

Needle position determined by tissue impedance

H. Kalvøy¹, S. Grimnes^{1,2} and Ø.G. Martinsen²

¹ Rikshospitalet/Dept. of Biomedical & Clinical Engineering, Oslo, Norway

² University of Oslo/Dept. of Physics, Oslo, Norway

Abstract— In this project we have shown that small needle electrodes can be used to characterize tissue with high spatial resolution and determine the anatomical position of a needle for clinical use. Invasive needle electrodes have different designs for a wide range of applications. We studied the electric properties of some commercial available needle electrodes. Fundamental knowledge about impedance and current distribution in monopolar needle electrode systems were gathered. Needle electrodes were then used to measure different tissue models in-vitro and in anesthetized pigs. Data gathering was done by monopolar measurements of complex impedance. Tissue impedance and polarization impedance, sensitivity zone and capacitive properties of the electrodes were determined. In the measurements the small electrode areas gave considerable electrode polarization effects, but the impedance of small volumes adjacent to the needle tip also was reflected. In agreement with the analysis, only a few millimetres movement of the needle between tissues of different properties could give substantial changes in the measured impedance. These findings were used to develop a medical device prototype for the determination of needle position during insertion.

Keywords— Needle, tissue in-vivo, sensitivity zone, pig

I. INTRODUCTION

Different types of tissues are known to have different electrical impedance properties [1]. If these properties are measurable and characteristic for tissue types, an impedance measurement can be used to distinguish different types of tissue from each other. Impedance based methods have earlier been developed for finding the apex of teethes [2]. These applications are used to find the depth of a root canal, which has a defined type of geometry and electrical properties, quite different from the surrounding pulp tissue. By obtaining new knowledge and impedance data, our aim is to develop new methods for needle positioning in soft tissues.

In a monopolar setup the measured tissue impedance is dependent of the area of the measuring electrode. The measured value will reflect some kind of averaging over the tissue in electrode's proximal zone. The smaller electrode area the higher spatial resolution can be obtained. Grimnes & Martinsen [3] have pointed out that for a spherical electrode 70 % of the measured resistance are enclosed by a spherical volume with radius 3,3 times the radius of the

electrode. If we can measure the impedance in a small volume around the tip of a needle we may be able to determine the electric properties of this volume. For a type of tissue with unique properties an impedance measurement then could tell us if a needle electrode is placed in this type of tissue or not. Our idea is to exploit these fundamentals and develop a new needle positioning method for clinical use. To develop such a method we have to find applicable needle electrodes with sufficiently small sensitivity zone. And of course the feasibility is dependent of sufficient differences in characteristic properties among the tissue types in question. To determine the sensitivity zone around a needle tip, in-vitro impedance measurements tissue models was done. With knowledge of fundamental electrical properties of the needles, gathering of in vivo impedance data was done on an anesthetized pig. In a planed application for drug administration, the separation of fat and muscle are crucial. Thus one of the objectives in this study has been to determine the feasibility of such separation.

II. MATERIALS AND METHODS

Measurements: All measurements were monopolar measurements of complex impedance done with a Solartron 1260/1294-system. Spectra were taken with frequencies from 10 Hz to 1 MHz, and constant frequency measurements were done at 100 kHz and 10 kHz. Different types of needles was used, but we here only refers the experiments done with the solid measurement electrode: "Disposable Monopolar Needle Electrode, 37 x 0,33 mm" (REF 9013S0631, electrode area of 0,3 mm²), from Medtronic A/S. Pilot studies showed that a preconditioning of the needles with a cathodic current (1 μ A in 1 minute) in a sterilized saline bath (0,9% NaCl), lowered the impedance and ensured stabile measurements. All the needles were preconditioned in this way before use. Small electrode area gives substantial electrode polarization impedance (EPI) contributions in the measurements at low frequencies [4]. This is often a concern in impedance measurements which can lead to rejection of the data. But here we have taken the low frequency data in to account. We hope the EPI can make a beneficial contribution in our tissue characterisation analysis.

