Basic research on the development of a device for predicting the fracture of a nickel titanium rotary file applying eddy current

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detection of cracks in NiTi file using eddy current

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Abstract

Since nickel-titanium (NiTi) files have very high flexibility, they have a high ability to follow the root canal, so that displacement of the root canal due to root canal enlargement is reduced. On the other hand, one of the major drawbacks of NiTi files is instrument fracture during root canal formation. Therefore, we are trying to develop a device that can detect cracks before the NiTi file breaks. Because NiTi is a non-magnetic conductor, it was difficult to detect a groove in a sample by the same method as that for stainless steel which is a magnetic conductor. Specimens of nickel titanium rod having a diameter of 1.3 mm and a length of 30 mm were inscribed with grooves having a depth of 1/4, 1/2, and 3/4 of the diameter at a distance of 5 or 10 mm from the end. Electrodes were placed at 1 mm intervals with respect to the part of the specimen closest to the excitation coil, and the potential difference in the specimen caused by the eddy current was measured. The result was that a groove having a depth of 3/4 of the diameter could be detected by measuring the potential difference. As a clinical application, the possibility of detecting cracks in nickel-titanium files is suggested.

Introduction

Since the introduction of nickel-titanium (NiTi) alloys into endodontic devices in 1988 (1), many types of NiTi files have been created and described (2). Since NiTi files have very high flexibility, they have a high ability to follow the root canal, so that displacement of the root canal due to root canal enlargement is reduced. Therefore, the use of NiTi files is considered to be more successful than stainless steel files (3). NiTi files are being used more frequently. On the other hand, one of the major drawbacks of NiTi files is instrument fracture during root canal formation. Since NiTi files have superelastic properties, they are unlikely to undergo plastic deformation, and it is difficult to judge when a file has reached the end of its useful life from its appearance. Instrument fracture rates in the clinical use of NiTi files have been reported to range from 0.9% to 5.1% (5-7).

Scientific and industrial applications use non-destructive testing methods to assess material degradation without damaging the test specimen. Common non-destructive tests include electromagnetic, ultrasonic and liquid penetration tests. One test is an eddy current non-destructive inspection, an electromagnetic method used for inspecting conductive materials such as copper, aluminum, and steel (8). In the eddy current flaw detection test, an eddy current is induced near the surface of the test piece by a test coil to which an alternating current is applied. The electromotive force of the test coil changes due to a defect such as a crack on the surface of the test body. Therefore, flaw detection can be performed using the change in the electromotive force of the test coil. It has been found that it is more difficult to detect cracks in nonmagnetic conductors than magnetic conductors (9). The authors recently reported an attempt to detect cracks in stainless steel instruments using eddy current testing (10). When the same procedure was performed using a NiTi rod, it was difficult to carry out measurements on NiTi which was nonmagnetic conductor.

The purpose of this study is to find a new method for crack detection in NiTi endodontic instruments.

Materials and Methods

1. Specimen

The specimens used consisted of a 1.3 mm diameter NiTi rod (manufacturer undisclosed, Japan). The specimens were prepared NiTi rods in the same manner as the stainless steelrods prepared by the method of Ozeki et al (10). The specimens were cut to a length of 30 mm, and a 0.5 mm thick diamond disc was used to make grooves perpendicular to the long axis of the rod. Grooves were placed at 5 mm or 10 mm from the end of the rod, at depths of 1/4, 1/2, or 3/4 of the rod diameter. A control and reference group with no groove was designated as group A. Groups having a groove at a position 5 mm from the end and having a groove depth of 1/4, 1/2, 3/4 were designated as groups B-1, B-2, B-3 respectively. Those having a groove at a position 10 mm from the end were similarly designated as groups C-1, C-2, and C-3. Ten specimens were prepared for each group.

