In vitro comparison of measurement accuracy in pre-enlarged and enlarged canals with four apex locators

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ABSTRACT

The purposes of this study were to assess the accuracy of measurements in pre-enlarged canals with small instruments and to compare the accuracies, in enlarged canal, with small size instruments and instruments that match the actual canal diameter using Root ZX, Bingo1020, SmarPex, and e-Magic Finder. Ten extracted teeth were embedded in an alginate model made for testing apex locators. A size 10 file was placed into the root canal until the tip of the file reached the plane of the major diameter of the foramen under a dental operating microscope at the 25 × magnification. The measurement was done with digital caliper and defined as actual length. Electronic length measurement with a size 10 file in pre-enlarged canal was done by reading the index indicating Apex of each device to gain a definite value. After completion of canal enlargement to a size 45 file, each difference between actual length and electric measurement value with a size 10 and 40 files in enlarged canal was recorded as L10 and L40. The one-way ANOVA and Scheffe's multiple range tests were computed for analyze the differences among the four apex locators in the same group. The Student's t-test between L10 and L40 of each locator was done. The accuracies of electronic measurements were significantly different among the 4 devices. The file size made no difference on the accuracy of electronic measurement in enlarged canal with same device. The e-Magic Finder was the most accurate device among the 4 apex locators used in this study. 〔J Kor Acad Cons Dent 31(5):371-377, 2006〕

Key words: Electronic Apex Locator, File size, Measurement accuracy, Working length

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Ⅰ. INTRODUCTION

Accurate determination of the length of the root canal is one of the most important preconditions for successful root canal treatment[1]. Establishing the length of the root canal system at the apical constriction is considered an ideal working length for endodontic treatment.

The traditional radiographic method has shortcomings[2], including the use of ionizing radiation, and the potential inaccuracy in root canal due to difference between radiographic apex and actual apex. In addition, technical problems such as film positioning, beam angulation, processing problems[3] have been the catalyst for the develop-

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ment of alternative methods for the determination of root canal length. Numerous devices have appeared on the market since Sunada[4] first introduced electronic measurement of root canal length in 1962.

Unfortunately, many apex locators are inaccurate on root canals that contain moisture, vital pulp tissue, blood and other exudates or remnants of intracanal irrigants[5-7]. Recently, the 'ratio method' for measuring root canal length was introduced[8]. In this method, the quotient of two simultaneously measured impedances of two different frequencies is calculated to reveal the position of an electrode (endodontic file) inside the root canal. The latest generations of apex locators are based on this principle and have many advantages when compared to earlier devices, especially because these instruments are reliable in both dry and wet canals.

Since the development of the most recent generation, electronic apex locators (EALs) have gained in popularity. This generation uses two frequencies and enables tooth length measurements in the presence of electrical conductive media in the root canals[9]. Accuracy of the recent generation of EAL averages around from 83% to 93%[3,5,7,10-12]. An EAL that further improves the accuracy rate is desirable and, if proven to be a reliable tool, could potentially replace, in many instances, the classic radiographic method for tooth length determination.

EALs are frequently used attached to a small size endodontic file, however, the effect of the relative diameters of the file on the measurement of the root canal length has not been clarified. Experimentally, researchers[3,10,13] often used files that appeared to match the canal diameter. But the manufacturer claims that the accuracy of measurement is allegedly not affected by the size of the canal or that of the measuring instrument[14]. It was necessary to clarify whether the accuracy of measurement would be affected by the use of a small size instrument in large canal. Because working length can be changed throughout canal shaping, it is necessary to measure electronic length again before canal filling. In this aspect, it is worth whether the size of measuring file affects accuracy of the EAL.

The purpose of this study was to compare the accuracy of measurements in pre-enlarged canals with small size instruments using four apex locators and to compare the differences between the measurements, in enlarged canal, with small size instruments and instruments that match the actual canal diameter with each apex locators.

