The New Era of Foramenal Location

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Predictable endodontic success demands accurate determination of, and strict adherence to the preparation length of the root canal space in order to create a small wound site and good healing conditions.[1] Each portal of exit (POE) on the root face has biologic significance; this includes the furcal canals of bifurcations and trifurcations, lateral and accessory arborizations and the myriad of apical termini (Figs. 1A-D).

The ability to distinguish between the inner-most (physiologic/histologic foramen) and outer-most (anatomic foramen) diameters of the apical terminus is essential to the creation of the Apical Control Zone.[2] The Apical Control Zone is a mechanical alteration of the apical terminus of the root canal space that addresses the rheology of thermolabile filling materials, offering resistance and matrix style retention form against the condensation pressures of obturation (Figs. 2A-C).

The determination of the instrumentation finishing level is one of the primary factors associated with the resolution of an endodontic infection both clinically and histologically.[3,4] The majority of studies postulate that optimal success rates occur when instrumentation, debridement, disinfection and obturation are contained within the region of apical narrowing (bracketed by the minor apical diameter and apical foramen.[5,6,7] In teeth/roots with apical periodontitis (AP) for example, a millimeter loss in working length can increase the chance of treatment failure by 14 percent.[8]

New modes of debridement and disinfection are constantly arriving in the endodontic armamentarium.

The Toronto Study noted that the highest healing rate differential (15 percent) was observed in teeth with AP that were most likely over-instrumented resulting in transportation of contaminated debris periapically.[9] The evidence is indisputable that electronic root canal length measuring devices provide significantly more accurate results than radiographs[10,11] and therefore offer greater control of the creation of the Apical Control Zone (Fig. 3).

In 1942, Suzuki discovered that the electrical resistance (sin-

FIGURE 1A—Arrows indicate multiple POE's associated with the mesial-buccal and distal-buccal apices of a maxillary first molar.

FIGURES 1B & C—The complexity of the root canal system has been graphically evidenced since the work of Hess in the 1920s. Radical improvement in materials and techniques are now enabling the clinician to replicate that complexity as evidenced in the cleared specimen (1B) and the radiograph (1C). *(Courtesy of Dr. William Watson.)*

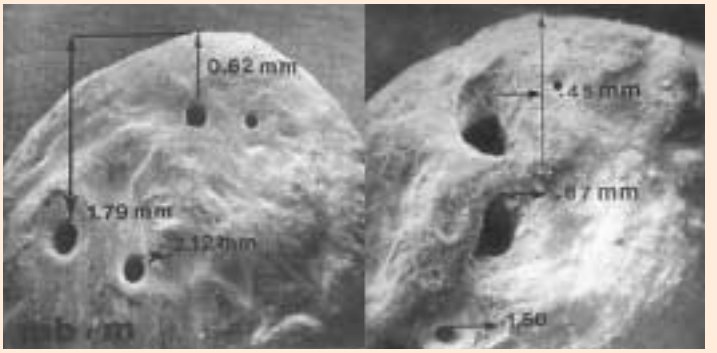

FIGURE 1D—(right) The number, shape and diameter of the physiologic foramena at the root apex mandate the continuing pursuit of excellence in endodontics through increased sophistication in materials and methods and the alliance of scientific innovation and clinical acumen. From Gutierrez and Aguayo, OS, OM, OP June 1995.

gle current source) between an instrument inserted into a root canal and an electrode attached to the oral mucosa registered a consistent value. In 1962, Sunada using a direct current device with a simple circuit, demonstrated that the consistent electrical resistance between the periodontium and the mucous membrane was 6.5 kOhms [DC Resistance]. Through the 1970s, frequency measurements were measured through the feedback of an oscillator loop by calibration at the periodontal pocket of each tooth. This culminated with the efforts of Hasedgawa in 1979 with the use of high frequency waves and a specially coated file which could record in conductive fluids.

