Sensitivity of the Root Canal Impedance to Electrode Displacement – in vivo and in vitro Measurement

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Abstract. *Root canal impedance measurement was carried out in vivo on a series of patients and in vitro on a model (tooth dipped into a saline solution). Impedance was measured for several file tip displacements from apical foramen in the frequency range from 100 Hz to 1 MHz. Comparison between in vivo and in vitro results was performed for the measured value of impedance and for the components (Rp, Cp) of two element parallel equivalent circuit. It has been shown that normalized values obtained on apex have very similar frequency dependence, but the sensitivity to electrode displacement differs great in magnitude and its frequency dependence when measured in vitro from the one obtained in vivo. It is possible to use model – based measurements to draw some conclusions or test apex locator devices if the measurement is conducted on apex, when the file is displaced from apex difference towards in vivo measurement becomes significant.*

Keywords: apical foramen location, impedance sensitivity, in vitro measurement

1. Introduction

Apical foramen (*apex*) location is important part of endodontic treatment; its accuracy directly affects the success of entire treatment.

Nowadays there is a tendention to use electronic devices, the so-called apex locators, because their use minimizes the need for x-ray examination. Accuracy of modern apex locators is very close to the one achieved by radiological methods. The operating principal of apex locators is measurement of electric impedance [1] [2] (or some other parameter i.e. impedance ratio at different frequencies as described in [3]) between the file introduced into the endodontically prepared root canal and the large area electrode that is fixed on the lip. The file is moved in the canal until the instrument indicates that the tip of the file is positioned at the apical foramen.

Measurement of root canal impedance is used as a research method to determine the behavior of impedance under influence of different factors (frequency, excitation waveform and magnitude, measurement method, file tip position…) and for testing and comparison of electronic apex locator devices.

Often measurements or tests on open root canal (*in vivo*) are not feasible, then the physical model is introduced [2] [4-7]. Because model based measurements are used to draw conclusions about construction parameters of apex locator it is important to know what are the limitations of model usage.

This study intends to compare the behavior of impedance and components of two element parallel equivalent circuit when measured in vivo and in vitro.

2. Subject and Methods

In vivo measurement were carried out on a series of 13 open root canals. Kerr file introduced in the root canal was used as active electrode. Large area passive electrode of stainless steel was fixed on a lip. Value and phase angle of impedance between electrodes were measured at 13 logarithmically distributed frequencies in the range from 100 Hz to 1 MHz for 3 positions of the file tip: apical foramen, 0,5 mm below foramen (+0,5mm) and 0,5 mm above foramen (-0,5 mm). After the pulp was removed root canal was rinsed with 2% NaOHCl solution and dried with needle wrapped in cotton wool. File was then introduced in canal and moved until its tip reached apical foramen. Foramen was detected by electronic apex locator "Endometer ES-02". Root canal length was then marked on the file, as reference for –0,5 and +0,5 mm displacing.

Hewlet-Packard HP4284A LCR meter was used to measure impedance. Measurement and data storage were computer controlled via HPIB (IEEE-488) bus. Software to control measurement was built in HP VEE development environment.

Measurement in vitro was carried out on a physical model that consisted of a tooth dipped into a saline solution. [2] [4–7] Large area stainless steel electrode was also dipped into solution and Kerr file was introduced in the root canal and positioned by a micrometer. Measurement was repeated several times with different teeth. Impedance was obtained applying the same frequencies and excitation as in *in vivo* measurement.

3. Results

Measurement results were obtained as described for every canal. Average values were calculated for |Z|, Rp and Cp for *in vivo* and *in vitro* measurement. Fig 1. to 3. show frequency dependence of average values of |Z|, Rp and Cp when file tip is placed on apex.

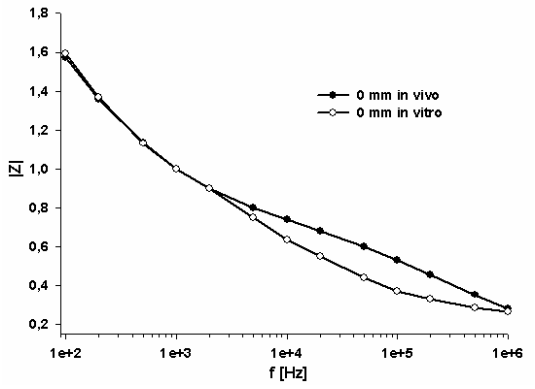

Fig. 1. Average values of |Z| *in vivo* and *in vitro*

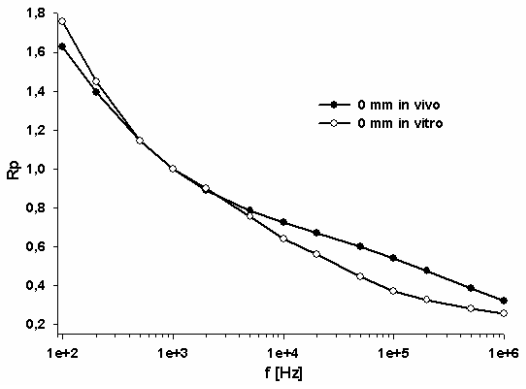

Fig. 2. Average values of Rp *in vivo* and *in vitro*

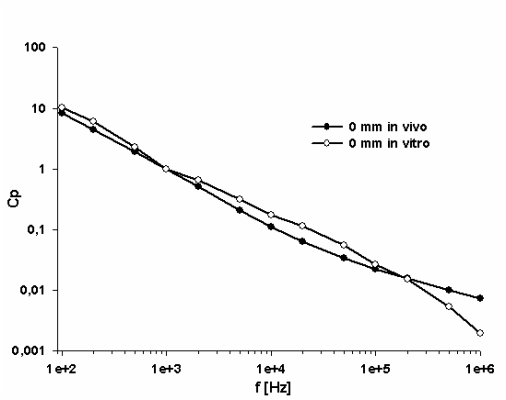

Fig. 3. Average values of Cp *in vivo* and *in vitro*

Because magnitudes of *in vitro* measurement results differ significantly from *in vivo* measurement. All results were normalized. Every result of measurement was divided with the value of specific measured variable obtained on apex at 1 kHz frequency. 1 kHz frequency was chosen because most of apex locators operate near that frequency. Effect of normalization can be achieved in measurement by decreasing the solution conductivity.

