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CONTENTS

Table legends

Figure legends

국 문 초 록

열처리된 니켈-티타늄 파일 파일을 이용한 전자 근관장 측정기의 정확도 비교

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근관 치료의 성공을 위한 핵심 요소 중 하나는 정확한 작업장 결정이다. 방사선 촬영, 촉각 및 전자 근관장 측정기의 사용을 포함하여 작업장을 결정하는 몇 가지 방법이 있으며, 그 중에서도 전자 근관장 측정기는 방사선 측정과 관련된 많은 문제를 없앨 수 있기 때문에 흔히 사용되고 있다.

이 연구의 목적은 열처리된 Ni-Ti 파일을 사용시 전자 근관장 측정기의 정확도에 미치는 영향을 평가하는 것이었다.

치근단이 완성된 30개의 발치된 단근치가 이 연구를 위해 선택되었다. 선택시 흡수, 만곡 치근, 또는 미성숙 치아는 제외되었다. 치아는 근관에 제한 없이 접근할 수 있고 모든 측정에 대해 안정적인 기준을 제공하기 위해 법랑백악경계부까지 치관부가 제거되었다. 각 치아에 1~30번으로 번호를 매기고 측정시의 정확성을 위해 평평한 면의 협측에 선을 표시했다. 실제 근관 길이는 rubber stopper를 제거한 #10 또는 #15 K-파일을 사용하여 치과 수술 현미경으로 주근단공에 도달한 것을 확인한 후 K-파일의 손잡이의 하방부부터 치아 표면에 표시한 선까지의 길이를 디지털 캘리퍼로 측정하여 그 길이를 K-파일의 길이인 25mm에서 빼서 값을 구하였다.

전자 근관장 측정기를 이용하여 작업장을 측정하기 위해 치아를 알지네이트 모델에 넣어 치주조직을 재현하였다. 2개의 전자 근관장 측정기 (DentaPort와 Bingo)를 이용하였으며, ProGlider(PG)와 Hyflex EDM Glide Path

File(HGPF)를 전자 근관장 측정기 상에서 'APEX' 표시가 나타날 때까지 근관 내에 진입시킨 다음 실제 근관 길이를 측정하는 방법과 동일한 방법으로 길이를 측정하였다. 모든 파일은 시술 전 길이가 25mm임을 확인하였다. 수집된 데이터는 p<0.05의 유의한 수준에서 교차 T-검정과 Wilcoxon 부호 순위 검정을 통해 분석하였다.

두 가지 전자 근관장 측정기에서 실제 근관 길이와 전자 근관장 측정기를 이용하여 측정된 길이의 평균 차이값은 PG와 HGPF 사이에 유의미한 차이가 없었다. 두 가지 전자 근관장 측정기를 기준으로 차이값을 비교하면, HGPF에서는 두 전자 근관장 측정기 사이에 유의미한 차이가 없었으나 PG를 이용한 경우에는 DentaPort에서 유의미한 차이가 있었다. (p<0.05)

본 연구의 한계 내에서 니켈-티타늄 파일에 대한 열처리는 전자 근관장 측정기를 통한 작업장 결정에 부정적인 영향을 미치지 않았다.

I. Introduction

For successful root canal treatment, one of the most important step is accurate working length determination (1). Methods like tactile sensation, radiograph, presence of liquid on the paper point, and the morphological knowledge of the dental anatomy have been used to determine the working length. In 1942, a constant electrical resistance of approximately 6.5 kΩ existing between the periodontium and oral mucous membrane in vivo was discovered by Suzuki (2). In 1962, Sunada formulated the principal theory of biological properties, which states that the value of electrical resistance between the periodontal ligament and the oral mucosa can be determined by electronic means and developed first electronic apex locator (3).

In recent years, electronic apex locators (EALs) to determine working length has gained increasing popularity because of their high accuracy rates (4). Both Bingo (Forum Engineering Technologies, Rishon Lezion, Israel) and DentaPort ZX (J. Morita, Tokyo, Japan) are fourth generation electronic apex locators. These devices do not process the impedance information into mathematical algorithms, but instead measure resistance and capacitance and compare them against a database to determine the distance to the root canal apex (5).

Nickel-titanium (Ni-Ti) instruments has superelasticity and shape memory, so they are commonly used for preparation and shaping of root canals (6). Ni-Ti alloy is composed of nickel and titanium. And this alloy has two different phases depending on crystal structure, austenite and martensite. Martensitic alloy is soft and ductile and shows increased cyclic fatigue resistance than austenitic alloy. If the temperature is above austenitic finish (Af) temperature, then the alloy exists in austenitic state. On cooling, if the temperature goes below the martensitic finish temperature (Mf), then the alloy exists in martensitic phase (7). For example, the Af temperature of the Protaper Universal (Dentsply Sirona, Charlotte, USA) is about 15˚C, and exists in austenitic state at room temperature (8).

