Transoesophageal detection of heart graft rejection by electrical impedance: using Finite Element Method simulations

G.Giovinazzo[1], N.Ribas[2], J.Cinca[2] and J.Rosell-Ferrer[1]

[1] Center for Research in Biomedical Eng. (CREB). Dept. of Electronic Eng., UPC, Barcelona, Spain

[2] Hospital de la Santa Creu i Sant Pau, UAB, Barcelona, Spain

E-mail: ggiovinazzo@eel.upc.edu

Abstract. Previous studies have shown that it is possible to evaluate heart graft rejection level using a bioimpedance technique by means of an intracavitary catheter. However, this technique does not present relevant advantages compared to the gold standard for the detection of a heart rejection, which is the biopsy of the endomyocardial tissue. We propose to use a less invasive technique that consists in the use of a transoesophageal catheter and two standard ECG electrodes on the thorax. The aim of this work is to evaluate different parameters affecting the impedance measurement, including: sensitivity to electrical conductivity and permittivity of different organs in the thorax, lung edema and pleural water. From these results, we deduce the best estimator for cardiac rejection detection, and we obtain the tools to identify possible cases of false positive of heart rejection due to other factors. To achieve these objectives we have created a thoracic model and we have simulated, with a FEM program, different situations at the frequencies of 13, 30, 100, 300 and 1000 kHz. Our simulation demonstrates that the phase, at 100 and 300 kHz, has the higher sensitivity to changes in the electrical parameters of the heart muscle.

1. Introduction

Organ rejection may cause edema, leucocytary infiltration, inflammation, ischemia and, in some cases, fibrosis or cell necrosis. That is why there are changes in the electrical properties of the myocardial tissues after transplanted heart rejection and for this reason electrical impedance measurement can be used to detect cases of heart rejection. In fact, previous studies [1][2][3][4] have shown that it is possible to evaluate heart graft rejection level using a bioimpedance technique by means of intramural electrodes or using an intracavitary catheter.

However, this last technique medical approach does not have important advantages compared to biopsy, because in both cases the patient has to be measured in a catheterization room under fluoroscopic guidance. Moreover, the cost of the percutaneous catheter is comparable to the catheter used for biopsies. For this reason, we propose to use a less invasive technique that consists in the use of a transoesophageal catheter and two standard ECG electrodes on the thorax.

The aim of this work is to evaluate, using Finite Element Method, several parameters affecting the impedance measurement, including: sensitivity to electrical conductivity and permittivity

of different organs in the thorax, changes in module and phase due to a lesion producing a scar, a global ischemia of the heart and pleural effusion in the lungs. From these results we deduce the best estimator for cardiac rejection detection and we obtain the tools to identify possible cases of false positive of heart rejection due to other factors.

2. Methods

In order to create the model (fig. 1), we used computer assisted tomography (CT) and magnetic resonance (MR) images of the trunk from [6]. Conductivity and permittivity values are taken from [5]. We developed an assembly of a thorax model, consisting on a combination of parts that are: thoracic muscles, subcutaneous fat, ribs and sternum, heart, lungs, blood inside the heart, spinal column, aorta, superior cava vein and, finally, surface electrodes. We choosed not to detail further the created model for two reasons: 1) the large differences in electrical conductivity and permittivity data for different tissues published in various studies, that will be a major source of error and 2) the design with SolidWorks must be simple in order to allow Comsol Multiphysics to import it and produce a Finite Element (FE) mesh with a limited number of elements.

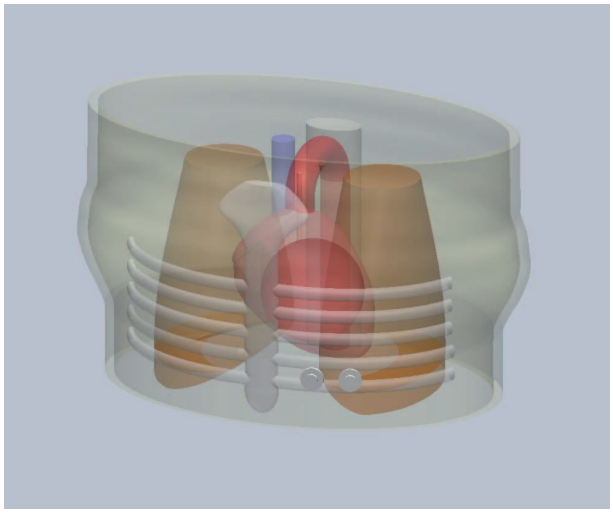

Figure 1. Design of a human thorax developed with SolidWorks.

