is at the foramen and the X-ray shows that the foramen belongs to a lateral canal

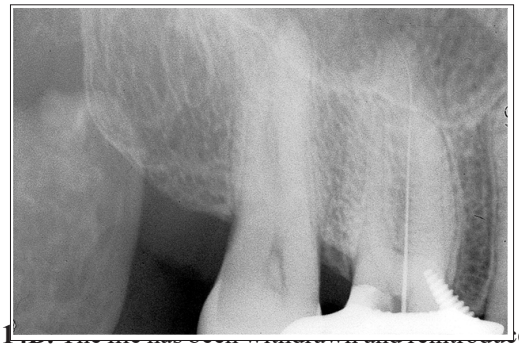

Figure 1 ed more apically, having the precurvature directed in a distal direction: the electronic apex locator indicates that a new foramen has been reached and the X-ray shows the file at the apical foramen

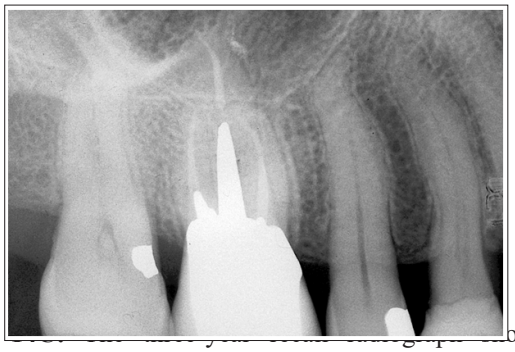

Figure ows the obturation of both, the main and the lateral canal

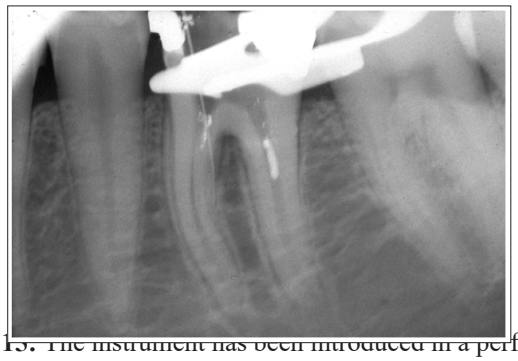

Figure 15: The instrument has been introduced in a perforation; therefore, its tip is not surrounded by dentin and there will be big drop of impedance, it doesn't matter how many millimeters the instrument is long, the reading will be the same: out!

If once the radiograph has been taken, a variance occurs between the radiographic image which shows a "short" file with respect to the radiographic terminus of the canal and the apex locator which has just indicated that we have reached the foramen, then one must consider the locator reading as valid since evidently the foramen is in an area (buccal or lingual/palatal) not radiographically identifiable (Figure 16). Our therapy will therefore be based on a measurement carried out by an electronic apex locator (it will be at the Electronic Apex and not just 0.5 mm from the radiographic apex!) and we will know from the beginning that in the post operative radiograph the canal obturation will appear "short", but it will instead be accurate, at the apical foramen [47]. Not taking the radiograph as some do, believing blindly in an electronic instrument, our "short" obturation will be a post operative surprise and we will never know whether or not we are truly short.

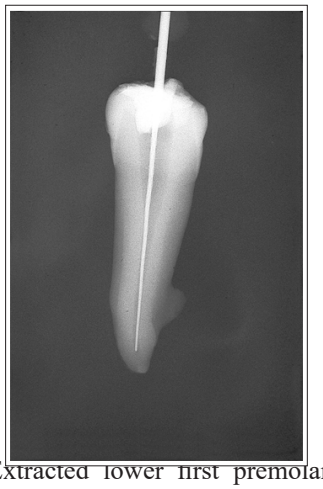

Figure 16A: Extracted lower first premolar having the file positioned exactly at the foramen under the stereo microscope at 64 magnifications. On the radiograph the instrument seems to be very short

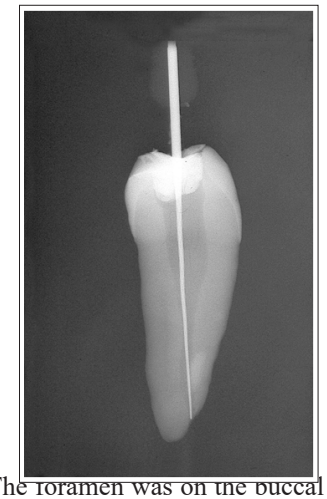

Figure 16B: The foramen was on the buccal aspect of the root, impossible to be detected by the radiograph, but only by the apex locator

Figure 16C: If the operator relys on the radiograph positioning the instrument at the radiographic apex, this is the number of millimeters through the foramen

Figure 16D: The same in a mesio-distal view. If the operator measures the working length 0.5 mm from the radiographic apex, in such a case he/she will be 2.5 mm instead of 3 mm long, and this doesn't make any difference. The only way to avoid this problem is to irrigate, shape and obturate at the "electronic apex"

Consistent Drying Point

The concept behind paper points being used to provide accurate length information comes from the idea that when the contents of the root canal system are removed the canal should be dry. The extraradicular (or more accurately extracanalar) environment is living and hydrated. There is the PDL, granulation tissue, pus, blood, bone, or some other hydrated tissue containing fluid that exists beyond the apical foramen [48].

If a paper point is placed into a dried canal and removed short of the apical foramen, it should be retrieved dry. If a paper point is placed into a dried canal and taken past the foramen it will be retrieved with fluid (blood, pus, serous fluid, or mucus) on that portion of the point that extended through the apical foramen. Because of capillary action the wet portion will be extended some distance further along the point than the portion that was directly in contact with the fluid. The length of paper point affected by this capillary action is dependent on the viscosity of the fluid present beyond the canal and the absorbency of the paper point. We don't need to know this information in order to get accurate length information from paper points.

The technique for paper point measurement can be simple. Into a dried, patent canal, place a paper point. A trial paper point is placed 1/2 mm short of the electronic working length. If the point comes out dry advance it until it picks up some fluid. Note the length of the point that is dry. Now, another point is taken just short of this length, removed and observed. For this exemple assume that the point comes out dry (Figure 17). Re-introduce and advance the point until the very tip of the point has the slightest bit of fluid on it (Figure 18). The point should not remain in contact long enough for any capillary action to have taken place. Record the maximum length that the point can be placed into the canal and remain dry as the length of the canal. This is the correct working length of the canal.

Figure 17: The paper point has been introduced in the shaped portion of the root canal and it is completely dry

Figure lvance until its tip has the slightest bit of fluid on it. The maximum length that the point can be placed into the canal remaining completely dry correspond to the correct working length of the canal

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