There are some Ni-Ti files which raised Af temperature by heat treatment, to keep martensitic at room temperature for improving mechanical property. Hyflex EDM (Coltene/Whaledent AG, Altstatten, Switzerland), one of those files, is manufactured through unique manufacturing process called electrical discharge machining (EDM). (9) Af temperature of the file is about 52˚C (7), thus it remains martensitic at room temperature in contrast to conventional Ni-Ti files, making the files extremely flexible and fracture resistant (10).

There are some studies comparing the accuracy of the electronic apex locators when using Ni-Ti files and stainless steel (SS) files (4,11,12,13). Although heat-treated files with improved mechanical properties are widely used, from what we looked up, there was only one study which was reported the accuracy of EALs with heat-treated Ni-Ti files.

The purpose of this in vitro study was to investigate the accuracy of 2 EALs using heat-treated Ni-Ti files. Null hypotheses of this study was there is no difference in root canal length determination between conventional and heat-treated Ni-Ti files by 2 EALs.

II. Materials and methods

The research protocol of this study was approved by the Institutional Review Board of Chosun University Dental Hospital (CUDHIRB-2002-001). Thirty extracted, straight, single-rooted permanent human teeth with mature apices were selected for this study. Teeth with resorption, curved root or open apex were excluded. Teeth were soaked in 3% sodium hypochlorite for 1 hour for removing residual soft tissue. The temperature of irrigation solution was same as room temperature.

Teeth were decoronated at the level of cementoenamel junction to allow straight access to the root canal and to provide stable reference points for all measurements.

Teeth were numbered 1 to 30 and a line was marked on the buccal side of flattened surface for experimental repeatability. The true root canal length (TL) was determined by introducing a size 10 or 15 K-file without rubber stopper into the root canal until its tip reached to the major apical foramen under a dental operating microscope (Global Surgical Corporation, St. Louis, USA). The length between the occlusal surface of the tooth and the bottom of the handle of the file was measured to the nearest 0.01 mm by using a digital caliper (Mitutoyo, Kawasaki, Japan) according to Jung et al (14). The measurements were subtracted from the whole K-file length, 25mm.

For measuring electronically measured length (EL) with EALs, periodontium was simulated by placing teeth in an in vitro alginate model as described by Higa et al (15). During experiment, root canals were irrigated with 3% sodium hypochlorite with a 27 guage needle.

ISO #16 tip sized ProGlider (PG; Dentsply Maillefer, Ballaigues, Switzerland), and ISO #15 tip sized Hyflex EDM Glide Path File (HGPF;

Coltene/Whaledent AG, Altstatten, Switzerland) were attached to the file holder and introduced apically into the root canal until the two EALs (DentaPort and Bingo) displayed 'APEX' reading. The length of the files were measured same as TL. And every file was checked it was 25mm before measuring procedure.

Difference between TL and EL was calculated for each measurement. Collected data were analyzed by paired T-test and Wilcoxon signed rank test at a significant level of $p<0.05$. The statistical analysis was performed with Statistical Package for the Social Sciences (SPSS 23, SPSS, Chicago, USA).

III. Result

The mean difference between TL and EL measurements of each files with two EALs are shown in Table 1. Negative value means that EL is shorter than TL. It means the file tip was over the apical foramen when EAL displayed 'APEX' reading. Mean differences between TL and EL were 0.024mm, 0.025mm for the DentPort with PG and HGPF, and -0.064mm, -0.026mm for the Bingo with PG and HGPF, respectively. In the groups using PG, there was a significant difference between the measured values using DentaPort and Bingo. ($p<0.05$) However, no significant difference was observed in the measured values in the groups using HGPF with 2 EALs. Figure 1 showed difference values between TL and EL of each group.

