EVALUATION OF IMPEDANCE SPECTROSCOPY FOR INTRAVASCULAR TISSUE CHARACTERISATION AND ENDOSCOPY

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Abstract: For medical treatments often the knowledge of certain tissue parameter are desirable in addition to tissue parameters provided by exiting methods. In this paper the impedance spectroscopy is evaluated for intravascular tissue characterisation and endoscopy. The impedance of vessel wall was recorded under *in vivo* conditions using an impedance catheter. Early arteriosclerotic plaques could be detected an distinguished. Simulations can support the design of electrode configuration and geometries for impedance catheters.

Introduction

During surgeries using catheters and endoscopes often the knowlege of certain tissue parameter are desirable in adition to tissue paramters provided by exixting methods. Since the composition and structure of a tissue as well as the structure of the internal tissue cells determine the electrical behaviours of a tissue [1] medical and biological tissue parameter can be determined from impedance data of a tissue recorded over a certain frequency range (impedance spectrum). Impedance spectroscopy has been used in medicine for the detection of ischemies, inflammation or cancer in larger tissue samples and hole organs. For example Brown *et al.* have presented a relative small pencil probe for electrical characterisation of the cervix as a screening method for pre-cancer [2]. The diameter of the probe was 5 mm and the diameter of the electrode at the tip of the probe had a diamter of 1 mm. Micro technologies provides new possibilities for the use of impadance spectroscopy under difficult special conditions like in cahterters and endoscopes. Lesions in arteries (plaques) can cause arteriosclerosis, which can lead to heart attack or stroke. The plaque rupture of a blood vessel with the subsequent thrombus formation frequently causes the acute coronary syndrome (ACS). However, most of ACS is triggered by the rupture showing non-critical stenoses in X-ray angiography. Hence, additional methods are required to determine the type of a plaque and to choose proper treatments for the advanced type of lesion. In this paper we evaluate the use of an intravascular impedance catheter for the caracterisation of vessel walls. We investigate wether the arteriosclerotic plaques can be detectec and distinguied by impedance spectroscopy. Further we estimade the influence of the extra vessel conditions and of the radius of the vessel on the impedance measurement of a vessel wall by using FEM simulation and a two layer model.

Materials and Methods

The impedance measurements on vessel walls under *in vivo* conditions were performed by using an coronary balloon catheter with intergrated microelectrodes (Figure 1).

To enabel the interpretation of impedance data measured in arteries, the characteristic impedance of the fabricated electrode array must be pretetermined. To validate the functionality of the fabricated micro electrode array, the impedance measurements were performed in 0.9% NaCl solution at room temperature using impedance analyzer (Solartron 1260) and interface (Solartron 1294). For the characterisation the impedance were recorded over a frequency range from 10 Hz to 1MHz at an input voltage of 100 mV.

For the evaluation of plaque detection an arteriosclerotic model was used. New Zealand White Rabbits were fed with cholesterol enriched diet to induce early forms of atherosclerotic plaques. All aortas were prepared from the aortic arch to the renal arteries and segments of 5-10 mm were marked by ink spots. A balloon catheter system with an integrated polyimide-based platinum microelectrode was introduced into the aorta and the impedance was measured at each spot by using an impedance analyzer Solartron 1260 in combination with a bioimpedance interface Solartron 1294. The impedance was measured at frequencies of 1 kHz and 10 kHz. After the impedance measurements the aorta were dissected and cryconserved for histological analysis. Sections were sliced near the centre of the marked segment. After staining the segments with hematoxilin-eosin migrographs were taken to measure plaque and media thickness. Segments were classified

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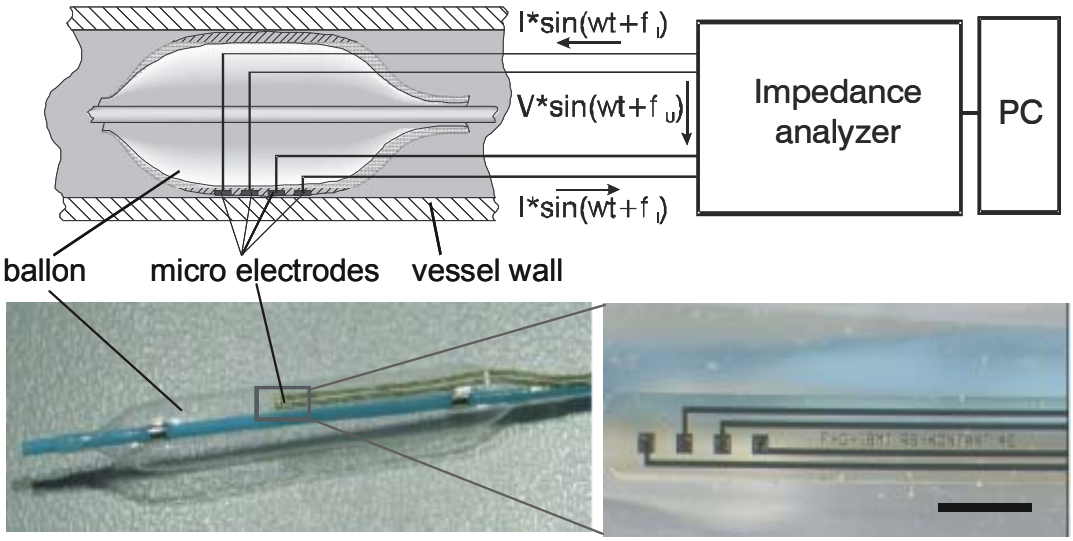

