Journal of Physics: Conference Series

Monitoring of breast tissue thermo-ablation by means of impedance measurements

To cite this article: K Lukaszewicz *et al* 2010 *J. Phys.: Conf. Ser.* **224** 012136

Monitoring of breast tissue thermo-ablation by means of impedance measurements

K Lukaszewicz[a,1], J Wtorek[a], A Bujnowski[a], and J Skokowski[b]
[a]Department of Biomedical Engineering,
Gdansk University of Technology, Narutowicza 11/12, 80-233 Gdansk, Poland
[b]Department of Surgical Oncology, Medical University of Gdansk, Dębinki 7, 80-233 Gdansk, Poland,
E-mail: lukaszewiczk@gmail.com

Abstract. A usefulness of a developed probe combining power delivery to ablated breast tumour and simultaneous impedance measurements is discussed in the paper. It consists of a cylindrical electrode used for applying ablation current and four rings electrodes. They are located, in pairs, at both ends of the ablation electrode. The probe properties were examined using a simulation studies - Laplace and bio-heat equations were solved. An associated distribution of power absorbed by tissue was calculated. Temperature dependence of tissues' conductivity was assumed. This dependence involved an iteration procedure for solving the considered problem. The four-electrode probe enabled monitoring the insertion and the ablation process.

1. Introduction

A breast cancer takes the second place on a list of the most common types of cancer. Moreover, it is a fifth reason of carcinomas-induced death worldwide. In 2004 this disease caused 519,000 deaths all around the world which is 7% of cases involved by cancer [1]. There are many treatment procedures applied e.g. chemotherapy, hormone therapy, radiation and surgery. It is mainly due to a diversity of breast cancer types. They are dependent on carcinoma stage, its aggressiveness or genetic makeup. There is a trend observed to use minimally invasive procedures and to avoid, if it is possible, surgical operations like mastectomy.

Radiofrequency thermo-ablation (RFA) is minimally invasive surgical technique which applies frequency alternating electrical current to destroy the pathogenic tissue. An electrical current of 500 kHz frequency while flowing through the biological tissue causes its heating. If it is strong enough it may cause a coagulative necrosis of the tissue, assuming that it is being heated above 50 Celsius degree. Nowadays, the method is commonly utilized in treatment of non-resectable hepatic tumours, tumours of bone, kidney, lung and also breast. It is also used to destroy abnormal electrical pathways in heart tissue.

The surgical intervention relies on accurate insertion of working electrode (needle) into the treated tissue and application of enough RFA power to destroy it. The procedure is performed under guidance using imaging techniques, e.g. X-Ray, CT or ultrasound. Recently, commonly discussed problems are how to reliably estimate the necrosis area caused by radiofrequency ablation current and how to find out if the changes in carcinoma tissue are irreversible one [4].

[1] To whom any correspondence should be addressed.

The objective of the presented study was to investigate usefulness of a developed probe combining power delivery to ablated breast tumor and simultaneous impedance measurements. The trial to use impedance measurement to evaluate the size of tumor before and after RFA was made in wide frequency range and in different temperatures of sample tissues. Electrical impedance measurements were also used for monitoring the position during an insertion procedure of the ablation catheter.

2. Methods

2.1. Problem statement and a probe construction

The developed probe is composed from one cylindrical electrode used as RFA current inlet and four rings electrodes. Ablation current is flowing between the cylindrical and the dispersive electrodes. In addition, these two electrodes enable electrical impedance measurement. The rings electrodes, which form a four-electrode probe, are used for measuring impedance of heated tissue. They are located, in pairs, symmetrically at both ends of ablation electrode (figure 1).

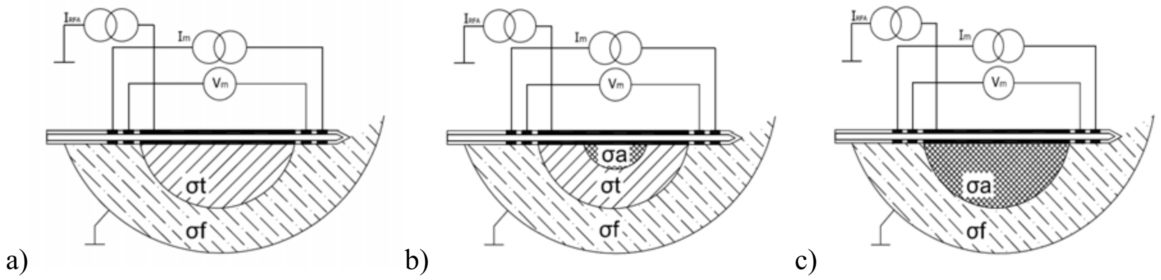


Figure1. Cases considered in the study a) beginning of ablation, b) intermediate state of ablation, c) final state after ablation, σ_t – conductivity of tumour tissue, σ_a – conductivity of ablated tissue, σ_f – conductivity of surrounding tissue, I_m – measurement current I_{RFA} – ablation current