2. New prototype testing device

Previous investigations have been carried out using the prototype testing device and method described in Ozeki et al. (10). For this study, a new prototype has been designed. Fig. 1 shows an outline of the prototype device. The excitation coil is a polyester copper wire (diameter 0.1 mm) wound 3,000 times around a ferrite rod (diameter 0.75 mm, Fair-Rite Products Corp., NY, USA) with a resultant coil width of 30 mm. A sine wave with a frequency of 1 kHz, 10 kHz, and 100 kHz and a voltage of 6 V (peak to peak) is generated by an oscillator (JYE Tech Ltd. Guangxi, China), and the sine wave is then amplified by a factor of three using an amplifier (LM7171, National Semiconductor Co., CA, USA) and supplied to the excitation coil. The specimen is located 1 mm from the end of the excitation coil and moved in intervals of 1 mm with respect to the long axis. The alternating current electromotive force created by the eddy current generated in the specimen was measured with a digital multimeter (PC500A, Sanwa Electric Instrument Co, Tokyo, Japan). Connection of the electrodes to the specimen was performed in the following two ways:

1) At both ends of the specimen

2) 1 mm interval between specimens approaching the coil

3. Statistical analysis

Tukey's test was used for statistical analysis of the results.

Results

First, we attempted to detect the generation of eddy currents in NiTi rods which are non-magnetic conductors, by using the method of detecting it in sensor coils using the eddy current flaw detection test reported by Ozeki et al (10). As a result, Fig. 2 shows the voltage of the sensor coil at excitation frequencies of 1, 10, 100 kHz and the difference between voltages when the specimen was present and absent. At all frequencies, no difference was observed when the specimen was present or absent. At 1 kHz, the voltage was 136.8 mV under both conditions. At 10 kHz, the voltage was 140.1 mV, and at 100 kHz, it was 121.0 mV.

Fig. 3 shows the change in voltage measured at both ends when specimen A is moved by intervals of 1 mm. At each frequency, constant values (0.23 mV at 1 kHz, 0.26 mV at 10 kHz, 0.1 mV at 100 kHz) were observed within the range of movement (1 to +1.5 mm). All 10 specimens at each frequency showed the same values, and the standard deviation was 0.

Fig. 4 shows a change in voltage measured at 1 mm intervals when specimen A is moved by intervals of 1 mm. At each frequency, a constant values (0.11 mV at 1 kHz, 0.15 mV at 10 kHz, 0.10 mV at 100 kHz) were observed within the measurement range (1 to +1.5 mm). All 10 specimens showed the same values, and the standard deviation was 0.

Fig. 5 shows the measurement results in the case of Group B and C in which grooves were formed at a position 5 or 10 mm from the end, for the voltage at 10 kHz with movement intervals of 1 mm and electrodes installed at both ends of the specimen. For specimens B and C, all measurements were 0.26 mV with no variation.

Fig. 6 shows the measurement results in the case of specimens B and C, for the voltage at 10 kHz with movement intervals of 1 mm and electrodes installed at 1 mm intervals. In group B, a negative peak was observed in groups B-2 and B-3 at the position of 5 mm corresponding to the groove. B-1 showed no peak, B-2 showed a peak of -0.08 ± 0.015 mV, and B-3 showed a peak of -0.28 ± 0.018 mV. Group B-3 was found to be significantly different compared with Group A as the control at a 1% risk factor. In group C, a negative peak was observed in groups C-2 and C-3 at the position of 5 mm corresponding to the groove. C-1 showed no peak, C-2 showed a peak of -0.09 ± 0.013 mV, and C-3 showed a peak of -0.031 ± 0.011 mV. Group C-3 was found to be significantly different compared with Group A as the control at a 1% risk factor.

Discussion

Two types of NiTi rotary file fractures have been reported: torsional fatigue fractures and periodic fatigue fractures (11). Torsional fatigue causes brittle rupture due to rotation of the shank even after the tip of the instrument bites into the root canal (12). Cyclic fatigue is due to repeated compression and elongation by bending the instrument while rotating (13). NiTi files have superelastic properties and are not susceptible to plastic deformation (4), making it difficult to find cracks visually and resulting in sudden breakage during root canal formation. Since the stress on the NiTi file during each use is not constant, it is difficult to completely prevent breakage. Therefore, we are trying to develop a device that can detect cracks before the NiTi file breaks.