3. Simulation results

3.1. Impedance changes in presence of ischemia or necrosis (scar) of heart tissues

The aim of this study is to verify the maximum expected changes in transoesophageal bioimpedance measurement considering the extreme cases of a global acute ischemia and a global scar of the cardiac tissue.

Our simulation demonstrates (fig. 2) that, comparing a transoesophageal measurement with normal values of electrical conductivity and permittivity with those in presence of a global cardiac ischemia, the maximum change in the module will be at a frequency of 13 kHz (0.82 Ω), while the phase will change more at a frequency of 100 kHz (-0.81^o).

Whereas, in presence of a global scar in the cardiac muscle, the maximum change of the module ($-2.15\ \Omega$) will be at a frequency of 13 kHz, while the phase will vary more at a frequency of 300 kHz (1.34^o).

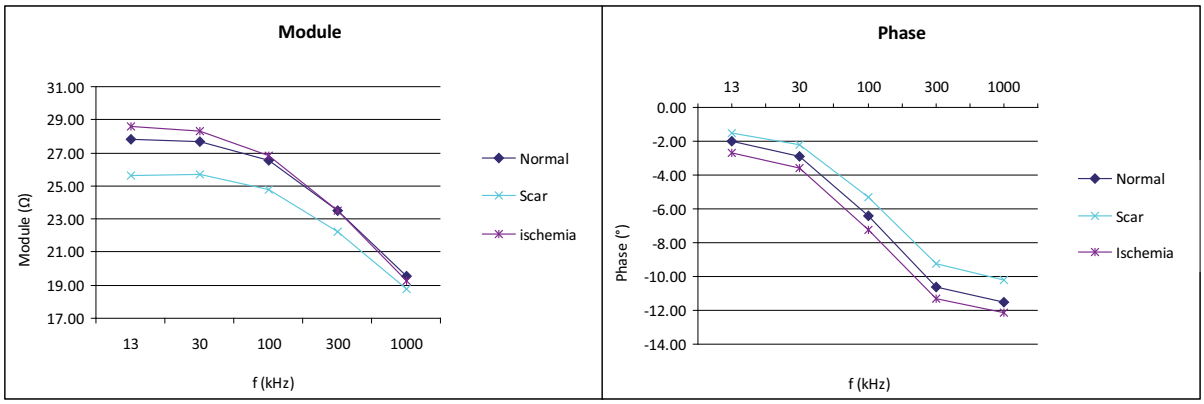

Figure 2. Simulation of the electrical impedance variation due to a change in the electrical parameters of the heart.

3.2. Sensitivity to conductivity and permittivity changes of thoracic tissues

In figure 3 there are summarized the values of the relative sensitivity of the module ($Sr = \frac{\delta|Z|/|Z_{\sigma 0}|}{\delta\sigma/\sigma_0} \times 100$) and the variation of the phase, to an increase in the electrical conductivity and to a decrease in the electrical permittivity of 10% respectively, considering all the tissues in our model.

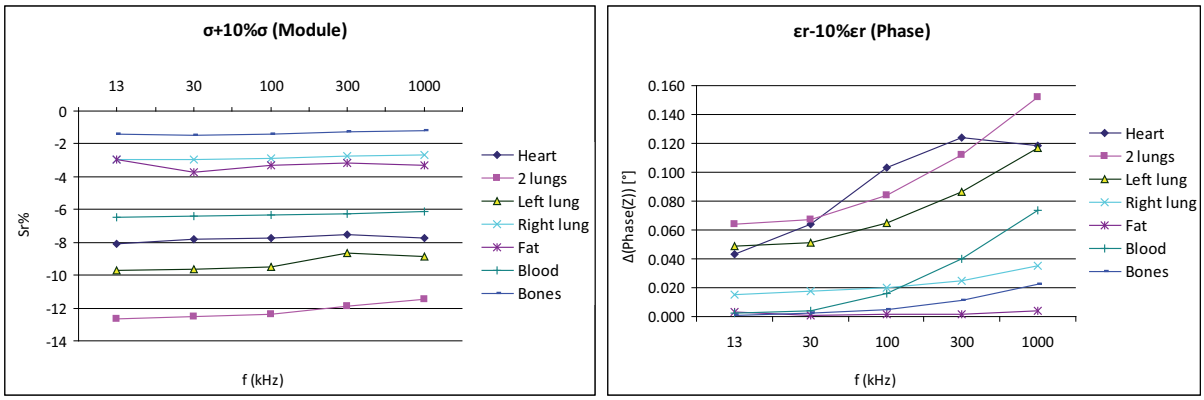

Figure 3. Summary of the simulation of the percentage relative sensitivity of the module to an increase in the electrical conductivity of 10%, in the different tissues.

