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Electronic Detection of Root Canal Constrictions

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The aim of this study was to investigate the possibility of detecting root canal constrictions by using an apex locator. Seventy impenetrable canals in extracted human teeth were used. Based on contact microradiographic findings, they were divided into three groups: group A (constricted within 3 mm of the radiographic apex, 23 canals), group B (nonconstricted within 3 mm of the radiographic apex, 28 canals), and group C (constricted more than 3-mm short of the radiographic apex, 19 canals). Electrical impedances at two different frequencies (8 kHz and 0.4 kHz), as well as the meter values of the Root ZX were recorded at the position where a file tip could reach. The impedance ratios (Z_{8kHz}:$Z_{0.4kHz}$) and the meter values of the Root ZX showed a statistically significant difference between groups A and B. It was suggested that the Root ZX might be useful for detecting root canal constrictions.

One of the problems frequently encountered during root canal instrumentation is an inability to reach the apical foramen. The reason for this may be constriction of the root canal due to deposition of hard tissue (1) or severe curvature of the root canal (2). Regardless of whether operators can recognize the reason for inaccessibility, they must take proper measures for negotiation. If the canal is not constricted but is severely curved near the apical foramen, which prevents negotiation, operators may try to negotiate the canal with a precurved file. If the canal is totally constricted near the apical foramen, however, forcible instrumentation may result in transportation of the canal or an apical perforation.

Apex locators of the third generation, which can analyze several impedance values at different frequencies simultaneously, are currently used in endodontics. The impedance of the root canal can be affected by a variety of canal conditions (3). The impedance of the root canal with an artificially closed apical foramen is reported to be different from that with an open one (4). Lack of patency and accumulation of debris in canals have been reported as impediments to electrical measurements of working length (5–7).

The purpose of this study was to investigate whether constriction of the root canal could be recognized by using an apex locator.

MATERIALS AND METHODS

Seven hundred seventy-one intact human extracted teeth, excluding third molars and immature teeth, were examined to obtain the sample used in this experiment. The crowns of all teeth were removed at the CEJ with a diamond disc. Reasons for extraction and the ages of the patients when they were extracted were unknown.

Under a stereoscopic microscope (SMZ-10, Nikon, Tokyo, Japan), the dentin covering the root canal orifice was removed by using an ultrasonic tip (Tip A, Piezon Master 400, EMS, Nyon, Switzerland). At first, a #1 Series 29 ProFile (Dentsply, Tulsa Dental, Tulsa, OK) was pushed apically without rotation. When the file met resistance, it was manipulated with the watch-winding motion (8). When necessary, the coronal third of the canal was flared with a Gates Glidden drill (#1 to #4, Mani, Tochigi, Japan). Then, the canal was negotiated again with the watch-winding motion. If patency of the canal could still not be obtained, the canal was negotiated further with a precurved file (9). When the canal caused not be penetrated after all these procedures, the canal was defined as impenetrable. There were 70 impenetrable canals out of 1416 canals in 771 teeth.

Each root with an impenetrable canal was fixed on the lid of a polystyrene specimen bottle (20 ml, Iuchi, Osaka, Japan) by using self-curing resin (Fig. 1). A stainless-steel rod, screwed into the body of the specimen bottle, was used as a neutral electrode. The canals were filled with 6% NaOCl. The electrical impedance

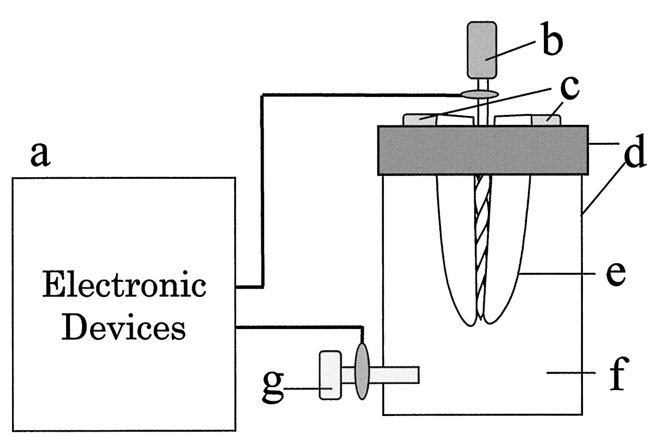

FIG 1. Experimental setup. (a) Electronic devices: impedance analyzer or Root ZX. (b) #1 Profile. (c) Self-curing resin. (d) Specimen bottle. (e) Tooth. (f) Saline. (g) Stainless-steel screw.