Figure 1: Balloon catheter with integrated electrodes. Upper panel: Schematic of the measurement setup. Lower panel: Photograph of balloon catheter (diameter of balloon: 3 mm) with micro electrodes (Bar = 1 mm).

into three groups. The groups G0 represented segments without any plaque formation, group G1 represented all segments with plaque thickness smaller than that of the aortic media and G2 describes segments containing plaques thick as or thicker than the aortic media.

Results

The magnitude of impedance recorded in 0.9% NaCl solution were not constant for frequencies below 1 kHz (Figure 3).

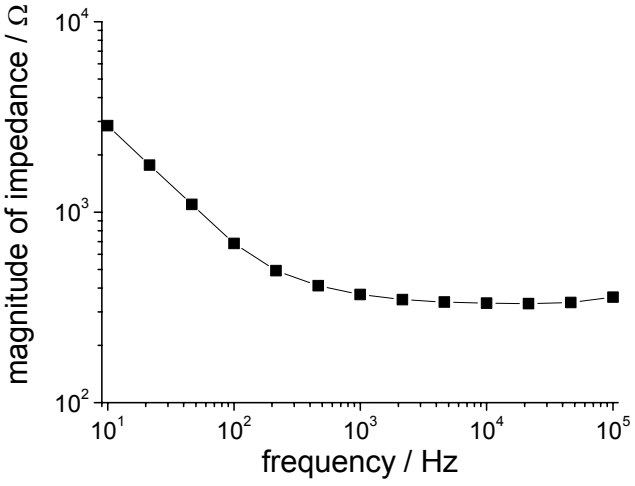

Figure 2. Impedance magnitude of the fabricated electrode array measured in 0.9% NaCl solution.

The impedance could be measured in aorta at different positions along the longitudinal direction (Figure 4).

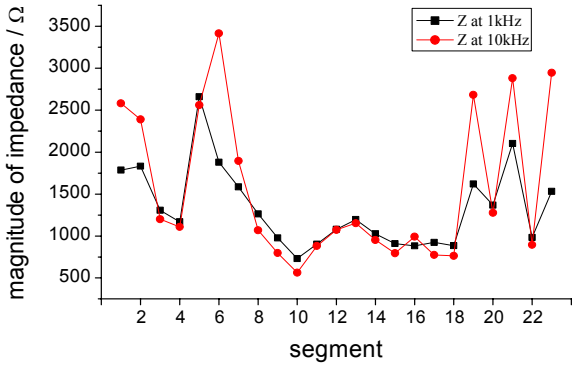

Figure 3. Impedances of aorta at the different segments. The separation distance between the segments was 5 mm.

The segments without plaques and with evolving atherosclerotic disease plaques (Figure 4) could be exactly matched by the histomorphometric analysis.
The difference of the magnitude of impedance at 1 kHz and at 10 kHz $\Delta Z_{(1\ kHz,\ 10\ kHz)}$ ($Z_{1\ kHz} - Z_{10\ kHz}$) was different for various groups of plaque formation (Figure 5). In normal aortic segments without plaque formation the change of the magnitude of impedance $\Delta Z_{(1\ kHz,\ 10\ kHz)}$ was 210±350 Ω. In the area of aortic segments with a plaque smaller than that of the aortic wall diameter, $\Delta Z_{(1\ kHz,\ 10\ kHz)}$ was 140±200 Ω, whereas in aortic segments with plaque formations larger than the aortic wall the change of impedance $\Delta Z_{(1\ kHz,\ 10\ kHz)}$ was significantly lower (p=0.002).

