A Study on Electric Method for Measuring Root Canal Length

by

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Abstract
As a fundamental study on the electric method for measuring root canal length, the various factors which affect the measured impedance were investigated using a wide range of frequencies.

1) The impedance between two saliva ejectors in contact with the oral mucosa near the bilateral premolars in the lower arch generally showed low values. The difference between the maximum and minimum measured impedance was reduced and eventually approached zero as the frequency increased.

2) When a 1.0-mm length of the reamer tip was inserted into 2% agar containing 0.90% or 0.45% NaCl solution, the impedance in the former solution was lower than that in the latter.

3) When the impedance of a reamer covered with insulating tape except at the tip, and exposed in a glass tube containing 0.90% NaCl solution was compared, the former showed a higher value than the latter. The smaller the inner diameter of the glass tube into which the reamer was inserted, the higher was the impedance of the reamer.

In every case, the measured impedance and the difference between them decreased as frequency increased. With regard to the electric method for measuring root canal length, the application of high frequency of more than 30 kHz was considered to keep the influence of such factors to a minimum and contribute to the improvement of this method.

Introduction
Since SUNADA\cite{1} first applied it clinically, the electric method for measuring root canal length has become widely used because of its comparatively simple manipulability. However, some reports\cite{2-4} have cast doubt upon its measuring accuracy, and in fact some clinical problems have occurred due to measurement errors\cite{5,6} in the presence of certain electro-conductive substances in the root canal. Consequently, in applying this method, several conditions have been suggested\cite{6} in order to reduce the degree of measuring error, and these have made the pro-
procedure more complicated.

With regard to the factors affecting the measured values, WAKI [7] in his experiments using the most widely used measuring apparatus on the market, proposed that the contact area between the reamer tip and the electrolyte should be kept constant in order to obtain the apex-indicating value, while YAMASHITA [8] suggested that the impedance arising when the reamer tip touched the electrolyte changed according to frequency. Furthermore, TAKEI [9] suggested the possibility of a change in the meter-indicated value according to the shape of the root canal. These reports confirmed that the measured values are influenced by various factors.

On the other hand, HASEGAWA et al. [10] developed the Endotape Method, utilizing the electric phenomenon that a tube made of non-conductive substance, similar to a root canal, produces impedance in the electrolyte, and reported that by applying this method using a high frequency of 400 kHz, the influence of disturbing factors was lessened, thus improving both manipulability and measuring accuracy. This presumably suggests the possibility of a decrease in influential factors to a greater degree through the use of high frequency, but few detailed studies examining the effect of changing frequency have been conducted.

The authors therefore carried out the present study with the aim of improving the electric method. In this study, the effect of frequency, one of the factors influencing the measured value, was changed from low to high, and the resulting effects on the impedance of live tissue, the reamer tip and a reamer placed in a glass tube were examined.

Materials and Methods

1) Measuring apparatus

Impedance was measured using an LCR-Bridge (LEADER, LCR-740). The measuring frequency was set at 0.1~100 kHz using a sine wave transmitter, CR oscillator (TRIO, AG-203), as the outer alternating signal. The output voltage was 0.5 V at maximum, and less than 0.1 V in most cases.

2) Methods

(1) Experiment 1: Impedance of live tissue

In each of 5 subjects, 2 metal saliva ejectors were placed in the oral cavity under the bilateral premolars in the lower arch, so that they were in contact with the bottom mucosa, and the impednace between them was determined. The contact pressure between the ejector and mucosa was of the same degree as that in clinical cases. The handling part of each ejector was covered with insulating tape to prevent it from making electrical contact with the outer surface of the subject. Measurements were repeated 5 times for each subject.

(2) Experiment 2: Impedance of reamer tip

Figure 1 shows a rough sketch of the circuit. The reamer (Pierce #15, stainless steel) was used as an electrode, while a stainless steel plate (50 × 10 × 0.5 mm), large enough not to affect the impedance of the reamer tip, was used as the opposite electrode, and the distance between the two electrodes was set at 6 cm. In order to minimize any change in the contact area between the reamer and the electrolyte due to surface tension, two kinds of 2% agar made of 0.90% and 0.45% NaCl
solutions respectively, were used as electrolyte. As a preliminary experiment, the impedances of the solution and the agar were measured using an electrode with a micro-exposed area (electrode coated with acrylic resin, $\phi=0.6$ mm, exposed only at the transverse surface), and no difference was found between them.

Measurement was carried out as follows: The reamer was fixed vertically to a holder, and 2% agar containing NaCl solution in an insulated vessel was raised using a 3-dimensional jig (Tokyo Seimitsu, EAT-S 10A) so that the reamer tip became inserted into the solution 1.0 mm below the agar surface, to allow measurement of the impedance between the reamer tip and the electrolyte.