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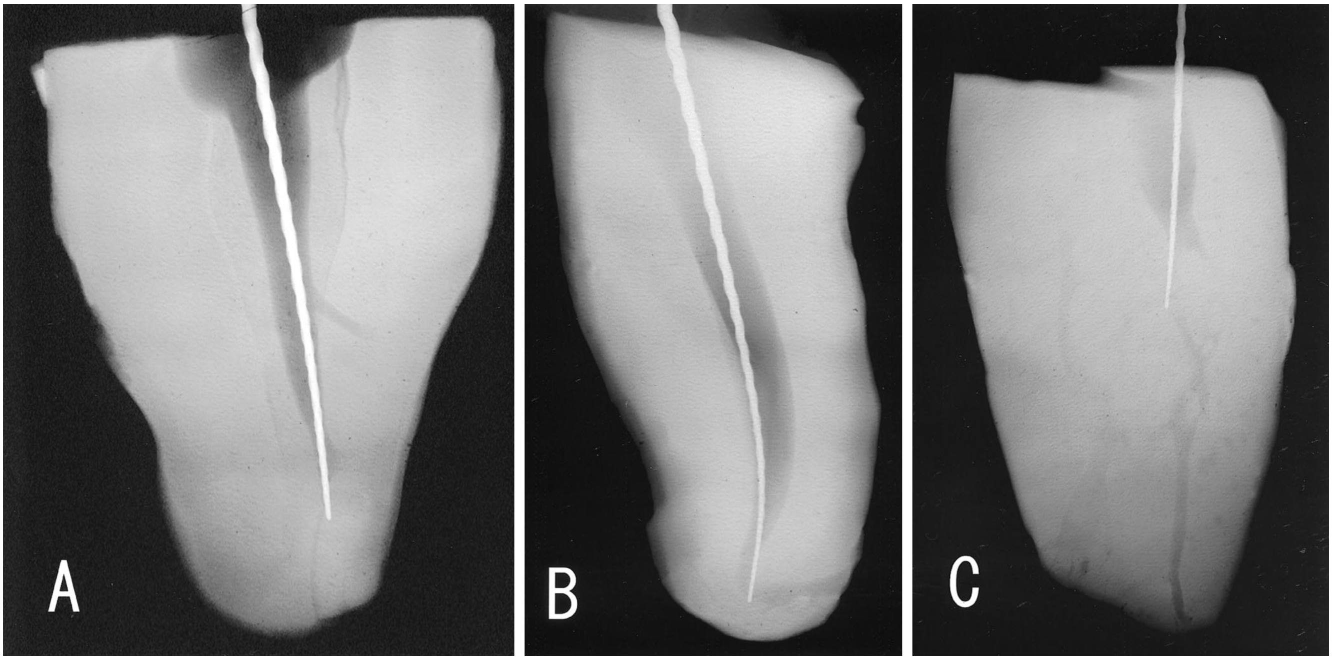

FIG 2. Contact microradiographs from three groups. (*A*) Group A, constricted canal. The file tip is positioned within 3 mm of the radiographic apex. (*B*) Group B, nonconstricted canal. The file tip is positioned within 3 mm of the radiographic apex. (*C*) Group C: the file tip is positioned more than 3 mm short of the radiographic apex.

between a file (#1 Profile, active electrode) and the screw was measured by using an impedance analyzer (4192ALF, YHP, Tokyo, Japan) with a solution of 6% NaClO in the canal. The file tip was manually fixed at the deepest position in the root canal that the file could reach. The low and high frequencies of the measuring current (0.1 V sine wave) were 0.4 and 8 kHz, respectively. Next, the Root ZX (J. Morita Co., Tokyo, Japan) was connected to the neutral and active electrodes, and the meter reading was recorded under the same conditions as the previous measurement by using the impedance analyzer. The meter readings on the display of the Root ZX were recorded at 0.125 increments.

After each file had been fixed with epoxy resin at the deepest position in the root canal that the file could reach, the root was ground mesiodistally or buccolingually to obtain a finer picture of the canal to a thickness of 1.5 mm (1.51 $\pm$ 0.19 mm) without exposing the canal. A contact microradiograph (CMR) was taken with high-resolution film (Eastman Kodak SO-343, Rochester, NY). The O-micron, OMC603, was used as an X-ray generator (Sofron, Tokyo, Japan), and each film was exposed at 60 kV and 3 mA for 90 s. The CMRs were converted to digital files by using a flat-bed scanner (GT-9500, Epson, Tokyo, Japan). The distance between the radiographic root apex and the file tip was measured on a personal computer (Vaio PCV-R60, Sony, Tokyo, Japan), using image-processing software (Photoshop 5.0, Adobe, San Jose, CA).