In 1983, Ushiyama introduced the voltage gradient method where a concentric bipolar electrode measured the current density evoked in a limited area of the canal. Maximum potential was reached when the electrode was at the apical constriction. The mid '80s saw the development of a relative value of frequency response method where the apical constriction was picked by filtering the difference between two direct potentials after a 1 kHz rectinlinear wave was applied to the canal space.

A Third Generation electronic foramenal locator (EFL) developed in the late '80s by Kobayashi used multi-channel impedance/ratio based technology to simultaneously measure the impedance of two different frequencies, calculate the quotient of the impedance and express it in terms of the position of the electrode (file) in the canal. This formed the basis of the technology used in the ROOT ZX® (J. Morita USA, Inc. Irvine, CA) where no calibration was required and a microprocessor calculated the impedance quotient.

Fourth Generation EFL's (Elements Diagnostic, SybronEndo, Orange, CA) measure resistance and capacitance separately rather than the resultant impedance value (impedance being a function of resistance and capacitance) [Fig. 4A]. There can be different combinations of values of capacitance and resistance that provide the same impedance (and thus the same foramenal reading); this can then be broken down into the primary components and measured separately ensuring better accuracy and less chance for error. In addition, the Elements unit uses a lookup matrix (Fig. 4B) rather than making any internal calculations.

While calculations take place very quickly, they are still relatively much slower than simply

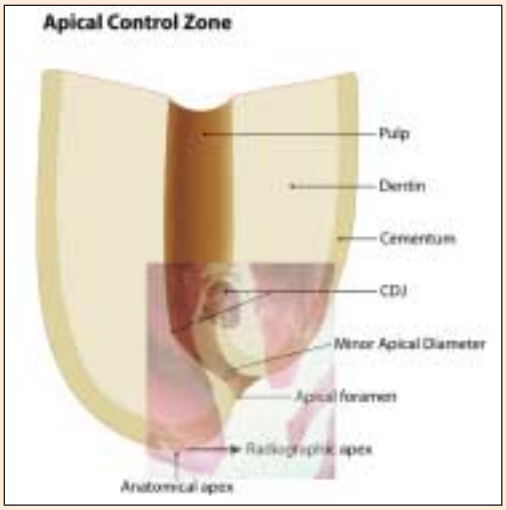

FIGURE 2A—The definitions of the morphologic entities comprising the regional terminus of the apex are shown diagrammatically with superimposition of the histologic anatomy.

FIGURE 2B—Retreatment of tooth #4.6 with K3 nickel-titanium [NiTi] files (G Pack system). The goal is identification of the histologic terminus of the root canal space and the use of variable tapered rotary NiTi instrumentation to create an apical control zone and optimize the seal produced by the new generation of resin thermoplastic root canal filling materials and sealers. *(Courtesy of Dr. Gary Glassman.)*

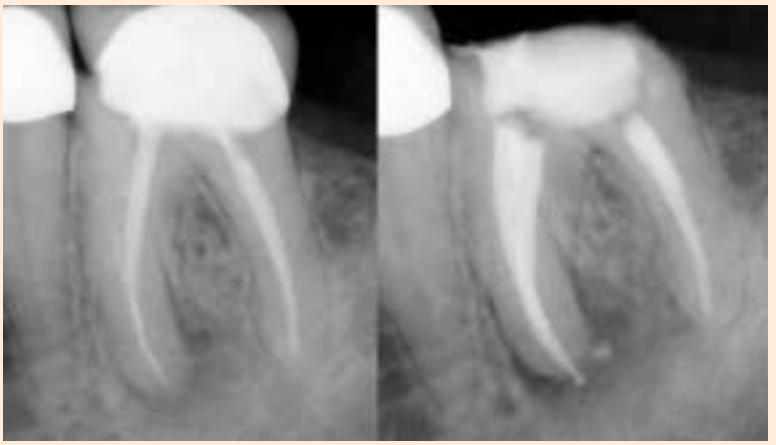

FIGURE 2C—Retreatment of tooth #3.6 with K3 nickel-titanium [NiTi] files Varible Tip Varible Taper (VTVT) system. The K3 file sequence after the two Orifice Openers/Body Shapers is: #35/.06, #30/.04, #25/.06, #20/.04. In the majority of cases, the #25/.06 or the #20/.04 will reach the desired working length on the first pass. If not, the sequence is repeated from the beginning. *(Courtesy of Dr. Fred Barnett.)*