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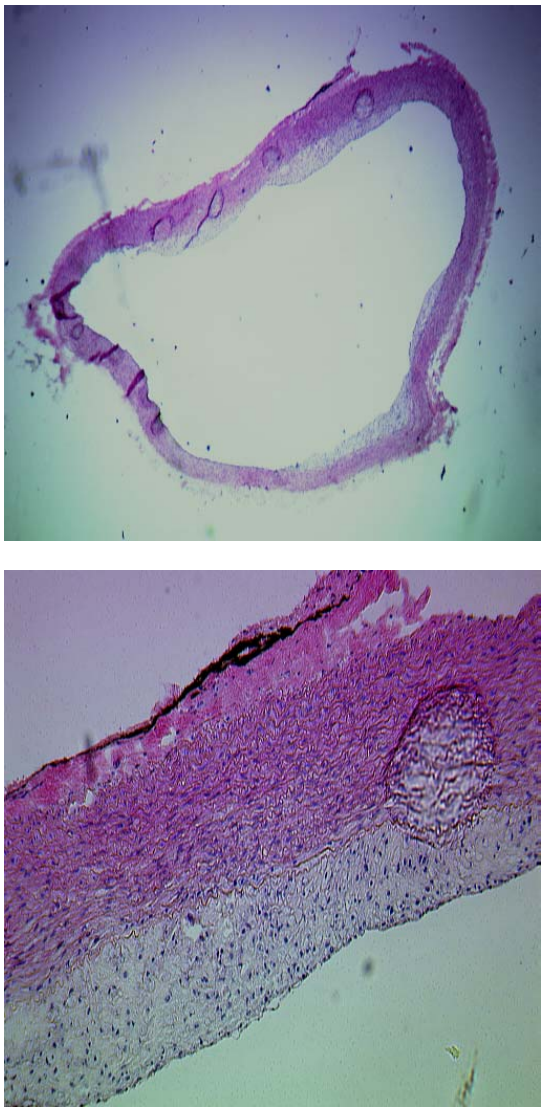

Figure 4: Example for an aortic segment with plaque formation (type G1). Upper panel: Micrograph of an whole segment. Lower Panel: Magnification.

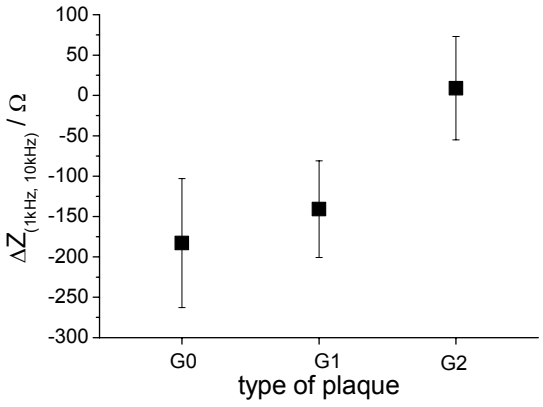

Figure 5: Change of magnitude of impedance for the different groups of plaque formation.

Discussion

The use of impedance catheters can provide information about the composition and morphology of early plaques. The fabricated micro electrode array in combination with an balloon catheter can be inserted inside of vessels and used to measure the impedance of vessel walls. To avoid an influence of electrode polarisation on the measured impedance, a four-terminal electrode arrangement is advantageous under certain conditions. However, in the low frequency range the polarization was still observed (see Figure 2). This polarization is because the potential electrodes are influence by the currents of the current electrodes. The polarization may not be uniform over the surface of potential electrodes, and is dependence on the local current direction and polarization admittance [3]. Schwan has provided a solution for this polarization to use recessed potential electrodes [4]. Although the fabricated electrode array has the limitation at the low frequency range, the measured impedance of the electrolyte became almost constant at higher frequency than 1 kHz. Thus, to avoid an influence of the electrode impedance on the measured impedance the measurements must be performed at frequencies above 1 kHz.
The thickness of arteries can also affect the measured impedance. If the thickness of artery is too thin, the current can penetrate the thin artery wall and undefined materials outside the vessels can influence the measurement. Therefore, for a correct interpretation of the impedance data recorded inside a vessel, an influence of extra vessel condition should be avoided. In [5] the influence of the extra vessel condition on the impedance measured on the inner vessel wall has been estimated by simulations using the finite element method (FEM) and experiments. It has been found that the measured impedance depends on the thickness of the vessel and on the separation distance of the electrode arrangement. FEM simulation can support an optimal design of electrode configuration and geometries regarding the type vessel.

Conclusions

Impedance spectroscopy is used for the characterization of biological tissue since decades. Micro electro mechanical system technologies (MEMS technologies) enable new applications of bioimpedance. We have presented an impedance catheter for the characterization of vessel walls. The impedance of vessel wall was recorded under *in vivo* conditions. Early arteriosclerotic plaques could be detected an distinguished. The FEM simulation can support the design of electrode configuration and geometries for impedance catheters.

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References

[1] SCHWAN H.P. (1993): 'Mechanisms responsible for electrical properties of tissues and cell suspensions', Med. Prog. Technol., **19**, pp. 163-5

[2] BROWN B.H., TIDY J.A. , BOSTON K., BLACKETT A.D., SMALLWOOD R.H. and SHARP F. (2000): 'Relation between tissue structure and imposed electrical current flow in cervical neoplasia', Lancet., **11**, pp. 892-5

[3] SCHWAN H.P. (1968): 'Electrode polarization impedance and measurements in biological materials', Annals of the New York Academy of Sciences, **148**, 191-209.

[4] GRIMNES, S. and MARTINSEN, Ø.G. (2000): 'Bioimpedance and bioelectricity basics', (Academic Press, San Diego)

[5] CHO S. and THIELECKE H. (2005): 'Design of electrode array for impedance measurement of lesions in arteries', Physiol. Meas., **26,** pp. S19-26

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