We have attempted to detect a crack in a NiTi rod using a prototype device by applying the eddy current testing that we reported previously for stainless steel specimens (10). Detection was possible with stainless steel rods, but not with the groove provided on the nickel titanium rod. Stainless steel is a magnetic conductor, and nickel titanium is a non-magnetic material. Non-magnetic conductors are said to be more difficult in which to detect cracks than magnetic conductors (9). As shown in Fig. ~~1~~ 2, nickel titanium did not result in a voltage change in the sensor coil of the device. It is considered that the generation of magnetic flux by eddy currents generated in the non-magnetic material was smaller compared with the magnetic conductor. Electrodes were then directly applied to the specimen, and an attempt was made to measure the potential difference in the specimen caused by the eddy current. The electrodes were placed on the specimen in the following two ways: (1) Electrodes were applied to both ends of the specimen, and the specimen was moved by intervals of 1 mm into the excitation coil; (2) Electrodes were applied at 1 mm intervals on the specimen close to the excitation coil, and the specimen was moved by 1 mm intervals. Figs. 3 and 5 show the results when the electrodes were applied to both ends. No change was observed in the measured voltage even when the grooved position of the specimen was closest to the excitation coil. The results when the electrodes were placed at 1 mm intervals are shown in Figs. 4 and 6. When the grooved position of the specimen was closest to the excitation coil, a negative peak was seen, with its size varying according to the groove depth. In both groups B and C, a significant difference was found at a 1% risk factor when the groove depth was 3/4 of the specimen diameter. It seems that narrowing the measurement distance between the electrodes and the coil made it possible to detect changes. In this study, the voltage measured was very small, close to the measurement limit of the measuring instrument, and could not be detected unless the groove reached 3/4 of the specimen diameter. At present, therefore, it is not practical for clinical application. By applying a bridge circuit that can detect minute electrical changes, differential analysis and Fourier analysis, it is possible to detect cracks smaller than the grooves formed in this study. However, even at this stage, the possibility of clinical application can be suggested.

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Figures

Fig. 1 Outline of the prototype device.

Fig. 2 Voltage of the sensor coil at a supply frequency of 1, 10, 100 kHz and difference between voltages when the specimen was present and absent. (n = 10, values are averages, S.D. was 0)

Fig. 3 Change in voltage measured at both ends when specimen A is moved by intervals of 1 mm. (n = 10, values are averages, S.D. was 0)

Fig. 4 Change in voltage measured at 1 mm interval when specimen A is moved by intervals of 1 mm. (n = 10, values are averages, S.D. was 0)

Fig. 5 Change in voltage at 10 kHz measured at both ends when specimens B (groove at 5 mm) and C (groove at 10 mm) are moved by intervals of 1 mm.

Fig 6 Change in voltage at 10 kHz measured at 1 mm interval when specimens B (groove at 5 mm) and C (groove at 10 mm) are moved by intervals of 1 mm.

* Significant difference compared with reference ($p< 0.01$, $n=10$)