looking up comparative values in a pre-calculated matrix (in the range of 10-20x slower). This allows the unit to "crunch" through much more data in a given amount of time; a larger sample size tends to make the results more accurate. Figure 5 demonstrates the technologic protocol difference between 3rd and 4th generation foramenal locators.

In the course of preparation of this paper, the importance of regulation of battery power was assessed. The Elements Diagnostic circuitry runs at 3.3 volts (common for electronics), which is internally regulated to remain extremely consistent. The battery pack is rated at a nominal 6 volts, 7.5 volts with a full charge and no load.

As the battery pack is depleted, the voltage decreases to a point where the electronics cannot continue to regulate the operating voltage to such a precise value and therefore the signals sent through the electrodes will not be as reliable either. The device is set to automatically shut off when battery voltage is a little above this threshold.

The ROOT ZX runs on AA alkaline or lithium batteries (mixing types is to be avoided) and will shut itself off after twenty minutes. There is a bar graph on the face of the unit which indicates residual battery power. The question of the accuracy of signals sent through the electrode is in doubt if the battery power level drops below the first three or four bars (author's observation) [Fig. 7].

A paper point measurement, foramenal detection technique has been advocated by Rosenberg.[12] It is designed to determine the point positional location of the apical foramen as well as three-dimensional information regarding the slope of the foramen. A trial paper point is placed 1mm short of the EFL determined length. If the point is retrieved dry, it is advanced further until fluid is noted. The length of the segment of the point that is dry is noted.

This sequence is repeated as evidenced in Figs 6A, B & C and the maximum length of the point

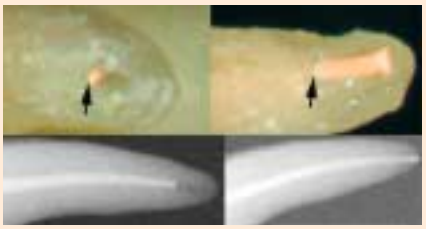

FIGURE 3—The subtraction approximation technique; the average disparity of 0.5 to 1mm between the radiographic apex or terminus (RT) and the cavosurface point of exit of the root canal space used as the standard for length determination is fraught with inaccuracy. *(Courtesy of Dr. William Watson.)*

FIGURE 4A—Fourth Generation foramenal locator (Elements Diagnostic, SybronEndo, Orange CA).

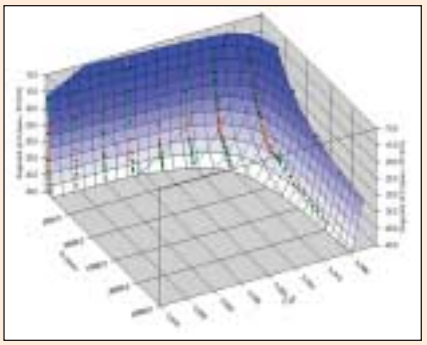

FIGURE 4B—Lookup matrix generated from in-vivo studies (x-axis capacitance, y-axis resistance, vertical z-axis is resultant displayed location in the canal).

FIGURE 5—The graphic shows the technologic difference between the operation of third and fourth generation foramenal locators.

that can be placed into the canal and remain dry reflects the orientation of the cavosurface of the apical foramen (Fig. 6D).