Depending on the morphology of the canal and the file tip position on the CMR, impenetrable canals were classified into three groups (Fig. 2). Group A (23 canals, 32.9%): the file tip was located within 3 mm of the radiographic apex. No root canal was observed beyond the file tip or the diameter of the canal beyond the file tip was smaller than that of the file tip. Group B (28 canals, 40.0%): the file tip was located within 3 mm of the radiographic apex. Root canal, larger than the diameter of the file tip, was observed beyond the file tip. Group C (19 canals, 27.1%): the file tip was located more than 3 mm short of the radiographic apex.

TABLE 1. Mean ± SD electrical impedance of impenetrable canals (kΩ)

Frequency	Group A	Group B	Group C
0.4 (kHz)	8.04 ± 5.28	7.14 ± 6.70	16.7 ± 27.3
8	7.43 ± 5.56	5.87 ± 6.80	16.0 ± 27.6

The impedance values at each frequency in groups A and B were analyzed with two-way ANOVA. Because the impedances in group C showed a wide range of discrepancies, they were not statistically analyzed. The ratio of the impedance at 8 kHz and 0.4 kHz (Z_{8kHz}:$Z_{0.4kHz}$) was calculated in each canal and statistically analyzed with the Mann-Whitney *U* test. The meter values of the Root ZX for groups A and B were statistically analyzed with the Chi-square test. Each statistical analysis was performed at the 5% significant level.

Neither the impedance nor the meter value of the Root ZX in group C was analyzed, because the meter value of the Root ZX showed little change when the file tip was located more than 3 mm from the radiographic apex (10).

RESULTS

Table 1 shows the electrical impedance measured with the impedance analyzer at two different frequencies in groups A and B. There was no statistically significant difference between the two groups at either frequency. This result suggests that the impedance measured with electric current of a single frequency is unable to detect root canal constrictions near the apical foramen.

Figure 3 shows the relationship between the impedance ratio and file tip position in groups A and B. The means and standard deviations of the ratios (Z_{8kHz}:$Z_{0.4kHz}$) were 0.91 $\pm$ 0.08 in group A and 0.72 $\pm$ 0.21 in group B, respectively. There was a statistically significant difference between the two groups ($p = 0.0002$).

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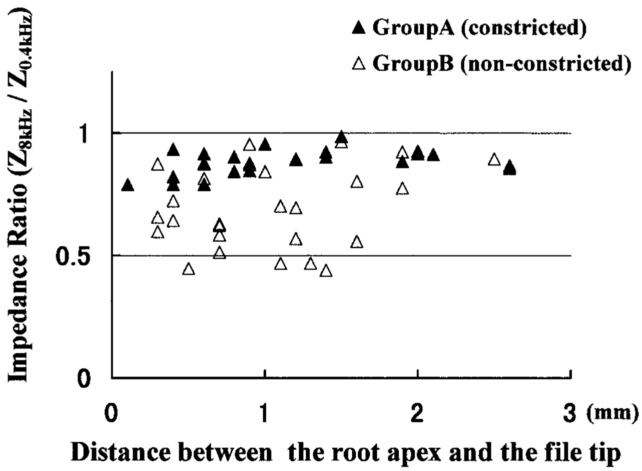

FIG 3. Relationship between impedance ratio and the file tip-root apex distance.

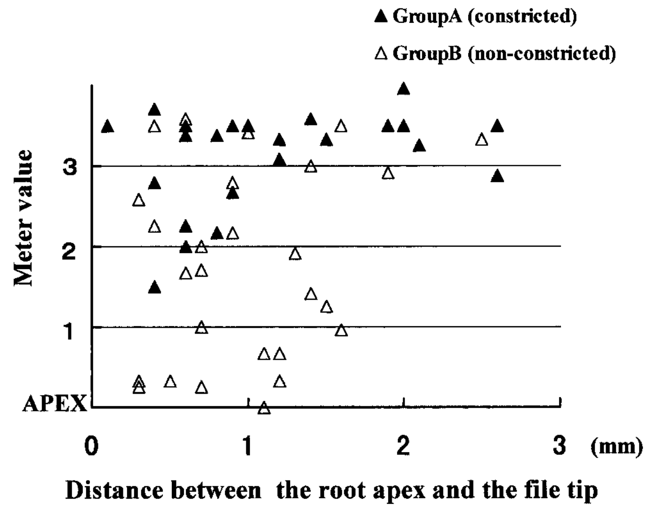

FIG 4. Relationship between meter value of the Root ZX and the file tip-root apex distance.

Figure 4 shows the relationship between the meter values of the Root ZX and the file tip position in groups A and B. Because the meter of the Root ZX is indicated by calculating the ratio of the impedances at 8 kHz and 0.4 kHz (Z_{8kHz}:$Z_{0.4kHz}$), Figure 4 is similar to Figure 3.

Table 2 shows the number of impenetrable root canals found at different meter values of the Root ZX. The number of the root canals having meter values less than 3 was 7 out of 23 canals (30.4%) in group A, whereas it was 21 out of 28 canals (75.0%) in group B. There was a statistically significant difference between groups A and B ($p = 0.0015$).