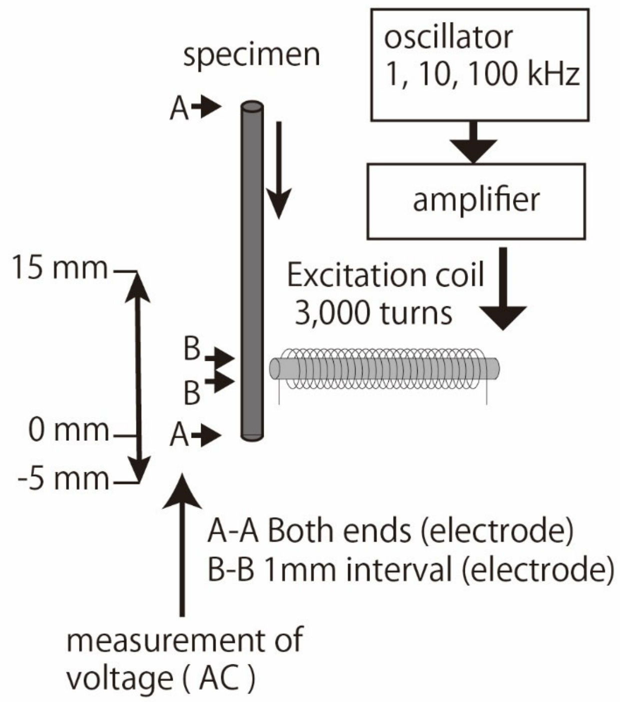
specimen
oscillator
1, 10, 100 kHz
amplifier
Excitation coil
3,000 turns
A
B
B
A
15 mm
0 mm
-5 mm
A-A Both ends (electrode)
B-B 1mm interval (electrode)
measurement of
voltage (AC)

Fig. 1

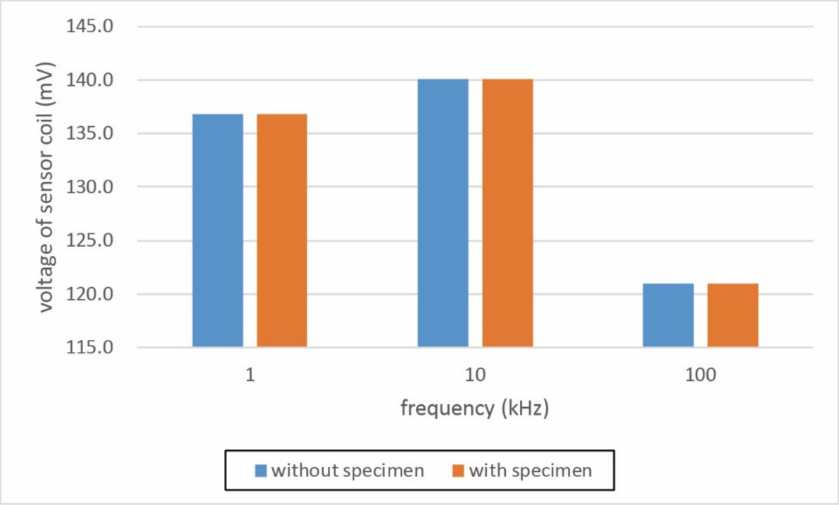
145.0
140.0
135.0
130.0
125.0
120.0
115.0
voltage of sensor coil (mV)
1
10
100
frequency (kHz)
without specimen
with specimen

Fig. 2

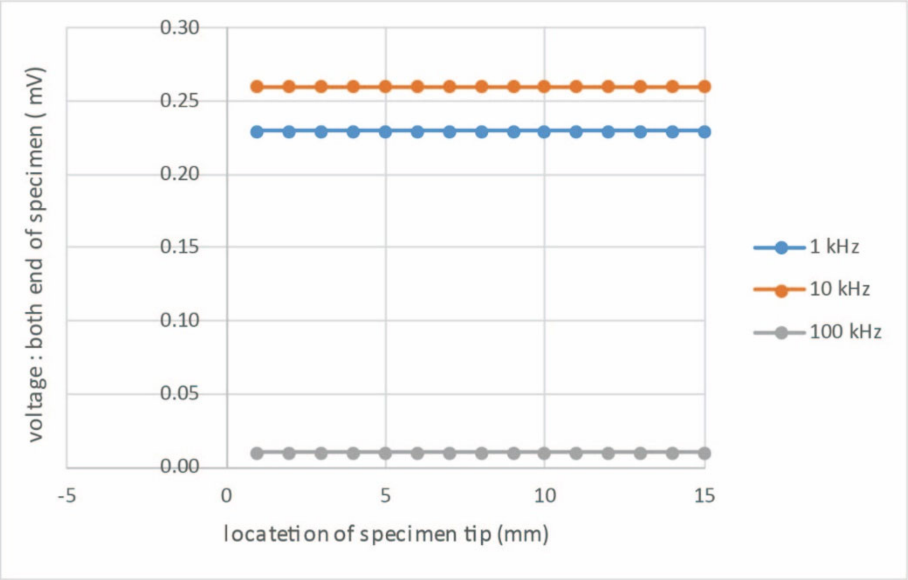
0.30
0.25
0.20
0.15
0.10
0.05
0.00
voltage : both end of specimen (mV)
-5
0
5
10
15
locatetion of specimen tip (mm)
1 kHz
10 kHz
100 kHz