There are several basic conditions that ensure accuracy of usage for all generations of foramenal locators;

1) preliminary debridement should remove most tissue or debris obstructions,

2) cervical leakage must be eliminated and excess fluid removed from the chamber as this may cause inaccurate readings,

3) extremely dry canals may result in low readings [long working length],

4) long canals can produce high readings [short working lengths],

4) lateral canals may give a false foramenal reading, and

5) the use with open apices is contraindicated. The residual fluid in the canal should possess a low conductivity value. In descending order of conductivity these are; sodium hypochlorite (NaOCl 5.25 percent), EDTA (17 percent), Smear Clear (SybronEndo, Orange, CA), saline, FileEze® (Ultradent Products, S. Jordan, UT), and isopropyl alcohol.

It is advisable to use a crown down canal preparation technique[13] and take the preliminary electronic measurement using a file that is approximately big enough to bind at the apical constriction.[14] A second working length measurement is advisable after flaring the coronal and middle thirds as shortening of working length occurs when instrumenting curved canals; this shortening can vary from 0.22mm to 0.5mm. However, once coronal flaring has been done little change in length occurs.[15,16] From a medico-legal

standpoint, a verification radiograph is recommended at this juncture. It is also advisable to do a final confirmation EFL reading after drying the canal and prior to obturation.

In the case of the third generation ROOT ZX (Fig. 7), the working length of the canal used to calculate the length of the filling material is actually somewhat shorter; the length of the canal up to the apical seat (i.e. the end point of the filling material) is found by subtracting 0.5 to 1.0mm from the working length indicated by the 0.5 reading on the meter.

The meter's 0.5 reading indicates that the tip of the file is in the vicinity of the apical foramen (i.e. an average of 0.2 to 0.3mm past the entrance to the apical constriction towards the apex). The disparity between the EFL reading of such units as the Ultima EZ and the ROOT ZX is demonstrated to be the +.0.5/-0.5 position indicated by the 0.5 reading on the meter. This finding has been consistently verified by numerous investigators.[17,18]

A recent investigation of the fourth generation EFL, the Elements Diagnostic (Sybron Endo, Orange, CA) demonstrated an unprecedented level of accuracy in usage. Length calibrations were performed on teeth to be extracted, the files cemented to position and the teeth cleared for microscopic examination.[19] In 22 out of 22 cases where the reading of the file was taken to 0.0 or into the minus numbers and withdrawn to the 0.5 mark on the scale, the file terminus was consistent with the position of the apical constriction (Fig. 8A).

When the file was cemented after going down to the 0.5 mark, in 20 out of 24 cases, the file was positioned a distance of 0.5mm from the external foramen (Fig. 8B). Of note was the finding that when the device displayed a minus number, the file was always beyond the apical constriction and in most cases out of the root structure (Fig. 8C).

FIGURE 6A—The paper point is introduced coronal to the level of the EFL determination. As it is shy of the cavosurface of the canal terminus, it should remain dry. *(Courtesy of Dr. David Rosenberg.)*

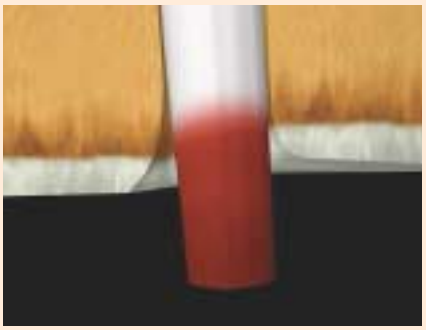

FIGURE 6B—Hydrostatics will cause periapical fluids to accumulate on the overextended paper point. *(Courtesy of Dr. David Rosenberg.)*

FIGURE 6C—The angle of the paper point discolouration reflects the three dimensional orientation of the cavosurface of the apical foramen. *(Courtesy of Dr. David Rosenberg.)*

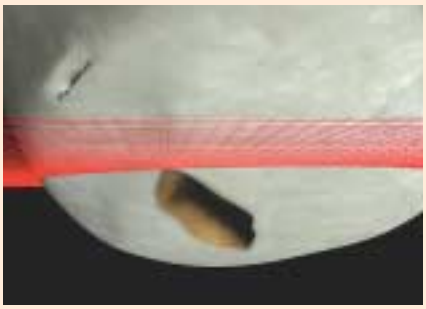

FIGURE 6D—The terminus of the canal is not a point in space; it is a multidimensional, topographically diverse plane. *(Courtesy of Dr. David Rosenberg.)*

FIGURE 7—The Root ZX® is a fully automatic, self-calibrating root canal foramenal locator.