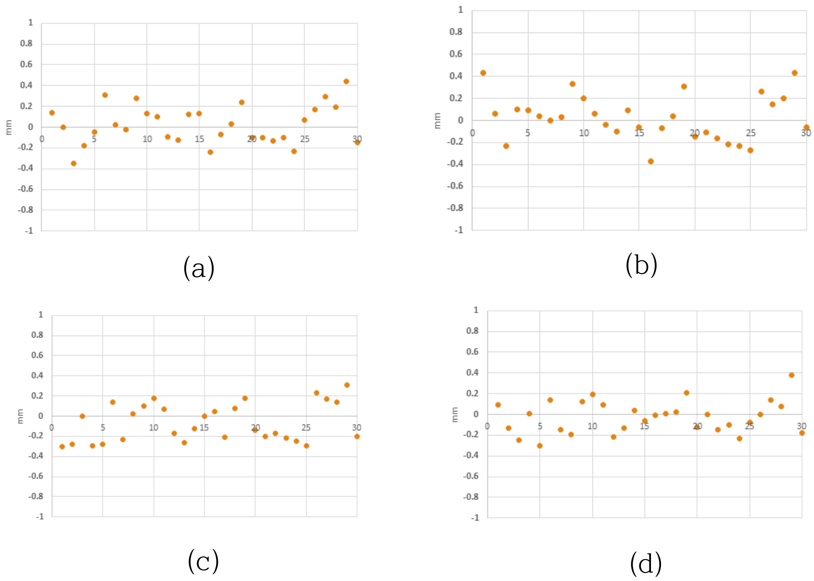
Regardless of files and EALs, all differences between TL and EL were within ±0.5mm. The incidence within ±0.2 of each group was 72% in DentaPort with PG, 63% in DentaPort with HGPF, 53% in Bingo with PG and 80% in Bingo with in HGPF, respectively (Table 2).

There was no significant difference between PG and HGPF for the mean differences between TL and EL in both EALs (Table 1, Figure 2).

Table 1. The mean difference between the true root canal length (TL) and electronically measured length (EL) of each files with 2 EALs

	ProGlider (PG) Mean* ± SD	Hyflex EDM Glide Path File (HGPF) Mean * ± SD
DentaPort	0.024 ± 0.186 Aa	0.025 ± 0.204 Aa
Bingo	-0.065 ± 0.189 Ab	-0.026 ± 0.157 Aa

- In the same raw, the same capital letters indicate an absence of statistical difference.
- In the same column, the same lower letters indicate an absence of statistical difference.
* Negative value means that EL is shorter than TL.



(a) (b)
(c) (d)

Fig. 1 Difference between TL and EL of each group.

* Negative value means that EL is shorter than TL.
(a) DentaPort x PG (b) DentaPort x HGPF
(c) Bingo x PG (d) Bingo x HGPF

Table 2 The incidence (%) of distance between TL and EL of each group within ±0.2 and 0.5mm

Group	-0.5 < X < -0.2mm	± 0.2mm	0.2 < X < 0.5mm
Dentaport x PG	3 (10%)	22 (73%)	5 (17%)
Dentaport x HGPF	5 (17%)	19 (63%)	6 (20%)
Bingo x PG	12 (40%)	16 (53%)	2 (7%)
Bingo x HGPF	4 (13%)	24 (80%)	2 (7%)

* Negative value means that EL is shorter than TL.

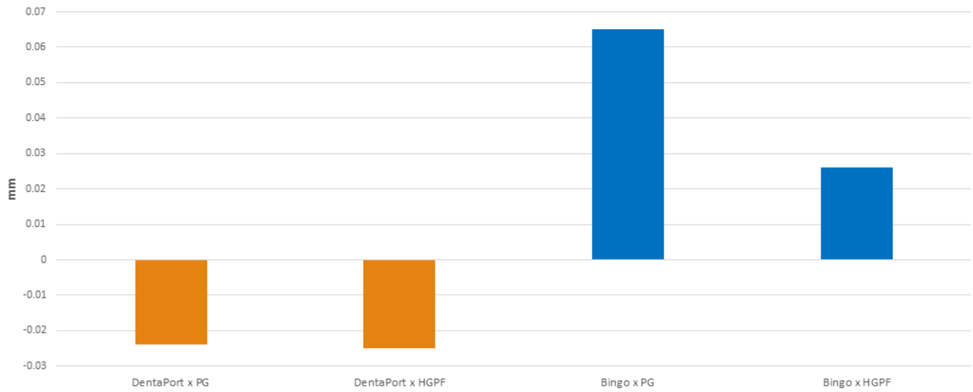


Fig. 2 Mean Difference between TL and EL of each group

* Negative value means that EL is shorter than TL.

Ⅳ. Discussion

The accuracy of the measurements by EALs depends on several factors including the type and size of the instrument and intracanal irrigant. Since the Ni-Ti file was first introduced in endodontic field by Walia (16), it has been widely used because of its superelasticity and flexibility (6). The recently introduced heat-treated Ni-Ti instruments showed improved fracture resistance and the mechanical properties, and used frequently (7). However, there was only one study reported the accuracy of EALs with heat-treated Ni-Ti files, from what we looked up (11).

In present study, to avoid enlarging the apical foramen size, all shaping procedures were done manually without endodontic motor and the two glide path files that had similar sizes were evaluated to compare the effect of file.