2.2. Theoretical model

Proposed probe was modelled using finite element method (FEM) in Matlab environment. It was assumed that RF ablation process would be described by bio-heat equation in thermal domain [4, 5]:

$$\rho c \frac{dT}{dt} = \nabla\left(k(T)\nabla T\right) + q + \rho_b C_b \omega\left(T - T_{bl}\right) + Q_m, \tag{1}$$

where ρ - the tissue density (kg/m3), c - the heat capacity (J/kg°C), k - the thermal conductivity (W/°C m), q - the electrical energy source, ρ_b - the density of blood, C_b - the heat capacity of blood, ω - the blood perfusion, T_{bl} - the basal temperature of the blood, and Q_m - the metabolic heat source.
In electric field domain Laplace equation is used [4, 5]:

$$\nabla\left(\sigma(T)\nabla\varphi\right) = 0, \tag{2}$$

where: $\sigma(T)$ - electrical conductivity, φ potential.

Above equations have been solved using appropriate boundary and initial conditions. Electrical and thermal conductivity of investigated tissue were assumed to be temperature dependent. Power distribution absorbed by tissue volume was calculated according the following formula:

$$\int q dV = \int \mathbf{E}\cdot\mathbf{J} dV = \int \frac{\mathbf{J}^2}{\sigma(T)} dV = \int \sigma(T)\mathbf{E}^2 dV \tag{3}$$

where: **E** – electric filed, **J** – current density.

Difference in electrical conductivity between normal, carcinoma and ablated tissue was found as potentially useful when electrode positioning and estimating of tumour and ablated tissue region [3, 7].

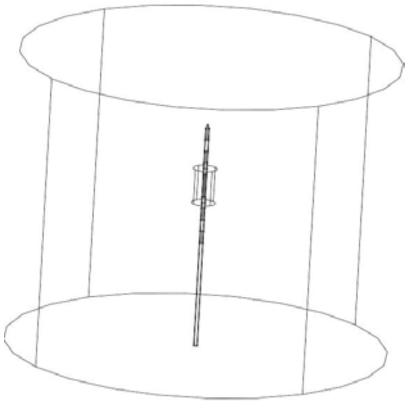


Figure 2. Cylindrical 3D model of the considered problem

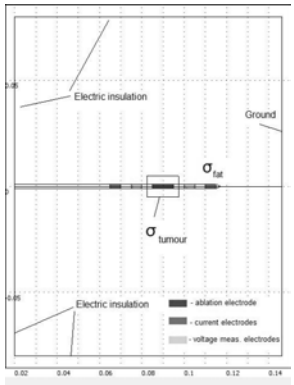


Figure 3. Axial cross-section of the model, conductivity of regions, boundary conditions and electrodes are also presented

A relatively precise model including all electrodes was developed using Finite Element Method (figure 2) [4, 5, 6]. Then, it was implemented and solved in Matlab. The measurement current was of frequency not exciding 1 MHz. The electrode placement was so chosen that the created spatial sensitivity was optimal to monitor conductivity change undergoing in the vicinity of ablation electrode (figure 3).

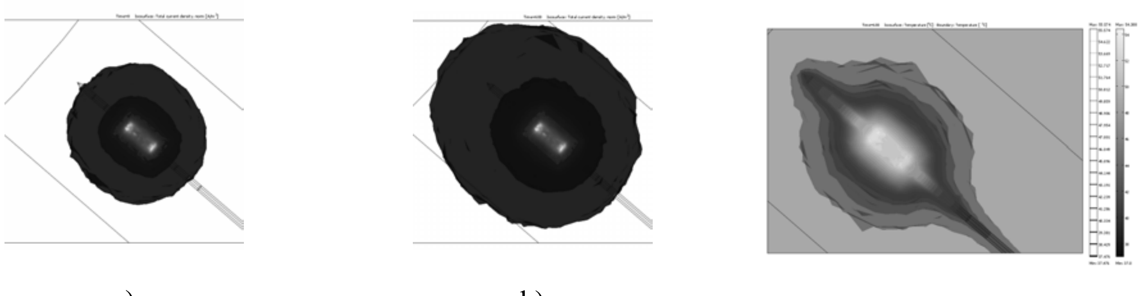
2.3. Experimental measurements

Conductivity of biological materials as a function of temperature was measured. A measurement system and a custom probe consisting of a glass pipe filled with saline and covered by accurately mounted four silver rings were developed. The probe was inserted into examined material filling a thermally isolated box. The selected temperature of examined material was set by passing a current through the saline. Electrical impedance module |Z| and phase φ were registered in wide frequency range of the current, from 10 Hz to 1 MHz, and in different temperatures of the examined sample.