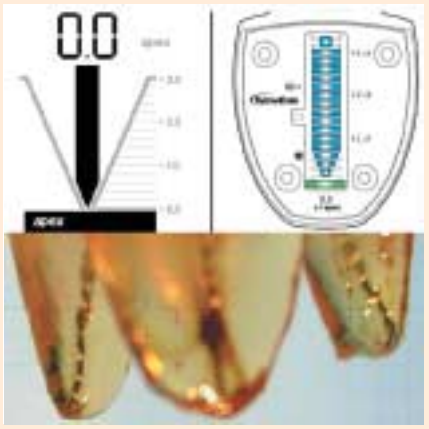

FIGURE 8A—When the file glide path is stopped at 0.5 on the digital display, the unit's accuracy in determining the apical foramen is less than 85 percent.

CONCLUSION

Evolutionary technologic sophistication is the hallmark of all scientific and clinical endeavour. Endodontics is the bedrock of all comprehensive care. As such, it is imperative that predictable endo-

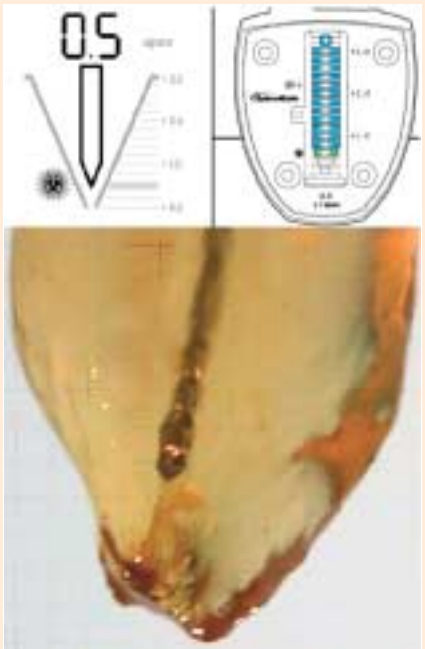

FIGURE 8B—When the file reaches the periodontal ligament, the digital display shows 0.0. When the file is withdrawn 0.5mm, an instrumentation terminus point consistent with the apical constriction resulted 100 percent of the time.

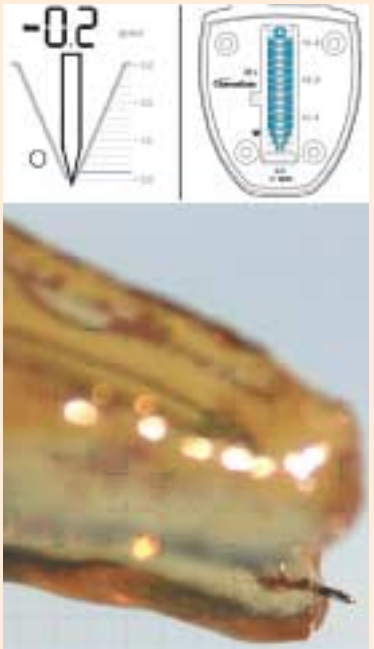

FIGURE 8C—When the file glide path is extended into a negative reading on the display, the file was out of the canal in all cases.

dontic success is projected as close to 100 percent as biologically possible. Outcome assessment studies indicate that formenal position is a pivotal factor if not the pivotal factor in the most favourable end result. New modes of debridement and disinfection are constantly arriving in the endodontic armamentarium. The Fourth Generation of foramenal locators will ensure that their usage in evolutionary endodontic protocols is optimized. **OH**

Drs. Serota, Vera, Barnett, Nahmias, Watson and Glassman are members of the cybercommunity ROOTS – www.rxroots.com.

Oral Health welcomes this original article.

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