Some literature studied the accuracy of EALs depending on irrigation solution, and there was no significant difference (17, 18). In present experiment, NaOCl solution was used because it is one of the most frequently used irrigant in root canal treatment (19).

In vitro Models for measuring accuracy of EALs were made by variable materials such as agar (20), gelatin (21), sugar-free Jell-O (22), and the alginate (15). Among them, alginate was used in this study because of suitable electrical conductivity and firm consistency (12).

One study evaluated where Root ZX's 'APEX' and '0.5' mark actually indicated, and reported both marks are reliable (14). However another literature suggested that EALs should be used to achieve a ''zero'' reading for the greatest accuracy because the impedance characteristics given for the canal coronal to the apical foramen cannot be calibrated accurately (23). Therefore, in this study, the 'APEX' mark was chosen as working length determination point.

Some studies compared accuracy of EALs between using SS files and Ni-Ti files (4, 12, 13). One study evaluated accuracy of '0.5' mark of 4 EALs using SS and Ni-Ti hand files. The accuracy of Root ZX with SS file in this study was 93.3%, but it was 70% with Ni-Ti file and there was significant difference ($p<0.05$). And there was significant difference in accuracy of SybronEndo Mini Apex locator (MINI, SybronEndo, Sybron Dental, Glendora, CA, USA) between using SS file and Ni-Ti file, but there was no significant difference in accuracy of Elements diagnostic unit and apex locator (ELE, SybronEndo, Sybron Dental) and Propex pixi (PIXI, Dentsply Maillefer, Ballaigues, Switzerland) between using SS file and Ni-Ti file (12).

Another study reported that using SS and Ni-Ti files on the accuracy in the 'Apex' mark of Root ZX had a significant difference. But the difference was approximately 0.11mm. Thus it concluded that it was clinically insignificant and both files could be used interchangeably (13).

Another study evaluated the accuracy of '0.5' mark of the Raypex 5 (VDW, Munich, Germany) using SS file and Ni-Ti rotary file and there was no significant difference regardless of type of files (4).

When the results of these studies are put together, the accuracy of EAL with Ni-Ti file was varied depending on the type of EALs (4, 12, 13).

According to Faulkner et al (24), different electrical resistivity existed between austenite and martensite in Ni-Ti alloy. It means values measured by EALs using heat-treated Ni-Ti file could be different from that of conventional Ni-Ti file at root temperature.

Although many literature have evaluated accuracy of EALs according to the file type, there was only one study about the influence of heat treatment of Ni-Ti files on the accuracy of EAL. this study examined the influence of reciprocating Ni-Ti instruments on the accuracy of apex locator integrated endomotors. They compared accuracy of 'Apex' mark at EAL using WaveOne Gold (Dentsply, Charlotte, USA) and WaveOne (Dentsply, Charlotte, USA), and no significant difference was found between them (11).

This study compared the accuracy of EAL with conventional Ni-Ti file (PG) and heat-treated Ni-Ti file (HGPF). There was no significant difference between PG and HGPF for the mean differences between TL and EL in both EALs and all values were within ± 0.5mm. Thus, heat-treated Ni-Ti file can be used with EALs in clinically and the null hypotheses was accepted.

There was a significant difference in measurement between DentaPort and Bingo using PG in present study. The difference could be depending on the frequency and mechanism of each EAL using. DentaPort uses a composite wave form of two signals, 0.5 and 4 kHz. However, Bingo uses two separate frequencies, 400 Hz and 8 KHz and the calculations of the position of the file tip in Bingo are based on measurements of root mean square (RMS) values of the signals (5, 25).

The results obtained from this in vitro study should be applied carefully to clinical situation because there is little inconsistency in EAL measurements even in fully controlled in vitro conditions. This experiment measured the length of the root canal with the Ni-Ti file manually, as being possible to accurately measure the length of the root canal and found there was no significant difference between PG and HGPF group. However, a lot of clinicians use Ni-Ti files being connected to the endomotor and the working length is measured at the same time. Thus, in order to avoid over-instrumentation, it should be used with caution, for example, using auto reverse mode and so on. One of the methods to increase wear-resistance and cutting efficiency of Ni-Ti file is surface treatment (26). And surface treatment of Ni-Ti file might have effect in electrical conductivity. Although most heat-treated Ni-ti files get surface processed, but there is no study about effect of it. Further studies should focus on these.

V. Conclusion

Within the limitation of this study, all values are within ± 0.5mm regardless of the kind of Ni-Ti files or EALs. Heat treatment on Ni-Ti file showed no adverse effect on working length determination with EALs. Thus, heat-treated Ni-Ti files could be used for determining working length using EALs.

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