(3) Experiment 3: Impedance of reamer in a glass tube

Figure 2 shows a rough sketch of the circuit. As in experiment 2, a reamer (Pierce #15, stainless steel) and a stainless steel plate were used as the electrodes. Two kinds of reamers were prepared: one covered with insulating tape except at its tip (1.0 mm) and an uncovered one. Three kinds of glass tubes were prepared: 20 mm in length, 1.0 mm in upper inner diameter, and 0.2, 0.3 and 0.4 mm in lower inner diameter, respectively, in a tapered shape. As the electrolyte, 0.90% NaCl solution was used.

Measurement was carried out as follows: Into the glass tube the reamer was inserted until its tip reached the lower end of the tube\(^\text{[11]}\), and the reamer and the tube were dipped into the solution to be fixed to the holder through an insulating cover, where the upper end of the glass tube coincided with the solution surface,
and the impedance between the reamer and the stainless steel plate was measured. The distance between the electrolytes was 6 cm.

The above experiments were all performed at a room temperature of 23±1°C and a relative humidity of 50±5%. For experiments 2 and 3, as the measured values were not so dispersed, the values for 3 cases were averaged.

Results

Experiment 1: Impedance of live tissue

For 5 subjects, the authors measured the impedance between 2 saliva ejectors inserted into the oral cavity, 5 times in each subject. Figure 3 shows the maximum and minimum values obtained, proving that the impedance was quite low in general, over a range from low to high frequency, and showing a tendency to decrease, approaching zero, in accordance with increased frequency. Again, in the low frequency range, some differences appeared among subjects, but these disappeared as the frequency became higher.

Experiment 2: Impedance of reamer tip

Figure 4 shows the experimental results. Impedance decreased in accordance with increased frequency, and this tendency was rather abrupt in the low frequency range. At a frequency of more than 10 kHz, the change in impedance was small and the value became almost constant. When the values obtained in 2% agar containing 0.90% and 0.45% NaCl solutions were compared with each other, the former showed a lower impedance, and the difference decreased as the frequency increased, both values becoming approximately equal at a frequency of more than 10 kHz.

Experiment 3: Impedance of reamer in a glass tube

Figure 5 shows the experimental results. The impedance decreased in parallel
with increasing frequency. With the same frequency and the same lower inner diameter, the covered reamer showed a high impedance, and the change in impedance due to change of frequency was also large in comparison with the uncovered reamer. Again in both cases, the smaller the lower inner diameter, the larger the impedance. The difference in impedance due to these conditions was larger in the lower frequency range, and decreased in accordance with increasing frequency.

**Discussion**

Many electric devices for measuring root canal length are now on the market, and most of them are produced on **Sunada's**\(^{[12]}\) principle; “Impedance between the oral cavity mucosa and root canal membrane shows a constant value, unrelated to measuring position, and which does not vary according to the patient’s age, type of teeth and sex.” However, some authors\(^{[2-4]}\) have cast doubt on the stability of the apex-indicating values, and various studies\(^{[7,8,11-14]}\) have been performed with regard to this problem. Furthermore, it is known that each device has its own electric characteristics\(^{[14]}\). **Nomoto et al.**\(^{[17]}\) reported differences in the meter-indicating values among these devices, and recommended that it was necessary to know their individual characteristics in use. This suggests that the impedance may vary in accordance with the measuring frequency, since these devices use different frequencies for measurement.

**Waki**\(^{[7]}\), in his studies on possible influential factors, performed an experiment using an Endodontic Meter with a 400-Hz frequency, and concluded that the contact of the reamer tip with the electrolyte was the most important factor affecting impedance, while **Takei**\(^{[9]}\), also using an Endodontic Meter, showed that impedance was affected by the shape of the glass tube used as a simulated root canal. Furthermore, **Yamashita**\(^{[8]}\) reported the existence of various influential factors such as the size of the reamer, the surface condition of the reamer, the type of solution in the root canal, the size of the root canal and the measuring frequency,
and that considering these factors, of the three frequencies 55 Hz, 400 Hz, and 5 kHz, the highest one, 5 kHz, showed the most optimal results. These studies suggest that the measured value is determined by a complex interrelationship of these factors.

HASEGAWA et al. [10] presented a new measuring principle; "Impedance is formed by a narrow tube made of insulating substance and small hole," and reported that a high measuring accuracy could be obtained by applying a high frequency of 400 kHz.

The authors, on the basis of HASEGAWA et al.'s report [10], attempted to examine the relationship between frequency and impedance so as to ascertain feasibility of applying frequency to such electric devices for measuring root canal length. In the present study, the authors set up 3 impedance-forming elements, and measured the impedance in each case, i.e., the impedance of live tissue between the oral cavity mucosa and root canal membrane, the impedance formed by contact of the reamer tip with the electrolyte, and the impedance formed by the root canal itself. Furthermore, the authors devised basic conditions with regard to differences in the apical foramen diameter and the conductivity of the electrolyte, performing experiments over a wide range of frequency.