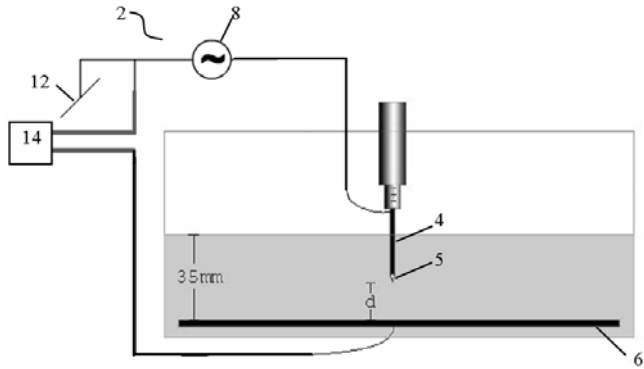


Fig. 1 2-electrode monopolar measurement setup with small active electrode (5) and large neutral electrode (6). The impedance measuring was done with a Solartron system (2). For illustration of the principle we have here drawn the voltage reference (12), voltage source (8) and the current reader (14) as separate components.

In-vitro: For the in-vitro measurements the monopolarity was obtained by using a 2-electrode setup with a large neutral electrode. Such electrode configuration enables simple setup geometries which is suited for analytical analyzes, and thus are well suited for gathering fundamental properties of the needle. A insulating vessel (bottom area 15 x 21 mm) was filled with saline (0,9% NaCl) to 35 mm high. The needle was used as active electrode (5), and the counter electrode (6) was a stainless steel plate of 104 x 150 mm. This setup is shown in fig. 1. Compared to the needle this gives us a counter electrode that is about 52 000 times larger. Intuitively the needle and its proximal zone will contribute to the majority of the systems impedance. By using a micrometer screw the needle was moved from the bottom of the vessel (0 mm, given from the counter electrode) and up to the surface of the saline (35 mm) in steps from 50 μ m to 6 mm. The steps size was smallest near the bottom and the top, and broader in the middle of the bath. At each distance from the bottom the impedance at 100 kHz was measured.

For further investigating the spatial dependence we wanted to use a more complex and tissue like model. Impedance modulus at 10 kHz as a function of time was measured with a piece of bacon as a model. We used ordinary salted bacon from the supermarket. This most probably have quite different impedance properties from tissue in-vivo, but can still be a beneficial model of a sample containing tissue with different properties. An electro motor was arranged to give constant needle insertion speed. This way we could reconstruct the position of the needle from the time scale. To obtain monopolar measurements in vivo the Solartron system was used as a 3-electrode setup. The principles of such a setup are described by Grimnes and Martinsen, 2000 [3]. Silver-silverchloride electrodes (“Blue sen-

sor” Q-00-A, Ambu Medicotest A/S DK) was placed on the skin and used as current and reference electrodes.

In-vivo: In-vivo impedance data were gathered by measuring on an anesthetized pig (app. 30 kg). We here used 3-electrode system with the same type of needle and silver-silverchloride electrodes, as used in the bacon measurements. The placement of the current and reference electrodes was done so that no unnecessary series impedance was introduced. To ensure fully contact the skin was shaved before placement. The needles were placed in different types of tissue by an experienced surgeon. Accesses to muscle, fat, spleen, liver, bile, urine and blood were obtained by cutting through the skin and place the needles directly into the tissue. Needle placements were picked so that the tissue around the needle tip was as homogenous as possible, and the insertion depth was approximately 10 mm. The homogeneity of the tissue sample volume and the needle position was ensured by Ultra Sound (GE Vingmed Ultrasound, System Five) operated by an experienced radiologist. Such measurements were done with repeated placements in up to 6 samples of each tissue type. Exclusion criteria were that the ultra sound tissue characterization was uncertain or if any production error or damage was detected in the needle insulation. All needles were inspected before and after the measurements.

III. RESULTS

The dependency between position and impedance in the in vitro measurements are shown in fig. 2. The curve clearly shows that the modulus ($|Z|$) almost is independent of the position in the middle of the vessel, but has abrupt changes near the top and bottom. Moving the needle from 0 to 2,6 mm up from the bottom increases the modulus from short circuit to 385 Ω . This corresponds to 97 % of the 396 Ω modulus at 17 mm. A corresponding change is seen at needle positions near the saline surface, where the modulus increase as the needle are moving toward the high impedance in air.

