The Effect of Contact Pressure on Ex-vivo Measurements of the Conductivity of Liver

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Abstract—In this study we measured the electrical conductivity of bovine liver. The measurements were performed at frequencies from 10 Hz to 10 kHz (N=5 frequencies) using a custom four-electrode probe and a galvanostat. We examined how the pressure applied between the probe and the tissue influenced the conductivity of the tissue. We performed measurements at N=10 different pressure levels by both increasing (forward direction) and decreasing (reverse direction) the pressure. We found that the conductivity of the tissue drops with pressure, regardless of the direction. However, we found that the decrease of conductivity with respect to applied pressure was small compared to other soft tissues (e.g. muscle tissue). The results from this study suggest that the dependence of conductivity on applied pressure should not have a significant impact on the design of medical devices which depend on accurate knowledge of the impedance provided that their target is the liver.

Index Terms—liver, conductivity, biological tissues, measurements.

I. INTRODUCTION

The electrical conductivity of liver is important in both the design of the irreversible electroporation (IRE) devices and electroporation treatments of the liver cancer [1] as well as for the assessment of electroporation by electrical impedance methods [2]. Electroporation is a phenomenon that increases cell membrane permeability due to externally applied pulsed electric fields [3]. IRE, in which permeabilization disrupts cellular homeostasis and leads to cell death is gaining importance in routine clinical practice for nonthermal ablation of solid tumors [4,5]. IRE is based on the pulsatile application of an electric field (1,000-1,500 V/cm) between electrodes inserted around the tumour [1]. A power spectral analysis of IRE pulses shows that most of the energy of the pulses is between 10 kHz and 40 kHz for unipolar pulses and 500 kHz for high-frequency bipolar pulses, depending on the exact shape of the pulse [6].

One of the challenges in the measurement of electrical conductivity of soft tissues is the pressure dependency of the conductivity. Each type of tissue responds differently to compression, where the slopes of the conductivity-pressure plots differed between the tested tissues [7]. The change in conductivity due to the applied pressure is due to changes to the electrolyte or fluid volume in the tissue. Under tissue compression, pressure gradients develop within the tissue and act to drive fluid out of both the intra- and extracellular spaces [8]. This results in decreasing conductivity with added pressure as intra- and extracellular fluids contain electrolytes that contribute to the overall conductivity of the tissue.

In this study, we have examined how the applied pressure between the measurement probe and the liver influences the conductivity of liver. The potential change in the conductivity that is being measured would mean that the electrodes used to deliver the IRE pulses and the electrode used to assess the electroporation would measure different impedance depending on the pressure applied between the electrodes and the tissue. If the impedance would change drastically with the applied pressure then this effect should be accounted for in the design of the IRE treatment and monitoring devices.

II. MATERIALS AND METHODS

In this study, we examined how the amount of applied pressure between the liver tissue and the measurement probe affects the measurement of the electrical conductivity of the liver. The bovine liver was acquired from the local abattoir and transported to the laboratory immediately after being excised. The temperature of the liver was measured once before measurements and was T=23 °C. Figure 1 shows the liver sample used in this experiment.

Figure 2 shows the measurement setup. In order to measure the pressure between the tissue and the probe, the liver was placed on a weighing scale under the measurement probe. The weighing scale was "zeroed" before the probe made contact with the liver. The probe was then brought into contact with the tissue and the pressure was monitored on the weighing scale (via applied force).

The acquisition of the complex impedance at five different frequencies (f = 10 Hz, 100 Hz, 1kHz, 10 kHz and 100 kHz) was performed using the custom four-electrode probe [9–[11] with a PGSTAT204 galvanostat (Metrohm Autolab B.V., Utrecht, The Netherlands). The dimensions of the face of the probe are 20x8 mm which corresponds to the surface area of 160 mm².

The weight (in g) measured by the scale was only due to the force being applied between the probe and the tissue. Every 102g of measured mass corresponds to 1N of force (F=Gm, G=9.81 m/s²). We calculated the applied pressure by dividing the calculated force (in N) with the surface area of the probe (in m²). Each N of force corresponds to the pressure of 6.25 kPa. We applied the force first in forward direction by increasing it from 1N to 10N (1N steps, N=10). In the second part of the experiment we applied the same N=10 forces by decreasing the force from 10N to 1N (1N steps). The force range from 1N to 10N corresponds to the pressure range from...
conductivity of liver in the database is taken from from the previous studies by Gabriel et al. in 2009 [14], Geddes et al. in 1967 [15] and Hahn et al. in 1980 [16]. The database does not give the values of electrical conductivity for a list of frequencies, but lists only one value for all frequencies below 1 MHz. The conductivity of liver reported in the database is 0.221 S/m with a standard deviation (SD) of 0.352 S/m (ranging from 0.0637 S/m to 1.95 S/m) [13]. In Figure 3 we can see the liver conductivity measurement results versus the measurement frequency. We can see that the data points are very clustered at each frequency, meaning that there is no significant change in the measured conductivity with the applied force. We also see that the measured conductivity is lower at low frequency (around 0.035 S/m at 10 Hz) and rises with frequency (around 0.08 S/m at 100 kHz). Since our data at frequencies lower than 100 kHz falls below the minimum reported value from the literature [13], the pressure dependence was analysed only at 100 kHz. It is worth noting however that the literature data is highly uncertain with higher standard deviation than the mean value [13].

B. Pressure Dependency

Regression analysis in Table I shows only an 0.8% change in conductivity for every 1N of applied force (every 6.25 kPa of pressure) in both forward and reverse direction. Figure 4 shows the dependency of the measured conductivity on the applied force. We can see that this small change in the conductivity with pressure means that the conductivity essentially remains constant (around 0.08 S/m) for all applied pressures.

IV. CONCLUSION

This study shows that liver tissue conductivity does not change significantly with the moderate pressure changes with the four-electrode probe. The conductivity does decrease as we apply more pressure, which is an expected effect due to the fluid being pushed out of the tissue. The main difference between liver and other soft tissues is in how much the conductivity changes. In this study, the conductivity of liver only changes by 0.8% per 1N of applied force (per 6.25 kPa of applied pressure). Such small differences should not have a significant impact on the design of IRE treatment and monitoring devices, provided that their intended target is liver.

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