In experiment 1, the authors placed 2 saliva ejectors in contact with the bottom mucosa of the oral cavity, under the bilateral premolars, and measured the impedance between them. Saliva ejectors were used not only because they are generally used as opposite electrodes, but also because the authors considered it unlikely that they would cause measuring errors, since their impedance has been proved to be very small in studies by YAZAKI [12], KOMAMURA et al. [18] and HORIUCHI et al. [19]. In other words, the authors considered that in SUNADA' s method of measuring the impedance between the oral mucosa and root canal membrane, the use of a saliva ejector as an electrode in place of a reamer on the root canal membrane side, the effect due to reamer contact could be excluded, and that by measuring the impedance between them, the typical impedance of live tissue could be estimated. As shown in Fig. 3, the impedance became 2.5 ~ 1.1 kΩ, maximum and minimum, at 100 Hz, and the value decreased in accordance with the increase in measuring frequency, becoming almost constant at an extremely small value of approximately 0.1 kΩ, at 100 kHz. This result showed approximately the same tendency as that reported by YAMASHITA [18] who performed largely the same type of experiment and obtained a value of 0.5 ~ 1 kΩ at 800 Hz. YAMASHITA presumed that the impedance of a saliva ejector was 1/2 of these values, but it seems more reasonable to assume that these values include the impedance of live tissue. Therefore, it is impossible to extract the impedance of live tissue only, even though it is possible to make it extremely small through the use of high frequency. In other words, the result of experiment 1 seems to suggest that it might be possible to exclude one of the factors influencing the measured impedance.

In experiment 2, the authors measured the impedance produced by contact of the reamer tip with the electrolyte. Here they used two kinds of 2% agar containing 0.90% and 0.45% NaCl solutions as electrolyte, in order to consider the effect due to differences in solution conductivity. The depth of insertion of the
reamer tip into the agar was 1 mm, in accordance with the results obtained by WAKI[7], who, in his experiment to examine the relationship between the reamer insertion depth and the meter-indicating value using an Endodontic Meter, deduced that a #15 reamer should be inserted to a depth of 0.5～1.5 mm to obtain meter-indicated values of 38～40.

When the reamer tip was inserted 1.0 mm into 2% agar containing 0.90% or 0.45% NaCl solution, the impedance showed a tendency to decrease in accordance with the increase in measuring frequency, approximately in accordance with YAMASHITA’s result[8] obtained using a frequency of up to 5 kHz. In the present study, a large stainless steel plate was used as the opposite electrode, and it was proved in a preliminary experiment that the impedance did not change even if the distance between the reamer tip and the stainless steel plate varied. Therefore, it is presumed that most of the measured values are due to contact between the reamer tip and the agar.

In measurements using the same frequency, there was a difference in impedance between the 0.90% and 0.45% NaCl solutions, but this difference became smaller as the frequency increased. This result suggests that differences in conductivity between electrolytes with which the reamer tip is in contact are an influential factor causing measuring errors in clinical practice. However, by using high frequency, the effect of this difference in electrolyte conductivity becomes smaller, and this presumably suggests that it may be possible to exclude the influence of this factor.

In experiment 3, the authors measured the impedance of a reamer inserted into a glass tube. The measured value decreased in accordance with increased frequency, showing approximately the same tendency as seen in experiment 2. This means that even if the reamer tip remains at the lower end of the tube, the measured value is markedly related to the impedance of the reamer tip. If both the frequency and the lower inner diameter of the glass tube remain the same, a covered reamer shows a higher impedance than an uncovered one, and the difference between them, large at low frequency, becomes smaller as frequency increases.

The electric method for measuring root canal length is indeed widely used because of its simplicity. However, for practical application, it must be borne in mind that the inside and outside conditions of the root canal vary due to differences in anatomical shape such as the diameter of the root canal or apical foramen, symptoms of tooth disease, treatment procedures, etc. Therefore, the present method is invariably performed under fluctuating conditions, making it difficult for operators to specify fixed conditions for measurement. Judging from the accuracy and stability of the measured values in the present study, it is considered that by applying a frequency of more than 30 kHz to the present method, several influential factors hitherto mentioned can be excluded or minimized. Most of the measuring devices currently on the market employ a low frequency, and so would presumably be unavoidably affected by such factors with regard to their measured values.

**Conclusions**

Using a wide frequency range, the authors examined various factors determining the measured impedance in the electric method for measuring root canal
length. The results obtained were as follows:

1) Values of impedance between 2 saliva ejectors in contact with the mucosa under the bilateral premolars in the lower arch were generally low, and decreased in accordance with increasing frequency, eventually approaching zero.

2) When the reamer tip was inserted 1.0 mm into 2% agar containing 0.90% or 0.45% NaCl solution, the former showed a lower impedance, and the difference between them decreased as the frequency became higher.

3) Comparing the impedance of a reamer insulated except at its tip, with that of a non-insulated reamer inserted in glass tubes having different lower inner diameters set in 0.90% NaCl solution, the insulated reamer and smaller glass tubes with a lower inner diameter showed higher values. The difference between them decreased with increasing frequency in all cases.

4) It was considered that by applying a high frequency of more than 30 kHz in the electric method for measuring root canal length, the influence of such factors can be minimized, thus contributing to the improvement of the present method.

References

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