The left graph in figure 3 shows that the tissues causing the biggest change in the module, are, in order, lungs (mainly the left one), heart and blood; while the module and the phase are less sensitive ($S_r < 4\%$ at all frequencies) to a change in the conductivity of subcutaneous fat, right lung and bones.

The right graph shows that at 100 kHz and 300 kHz we are more sensitive to a change of the relative permittivity of the heart, in the phase, if compared to the same percentage change in other tissues.

In figure 4, we can see the graphs of electrical impedance (module and phase), with inflated and deflated lungs, as well as in presence of a left and right pleural effusion.

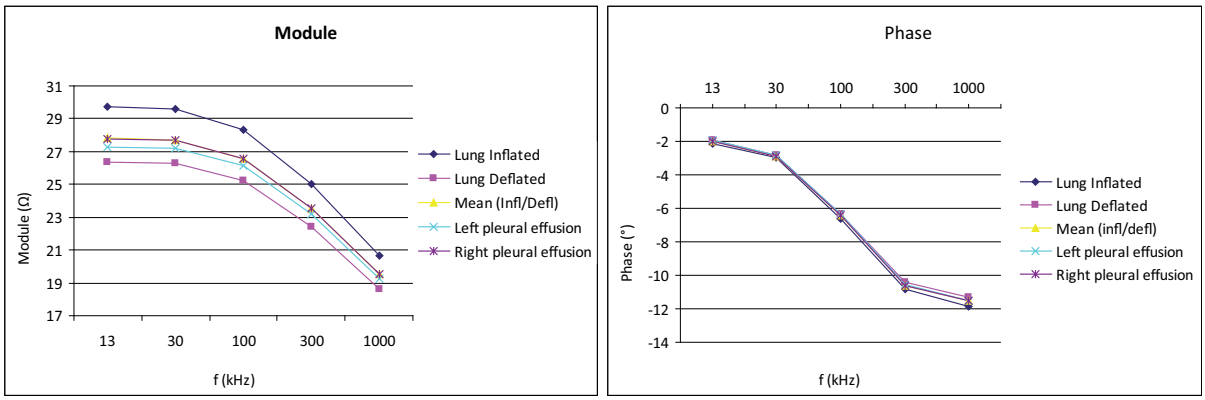

Figure 4. Simulation of the electrical impedance variation due to a change in the electrical parameters of the lungs.

4. Conclusions

Electrical impedance is more sensitive to a change in the electrical conductivity of lungs compared to other tissues, as happens, for example, during normal respiration. For this reason we propose to carry out a transoesophageal bioimpedance measurement during several respiratory cicles, with the purpose to reduce the effect due to respiration.

Moreover our simulation demonstrates that the phase, at the frequency of 100 and 300 kHz, varies more due to a percentage change in the electrical parameters of the heart muscle, if compared with the same percentage changes in other tissues.

Besides, from results not shown in this work, the phase is less influenced than the module to a displacement of the catheter position inside the oesophagus, as highlighted both from human measurement and FEM simulations (about 0.8 Ω/cm for the module while the phase change is almost comparable to the noise of the measurement device, less than 0.1 degrees).

Acknowledgments

This work has been supported by grants from the Spanish Ministry of Science and Technology and the FEDER project SAF2005-02270 and from the Spanish Ministry of Health, Redes de Investigacin del Instituto de Salud Carlos III (REDINSCOR).

References

[1] Cinca J, Ramos J,Rosell-Ferrer J et al 2008 *Changes in myocardial electrical impedance in human heart graft rejection* vol. 10 no. 6 (*Eur J Heart Fail*) pp. 594-600

[2] Grauhan O, Muller J, Knosalla C, Hetzer R et al 1996 *Electric myocardial impedance registration in humoral rejection after heart transplantation* vol. 15 no. 2 (*J Heart Lung Transplant*) pp. 136-143

[3] Grauhan O, Muller J, Pfitzmann R, Hetzer R et al 1997 *Humoral rejection after heart transplantation: reliability of intramyocardial electrogram recordings (imeg) and myocardial biopsy* vol. 10 no. 6 (*Transpl Int*) pp. 439-445

[4] Pfitzmann R, Muller J, Grauhan O and Hetzer R 2000 *Intramyocardial impedance measurements for diagnosis of acute cardiac allograft rejection* vol. 70 no. 2 (*Ann Thorac Surg*) pp. 527-532

[5] `http://niremf.ifac.cnr.it/docs/DIELECTRIC/AppendixB1.html#B01`

[6] Moeller T B, Reif E 2007 *Pocket Atlas of Sectional Anatomy Computed Tomography and Magnetic Resonance Imaging* vol 2 (Stuttgart - New York, Thieme) pp. 2–28