DISCUSSION

We intended to electronically detect root canal constrictions, with the canal filled with electro-conductive fluid. Because constricted canals had high electric impedance, a highly electro-conductive solution was needed in the root canal for electronic measurement. In this experiment, we filled the canal with 6% NaClO solution, which is highly electro-conductive and infiltrates into dentinal tubules (3, 11), resulting in greatly reduced electrical impedance of the root canal wall.

A measuring current at a single frequency could not detect the constriction of the canal in this study. The decrease of the canal wall impedance caused by the NaClO solution infiltration impeded the electronic detection of the constriction of the canal.

The electrical impedance of the root canal (Z0) is considered to be a combination of that of the root canal wall (Z1) and that of the apical foramen (Z2), which is shown as the following (12)

$$\frac{1}{Z_0} = \frac{1}{Z_1} + \frac{1}{Z_2}, \quad Z_0 = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

Figure 5 shows these relations. When the impedance of the root canal wall (Z1) is high, the impedance of the root canal (Z0) decreases conspicuously as the impedance of the apical foramen (Z2) decreases (Fig. 5, line a). On the other hand, when the impedance of the root canal wall (Z1) is low, the impedance of the root canal (Z0) shows only a small decrease as the impedance of the apical foramen (Z2) decreases (Fig. 5, line b). This is why canal constrictions cannot be detected by a single measuring current.

Kobayashi and Suda (13) showed that the ratio of the impedances at two different frequencies was very sensitive to the large capacitance of the apical foramen and that it was less likely to be influenced by electrical fluctuation factors. Thus, the location of the apical foramen was precisely detected by calculating the ratio. In this study, we showed that the constriction of the canal was also detected by calculating the ratio of the electrical impedances at two different frequencies.

In this study, when the file tip was located within 3 mm of the radiographic apex, the ratio of the impedances at 8 kHz and 0.4 kHz showed a significant difference between constricted (group A) and nonconstricted root canal groups (group B). This means that the ratio of impedances at two different frequencies is greatly influenced by the constriction of the apical canal. The result suggests that the constrictions of the canal may affect the meter value of the Root ZX. In fact, the number of root canals having meter values less than 3 showed a statistical difference between the constricted and nonconstricted root canal groups.

In our previous study (10), the meter value of the Root ZX did not change when the file tip was located more than 3 mm short of the radiographic apex. Therefore, we could not detect the constriction of the apical canal with the Root ZX in such cases.

In this study, we classified root canals into the constricted and nonconstricted groups. However, there are very few root canals

TABLE 2. No. of impenetrable canals determined by different meter values of the Root ZX

Meter Value	≧3	3 ~ 2.5	2.5 ~ 2	2 ~ 1.5	1.5 ~ 1	1 ~ 0.5	<0.5
Group A: constricted	16	3	3	1	0	0	0
Group B: nonconstricted	7	3	3	3	3	3	6

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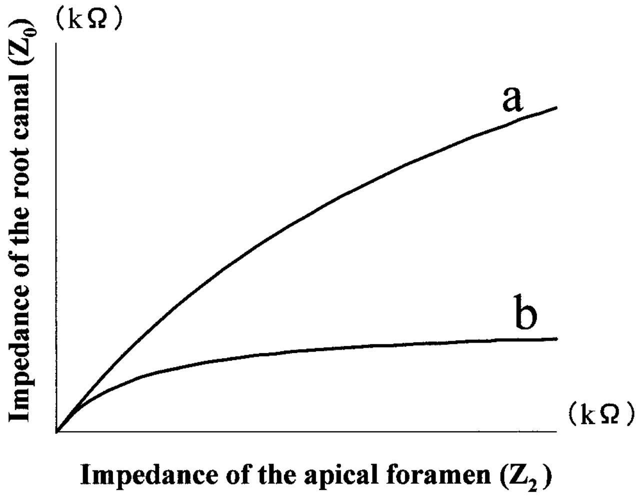

FIG 5. Hypothetical figure based on the formula for compound impedance. Relationship between compound impedance of the root canal (Z0) and that of the apical foramen (Z2), when impedance of the root canal wall (Z1) is high (a) and low (b).

that are completely constricted at the apical portion, even if an instrument cannot reach the apex (1, 14, 15). Judging from the CMR observation, there were only 4 out of 23 canals (17.4%) that seemed to be almost completely constricted in this study.

We concluded that the Root ZX is not only effective for accurately detecting the location of the apical foramen but also useful for detecting root canal constrictions. The ability to differentiate between a blocked canal and an open canal that is resistant to instrumentation because of severe curvature may be of clinical value.

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