Ⅱ. MATERIALS AND METHODS

Teeth selection and preparation

Ten intact, freshly extracted teeth were selected for study. Before the test, teeth were stored in sterile saline and placed into 5.25% sodium hypochlorite solution for 2 hours to remove the periodontal ligament. After rinsing in tap water they were transferred again to sterile saline. In each tooth, a standard endodontic access cavity was prepared and the occlusal portion of the tooth was flattened to secure a consistent reference point.

Determination of actual length

After access was gained, the excessive tissue of the chamber only was removed. A size 10 file (Flexofile; Dentsply Maillefer, Ballaigues, Switzerland) was placed into the root canal until the tip of the file reached the plane of the major diameter of the foramen as defined by Kuttler[15]. Proper positioning was verified using a dental operating microscope (OPMI pico Surgical Microscope; Carl Zeiss, Oberkochen, Germany) at the 25 × magnification setting to view the file tip. The file length was determined by placing the file's rubber stop to the flat horizontal coronal surface of the root when the file tip was placed to the level of the major foramen. Then, cyanoacrylate (Zapit; MDS Products Co., U.S.A.) was applied to file shaft and rubber stop for preventing inaccurate length measurement caused by movement of rubber stop. The measurement was done with digital caliper (Digimatic Caliper; Mitutoyo, Japan).

Table 1. Four apex locators used in this study

Device	Manufacturer
Root ZX	J. Morita Corporation, Tokyo, Japan
Bingo 1020	Forum Engineering Technologies, Rishon Lezion, Israel
SmarPex	META BIOMED co., Ltd., Chungju, Korea
e-Magic Finder	S-denti co., Ltd., Cheonan, Korea

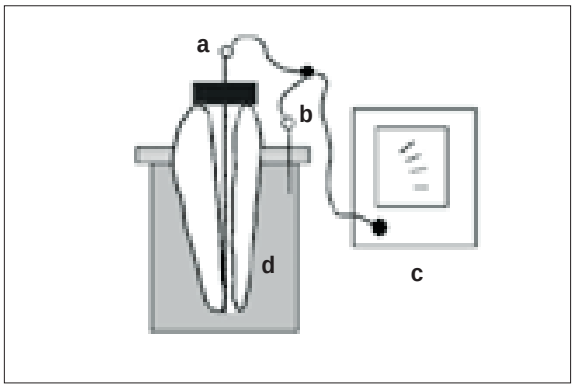

Figure 1. Schematic diagram of alginate model (a: file, b: lip clip, c: apex locator, d: alginate).

Measurement with EAL

Alginate model (Figure 1)

Alginate impression material (Shinprint-F; Shinhung, Seoul, Korea) mixed with physiologic saline was used as substitute for periapical conductive media. Each tooth was mounted in alginate model embedded up to the cervical level so that an electronic apex locator could be used to measure canal length[16-19]. Then the canal length was measured using four devices of Table 1, with the lip-clip electrode embedded in the mold.

Electronic length measurement in pre-enlarged canal

All electronic length measurements were accomplished by reading the index indicating apex of each device. During the measurement, normal saline was used as intracanal conductive fluids. And the difference between actual length and electronic measurement value with a size 10 file in pre-enlarged canal was recorded as S10.

Electronic length measurement in enlarged canal

After completion of enlargement of apical root canal to a size 45 file, root canal lengths were re-measured using each device with #10 and #40 files. The #40 file was selected for easy passing through the apex in the same way as #10 file. Differences between actual length and electronic measurement value with a size 10 file in enlarged canal were recorded as L10 and the differences between actual length and electric measurement value with a size 40 file in enlarged canal was recorded as L40.

Statistical analysis

Statistical analysis of the collected data was performed by SPSS™ version 12.0 (SPSS Inc., Chicago, IL, USA). The one-way ANOVA and Scheffe's multiple range tests were computed for analyze the differences among the four apex locators in the same group. The Student's *t*-test between L10 and L40 of each locator was done. Differences revealed in the data were designated as significant at $p < 0.05$.