From this we can conclude that the measured modulus is dominated by the impedance in a zone inside a 2-3 mm radius from the needle tip. The same trend is seen in the phase angle, but here we also have a small dependency in the middle area. This is mostly due to the capacitive coupling over the needles insulation (4 in fig. 1). The insulation can be looked upon as a dielectric layer between the needle and the saline. Such capacitance is proportional to the contact area in the saline, and thus proportional to the insertion depth. In other studies we have found that this dependency is more pronounced at higher frequencies and can be used as a measurement of insertion depth.

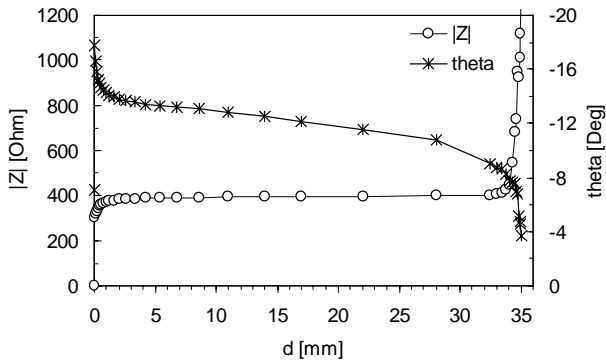


Fig.1 2 Impedance at 100 kHz in the saline filled vessel shown in fig. 1 Above the saline surface (35 mm) there is air which represents a volume with almost infinite impedance. In the other end (0 mm) the neutral electrode represents a volume with approximately zero impedance.

For the bacon measurement a visual representation of the result was made by plotting the measured impedance modulus on a picture of the bacon (fig. 3). The needle position was calculated from the insertion speed and sampling time. The bacon was sliced along the needle path to reveal the sampled part of the bacon. The picture of the measured bacon slice was taken and scaled proportional to the X-axis of the measured modulus. The needle was inserted horizontally starting from the red mark in the picture. Fig. 3 shows distinct differences in measured modulus between fat and muscle tissue, and the spatial resolution is seen in the abrupt changes caused by small movement of the needle.

The in vivo impedance for fat and muscle tissue is plotted in fig. 4. For frequencies higher than 200 kHz the modulus ($|Z|$) shows clear separation between the tissue types. For the phase angle (theta) a resembling result is seen between 20 and 100 kHz. Typical spectra for all tissue types are plotted in fig. 5. The spectra have quite different patterns dependent of tissue type, and both the modulus and phase seem sufficiently spread for tissue characterization.



Fig.3 Measured modulus at 10 kHz plotted as a function of insertion depth in a piece of bacon. The red mark indicates the starting point of the horizontal needle insertion path.

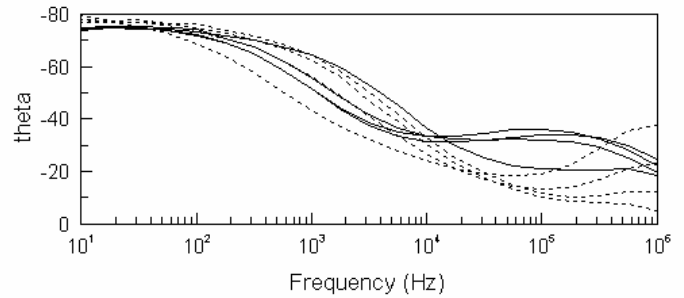
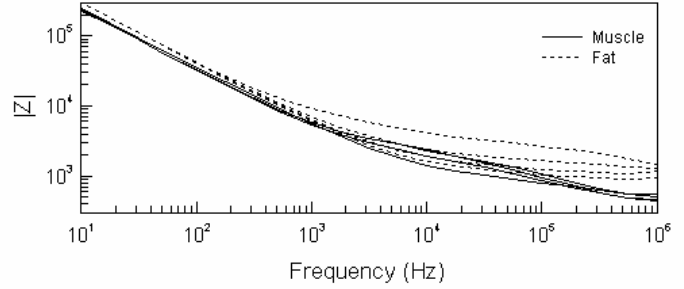