4. Discussion

Fig. 1. to 3. show that values measured on model have frequency dependence similar to the dependence of *in vivo* results. For the frequencies below 2 kHz differences between in vivo and in vitro value of |Z| are less than 1%. Above that frequency differences become larger. Maximal difference is 43% at 100 kHz. Although this difference is significant it should still allow model to be useful for some measurements. As shown in Fig. 2. and 3. Rp and Cp curves measured *in vivo* and on model show similar frequency dependence as |Z|.

Fig. 4. 5. and 6. show sensitivities to electrode displacement. Sensitivity is defined as a relative change of variable caused by displacing the tip of the file from apex.

$$S(X,0{,}5) = \frac{X(0{,}5) - X(0)}{X(0)}$$

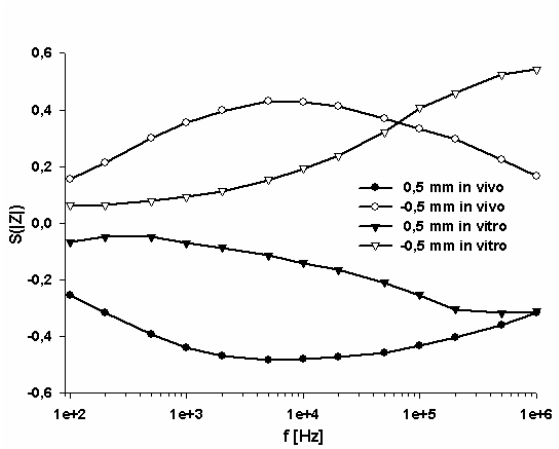

Fig. 4. Sensitivity of |Z| to electrode displacement

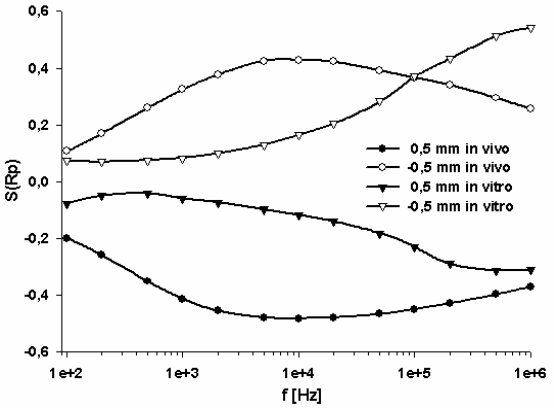

Fig. 5. Sensitivity of Rp to electrode displacement

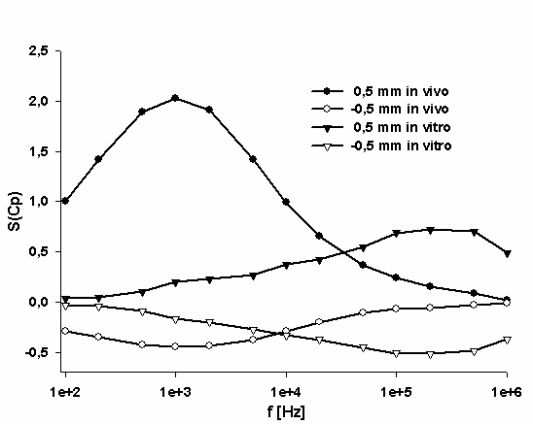

Fig. 6. Sensitivity of Cp to electrode displacement

One can see that sensitivities for |Z| and Rp *in vivo* measurement achieve maximum (or minimum) for value around 5 kHz and Cp around 1 kHz. Frequency dependence for in vitro measurement does not show any extremes. Sensitivity of |Z| can be around 6 times (f = 1kHz) greater when measured *in vivo* than in model measurement. Rp sensitivity shows similar behavior to |Z|, Cp model results behave completely at odds with *in vivo* measurement.

Differences in sensitivity are great enough to cause wrong indication of apex locator when tested on model.

5. Conclusions

In vivo and in vitro measurement of root canal impedance were carried out for three file tip positions and for the frequencies in the range from 100 Hz to 1 MHz. Frequency dependences of Rp and Cp components of two element equivalent circuit were calculated. Comparing the *in vivo* and *in vitro* results on apex conclusion is drawn that model gives a good representation of in vivo measurement.

Comparison of sensitivity to electrode displacement shows that there is no coincidence between *in vivo* and *in vitro* measurement when the tip of the file is displaced from apex. Accordingly model – based measurement should be used to draw conclusions about specific effects or to test devices only when measurement is carried out on apex, or when one is positive that different behavior when file is displaced does not affect his/her conclusions.

Beside file tip displacement there are other factors that affect the result of root canal impedance measurement (i.e. apical foramen and file diameter [8], substances used in endodontic treatment, blood, etc.) and were not considered here.

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