Ⅲ. RESULTS

In S10, the accuracy of EALs was revealed in the order of e-Magic Finder, Root ZX, Bingo 1020 and SmarPex (Table 2). There was significant difference between e-Magic Finder and SmarPex ($p < 0.05$). In L10 and L40, the accuracy of EALs was revealed in the order of e-Magic Finder, Bingo 1020, Root ZX and SmarPex (Table 3). The e-Magic Finder and Bingo 1020 were more accurate than SmarPex ($p < 0.05$). No devices had statistically significant differences between L10 and L40.

Table 2. Difference (㎛) between actual length and measured value with EAL in S10 (Mean ± SD)

	Root ZX	Bingo 1020	SmarPex	e-Magic Finder
S10	330 ± 195[ab]	340 ± 212[ab]	530 ± 316[b]	220 ± 178[a]

[a, b]: Groups identified by different alphabets are significantly different ($p < 0.05$). Groups identified by same alphabets are not significantly different ($p > 0.05$).

Table 3. Difference (㎛) between actual length and measured value with EAL in L10 and L40 (Mean ± SD)

	Root ZX	Bingo 1020	SmarPex	e-Magic Finder
L10	550 ± 314[ab]	490 ± 264[a]	990 ± 493[b]	320 ± 204[a]
L40	540 ± 310[ab]	430 ± 195[a]	1133 ± 444[b]	420 ± 175[a]

[a, b]: Groups identified by different alphabets are significantly different in horizontal row ($p < 0.05$). Groups identified by same alphabets are not significantly different in horizontal row ($p > 0.05$).

Ⅳ. DISCUSSION

In 1962, Sunada[4] developed the first apex locator based on the assumption that there is a constant resistance of 6.5 ㏀ at a defined current between the periodontal membrane and oral mucosa. Since this introduction, EALs have gained in popularity, especially since the development of the most recent generation. This generation uses two frequencies and is based on the change in impedance of the probing electrode to tissue fluids. When a file tip is located away from the minor foramen, the impedance in the canal is negligible, but when the file reaches the immediate vicinity of the minor foramen, the magnitude of the impedance of the canal suddenly increases. As the file tip contacts the periapical tissue, such as the periodontal ligament, the impedance value rapidly decreases, indicating that the file is beyond the minor foramen.

The main shortcoming of early apex locators such as erroneous readings with electrolytes was overcome with the introduction of the ratio method and the subsequent development of the self-calibrating Root ZX[8]. The ratio 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 and Suda[8], in 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.

The Root ZX uses two different frequencies (8 kHz and 400 Hz) to simultaneously measure the impedances in the canal. The device then determines a quotient value by dividing the 8 kHz impedance value by the 400 Hz impedance value. The minor foramen is located when the quotient equals 0.67. Different types of fluids in the canal will give different impedance values. By using two frequencies, almost devices currently can be used in all types of fluids because the quotient (0.67) is always the same.

The Root ZX and Bingo 1020 use two separate frequencies 400 Hz and 8 kHz, but e-Magic Finder uses 500 Hz and 5 kHz. The manufacturers of Bingo 1020 claim that the combination of

using only one frequency at a time and basing measurements on the root mean square values of the signals increases the measurement accuracy and the reliability of the device.

Several studies have assessed the accuracy of the Root ZX. An *in vivo* study carried out by Shabahang *et al.*[20] produced values to a precision of 96.2%. Also, Nguyen *et al.*[19] showed that the accuracy of Root ZX was not affected by a wide apical foramen. An *in vitro* study of the Bingo 1020 found it to be as reliable as the Root ZX[17]. Tinaz *et al.*[16] found the Bingo 1020 to be as accurate as the Root ZX in an *in vitro* study and easier for a beginner to use in preflared canals.

There were many studies about Root ZX and Bingo 1020, but were rarely about SmarPex and e-Magic Finder. So, this study was designed and performed.