Fig.4 Complex impedance spectra measured with Medtronic "Monopolar needle electrode" in 4 samples of fat and 4 samples of muscle tissue in living pig. The modulus ($|Z|$) is given in Ohms and the phase angle (theta) is given in degrees

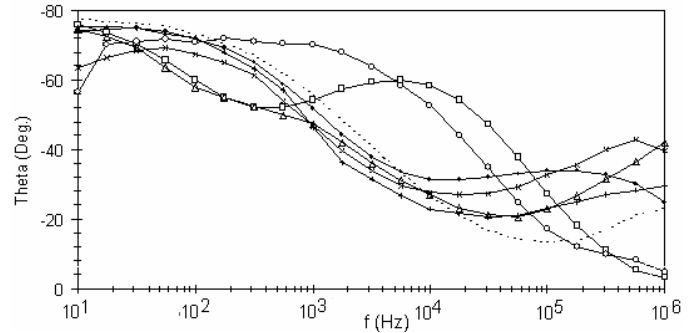
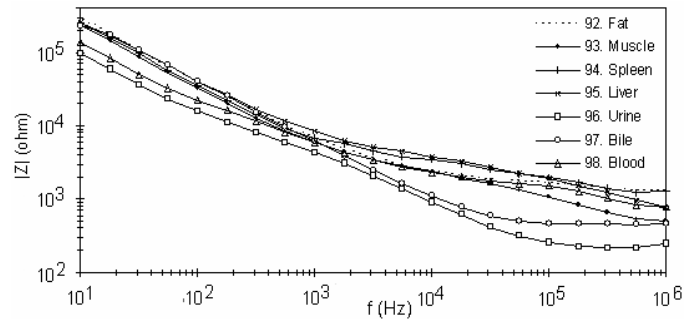


Fig.5 Impedance modulus and phase from measurements in 7 different tissues.

III. DISCUSSION

Above we have presented parts of our study concerning bioimpedance and determination of the anatomical position of a needle. Together these results form a convincing proof of the feasibility of our method for needle position guiding in clinic.

First fig. 2 shows that the sensibility zone of our monopolar needle electrode systems is small enough for tissue discrimination with relatively high spatial resolution. The phase angle measurements contained information of the contact area between needle and tissue. This enables determination of needle depth from our measurement method.

In fig. 4 we saw that characteristic tissue properties repeatedly could be measured in different samples of fat and muscle tissues. This result together with previous screenings of different needle types (not presented here) indicates that impedance-guided needle positioning can be used with needles for clinical applications.

Single measurements from 4 tissues and 3 body fluids, are plotted in fig. 5. The spectrum from these tissue types shows considerable differences both in phase and modulus. We are now working on a multivariate analysis to develop a separation algorithm based on our data. This analysis is not ready for publication yet, but the results looks promising so far.

EPI are traditionally looked upon as an error and exclusion criteria in tissue impedance measurements. But in our study we have seen promising results using measurements dominated by EPI. In the low frequency range of our measurements (fig. 4 and fig. 5) clear tissue dependence is seen. In our opinion interpretations of EPI-dominated measurements will bring considerable contributions to future bioimpedance applications.

III. CONCLUSIONS

We have in this study showed the feasibility of a new method for determining the anatomical position of a needle by monopolar bioimpedance measurements. This was done by uncovering fundamental properties of needle electrodes and tissue in vivo. For clinical use sufficiently spatial resolution are obtained due to the small sensitivity zone. The separation of fat and muscle tissue is proven, and the possibility to separate other tissue types looks promising so far.

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Address of the corresponding author:

Author: Håvard Kalvøy
Institute: Dept. of Biomedical & Clinical Engineering, Rikshospitalet
Street: Sognsvannsveien 20
City: 0027 Oslo
Country: Norway
Email: havard.kalvoy@rikshospitalet.no