To confirm the simulation results two measurements procedures were developed and applied. The measurements were performed using two- and four-electrode systems. Two-electrode system was composed of ablation and dispersive electrodes while the latter one of ring electrodes. Ablation and measurement currents were applied interchangeably. In case of ablation period the Rita system [2] was connected to the electrodes while during a measurement period Solartron SI1260 was used.

3. Results

The results of the current and temperature distributions depend on electrical properties of modelled tissues. However, spatial character of distributions was similar (figure 4).



a) b) c)

Figure 4. Current density distribution a) before ablation, b) after ablation and c) temperature distribution at the end of thermo-ablation procedure

Also potential distribution when measuring impedance by means of the four – electrode probe was as expected one (figure 5). A shape of the destroyed tissue is given in figure 6.

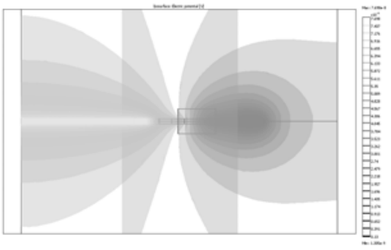


Figure 5. Potential distribution involved by measurement current when the four – electrode probe is utilized

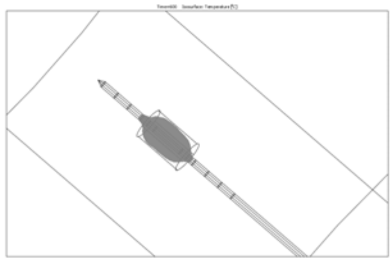
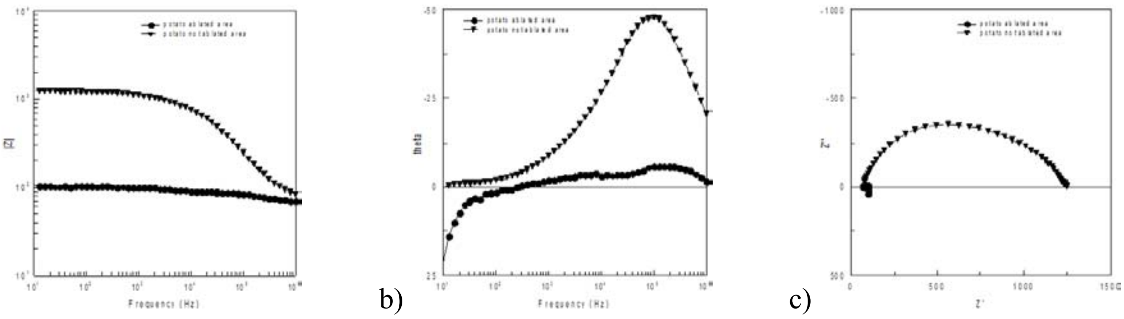


Figure 6. A shape of the ablated tissue assuming that a certain value of temperature inside of tumour tissue is reached

The values of measured impedance module and phase between life and coagulated tissues (potato, liver, muscle) were found to be visibly different (figure 7). The four-electrode technique was used.



a) b) c)

Figure 7. Electrical properties of biological tissue examined a) impedance modulus, b) phase function, and c) presentation of data on a complex plane. The tissue properties before applying ablation procedures are marked by triangles

4. Discussion and conclusion

Both theoretical and experimental studies were performed. The examined models have shown that maximum RFA current density occurs in area close to active electrode. The ablated tissue was also examined experimentally. The results obtained from experiments prove that tissue was destroyed in estimated theoretically region. Thus, it was possible to estimate the size of tissue characterized by an assumed value of temperature. It is expected that a further improvement of accuracy will be achieved due to introduction into estimation method the knowledge of ablation electrode temperature and more reliable thermal characteristics of tissues' conductivity.

References

[1] Breast Cancer *Merck Manual Online* www.merck.com/mmpe/print/sec18/ch253/ch253e.html
[2] Angiodynamics, Rita Model 1500X Generator and Uniblade RFA electrode user guide
[3] C Gabriel et al 2009, Electrical conductivity of tissue at frequencies below 1 MHz *Phys. Med. Biol*. 54 4863-4878
[4] Ekstrand V et al 2005 Influence of electrical and thermal properties on RF ablation of breast cancer: is the tumour preferentially heated? *BioMedical Engineering OnLine* 2005, 4:41
[5] Chang I 2003 Finite Element Analysis of Hepatic Radiofrequency Ablation Probes using Temperature-Dependent Electrical Conductivity. *Biomed Eng Online*, 2:12.
[6] Haemmerich D et al. 2002 Finite-element analysis of hepatic multiple probe radio-frequency ablation *IEEE TBME* 49:836-42.
[7] Hammerich D, Ozkan O R, Tsai J Z, Staelin S T, Tungjitkusolmun S, Mahvi D M and Webster J G 2002 Changes in electrical resistivity of swine liver after occlusion and postmortem *Med. Biol. Eng. Comput*. 40: 29–33