Fig. 3

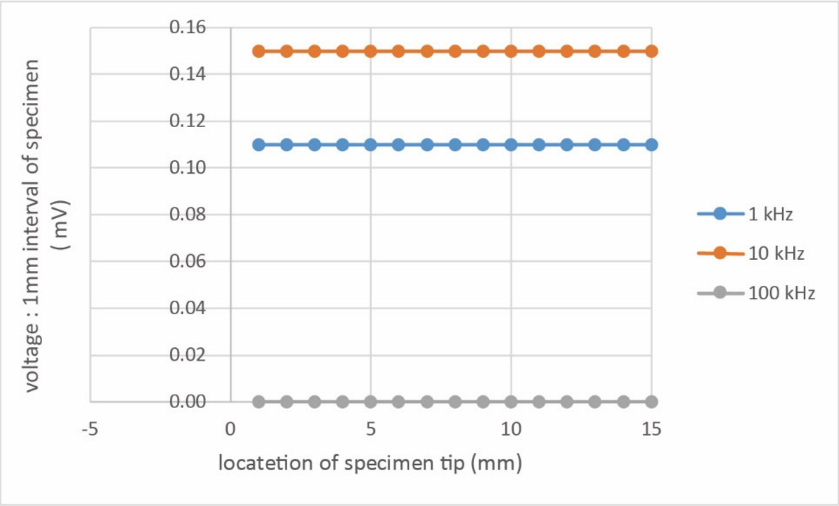
voltage : 1mm interval of specimen (mV)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-5
0
5
10
15
locatetion of specimen tip (mm)
1 kHz
10 kHz
100 kHz

Fig. 4

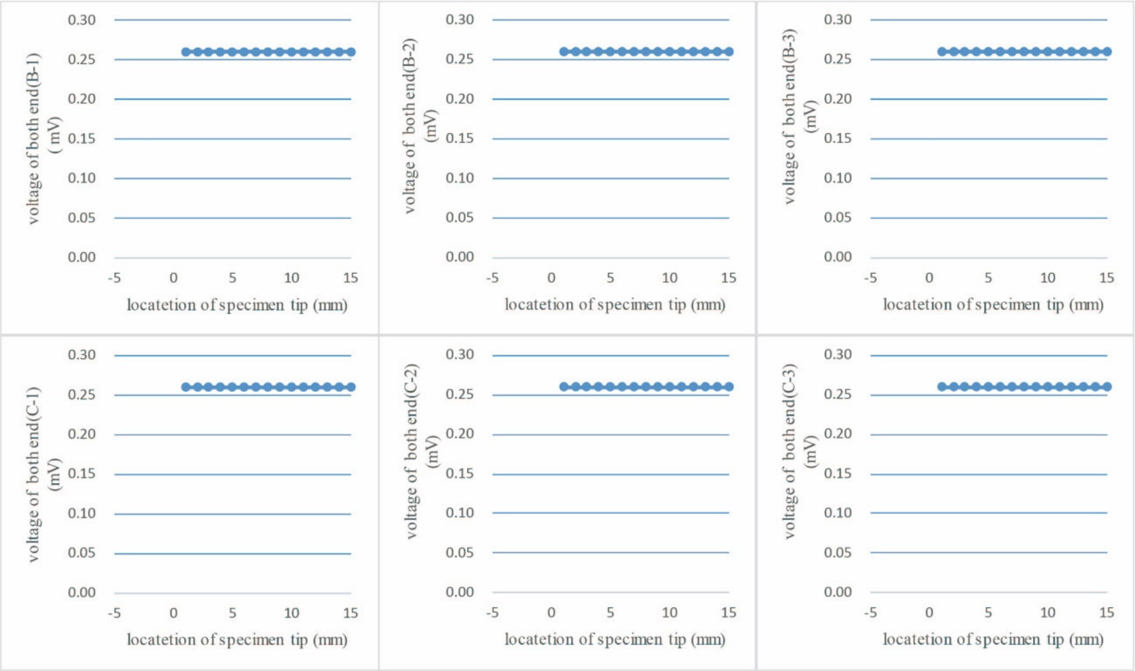
voltage of both end(B-1) (mV)
voltage of both end(B-2) (mV)
voltage of both end(B-3) (mV)
voltage of both end(C-1) (mV)
voltage of both end(C-2) (mV)
voltage of both end(C-3) (mV)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-5
0
5
10
15
locatetion of specimen tip (mm)