The instruction manual for the Root ZX states: "the bar indicating the apical constriction of the root canal flashes on and off… which indicates that the tip of the file is in the vicinity of the apical foramen (an average of 0.2 - 0.3 ㎜ past the apical constriction towards the apex)" A study by Weik *et al.*[21] demonstrated that the mean distance beyond the minor diameter was 0.19 ㎜, with - 0.5 ㎜ to + 1.73 ㎜. Thus, we could obtain more definite length by reading electronic length in index indicating apex of each device.

The *in vitro* model[2] for assessing the accuracy of EAL measurement utilized herein proved to be easy to fabricate and remained intact for the duration of the study. The rigid alginate firmly supported the teeth and permitted canal enlargement to be performed with the roots embedded. Thus, the operator remained 'blinded' as to the location of the file tip in the canal and had to rely on the EAL for controlling the apical extent of canal enlargement. In this respect, the alginate model appeared to simulate the clinical situation better than the previously used gelatin models[13,22,23].

In S10, the accuracy of EALs was revealed in the order of e-Magic Finder, Root ZX, Bingo 1020 and SmarPex. There was significant difference between e-Magic Finder and SmarPex. In L10 and L40, the accuracy of EALs was revealed in the order of e-Magic Finder, Bingo 1020, Root ZX and SmarPex. The e-Magic Finder and Bingo 1020 were more accurate than SmarPex. These results might come from the mechanical and electrical characteristics, e.g. microprocessor and internal calibration, of each device.

Nguyen *et al.*[19] reported the length measurement obtained with small and large size files were comparable in the enlarged canals. Similarly, all devices had not statistically significant differences between L10 and L40.

In addition, the ± 0.5 ㎜ to the foramen range has been considered as the strictest acceptable clinical range[24,25]. Thus, measurements attained within this tolerance are considered accurate. By the way, in this study, SmarPex showed fairly lower rates of measurement within ± 0.5 ㎜ of actual length than others.

The results of this study illustrate some variables that must be considered when using root canal length measuring devices. It seems users of apex locator in clinic need to consider the measurement accuracy of each device could be affected by various using condition such as file size, intracanal conductive media. Sometimes, by the measuring conditions, the device's measurements may be exaggerated to exceed the clinically tolerable limit.

Further studies about the accuracy of various apex locators in various using conditions are needed.

Ⅴ. CONCLUSIONS

1. The accuracies of electronic measurements were significantly different among the 4 devices.
2. The file size had no effect on the accuracy of electronic measurement in large canal with same device.
3. The e-Magic Finder is the most accurate of these 4 apex locators, while SmarPex is the worst in all situations.

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국문초록

근관 성형 전후의 네 가지 전자근관장측정기의 측정 정확성의 비교

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이 연구의 목적은 확대하기 전 근관에서 전자근관장 측정 시의 정확성을 평가하고 확대된 근관에서 파일의 크기에 따른 네 가지 전자근관장 측정기의 정확성을 비교하기 위한 것이다. 발치된 치아 10개를 #10파일을 이용하여 치아의 실제길이를 측정하였다. 현미경에서 25배 확대 하에 #10 파일이 치근단공을 넘어 해부학적 치근단공에 이를 때까지 전진하여 디지털 캘리퍼로 측정하였다. Root ZX, Bingo 1020, SmarPex, e-Magic Finder를 알지네이트를 이용한 인체 재현 모델을 이용하여 #10 파일로 apex 표시등에서 측정하였다 (S10). #45까지 핸드 파일로 확대한 다음 #10, #40 파일을 이용하여 전자근관장을 측정하였다. 실제 길이와 각각 측정값의 차이를 계산하여 L10, L40으로 정의하고 기계간의 비교는 one-way ANOVA통계처리하고, Scheffe's multiple range test로 사후 검증하였고, 같은 기계 안의 L10, L40은 Student's t-test로 비교하였다.

본 연구의 실험 조건 하에서, 측정값의 정확도가 기계 간에 차이를 보였고, 파일의 크기는 측정값의 정확도에 영향을 주지 못하며, e-Magic Finder는 이 실험 조건하에서 다른 기계에 비해 가장 정확하였다.

주요어: 전자근관장측정기, 파일 크기, 측정 정확도, 근관작업장