Fig. 5

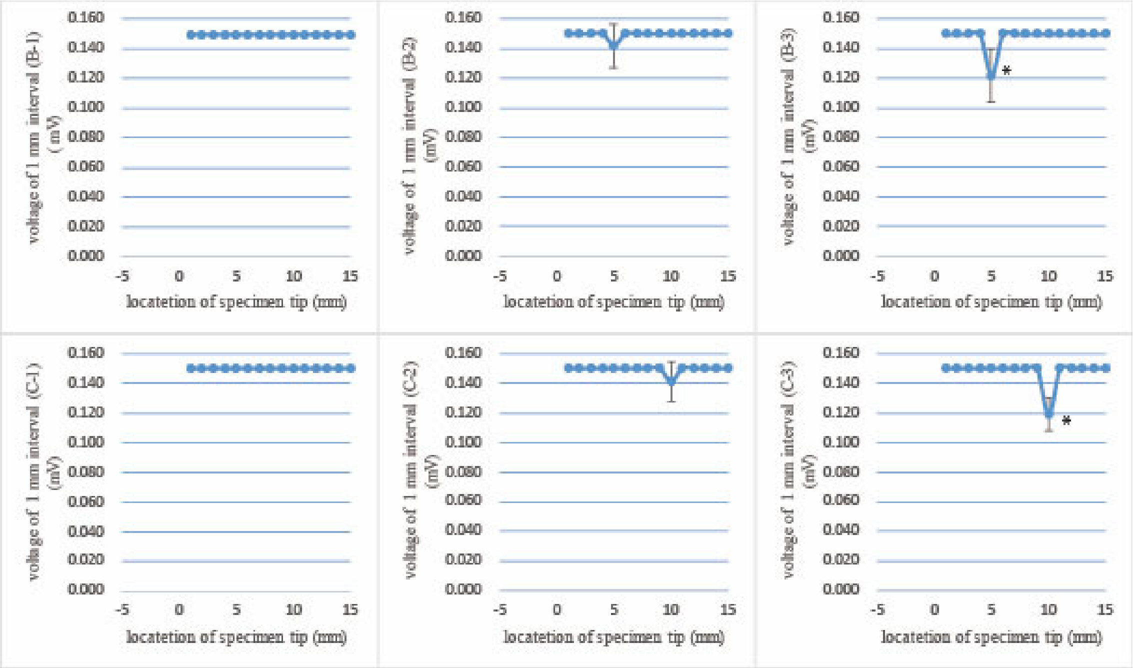
voltage of 1 mm interval (B-1) (mV)
voltage of 1 mm interval (B-2) (mV)
voltage of 1 mm interval (B-3) (mV)
voltage of 1 mm interval (C-1) (mV)
voltage of 1 mm interval (C-2) (mV)
voltage of 1 mm interval (C-3) (mV)
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-5
0
5
10
15
locatetion of specimen tip (mm)
*

Fig. 6