Reduction of anisotropy influence and contacting effects in in-vitro bioimpedance measurements

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Abstract. Experimental procedure is a decisive part in in-vitro bioimpedance measurement in order to get reproducible measurements. An electrode configuration is proposed to avoid several disadvantages produced by needle electrodes and circular non-penetrating electrode. The proposed electrode geometry reduces the influence of anisotropy and allows simultaneously a good probe contacting. We propose an experimental method to avoid the appearance of bacteria and to reduce water loss in meat during experiment post-mortem. The results show that electrode configuration with the developed experimental method have ensured reproducible measurements during a long period of 14 days post-mortem.

1. Introduction

An important challenge facing consumers is to obtain reliable and fast information on meat quality and freshness providing a higher safety for the consumers. In this scope, we aim to develop an in-vitro bioimpedance measurement method to get information about the state of vacuum packed meat in supermarkets. Sensitive measurements with high reproducibility represent an important objective in the development of the method. For that the electrode configuration is decisive factor, because meat has an anisotropic structure and electrode contact is very important. Different probes are used for in-vitro bioimpedance measurements such as needle electrodes and non-penetrating circular electrodes. Needle electrodes [1-4] assure a very good contact but have a big disadvantage considering reproducibility in anisotropic materials. Biological tissues, particularly meat have an anisotropic structure, so that impedance varies according to whether the current runs parallel or perpendicular to muscle fibres [5]. In ‘figure 1’ the Nyquist plot of impedance is shown using needle electrodes in a beef muscle in 4 directions in relation to the fibres direction: 0° (parallel), 45°, 90° (perpendicular) and 135°. The figure shows a high non reproducibility. The conductivity of meat increases in the case of measurement in parallel to the muscle fibres. In this case the current is better conducted by the fibres than in other cases where it is obliged to cross them. Non-penetrating circular electrode, used in [6], overcomes the fibers direction dependency. However it has a bad contact to the rough surface of the meat and needs a sufficient force applied to get acceptable results. ‘Figure 2’ illustrates the Nyquist plot of bioimpedance measurement using circular electrode for 2 different beef muscles (N ‘neck’ and LD ‘longissimus dorsi’). The result changes according to force applied on the electrode. This effect becomes more serious if the meat surface is drying.
Figure 1. Nyquist plot in 4 positions to beef muscle fibres direction in the impedance plane (f: 40Hz - 110MHz)

Figure 2. Nyquist plot of beef muscle N and LD with and without force using circular electrode in the impedance plane

2. Electrode configuration and experimental procedure

To reduce the dependence on anisotropy and to assure a good contact between meat and electrodes, we propose the use of a probe consisting of steel needle electrodes coated with gold positioned in a circular geometry. The excitation signal is delivered from the inner electrode to the meat and has a distance of 15 mm to the surrounded electrodes which are grounded. The electrode configuration is chosen according to a research carried out in [7] and supported by simulations using Finite Element Methods that provide information about the distribution of the electric field in the meat sample.

The meat phantom used in simulation is chosen according to the following geometric details; length 80 mm, width 80 mm, height 40 mm and to the physical details according to literature [8], [9] and [10] for the conductivity and the relative permittivity with 0.3 S/m and 100 respectively. In the presence of an electric field, the meat is subjected to a displacement of free charges (conduction current) and a movement of charges (displacement current) depending on the electrical conductivity $\sigma$ and the dielectric permittivity $\varepsilon_r$ respectively. The displacement field correspond to the following equation (1).

$$ D = \varepsilon_0 \cdot E + P $$

Where E is the electric field, $\varepsilon_0$ the vacuum permittivity (also called permittivity of free space), and P is the polarization density. The simulation ‘figure 4’ show that the electric displacement field D varies in the frequency range [10KHz-10MHz] between $2.87 \times 10^{-7}$ to $2.1 \times 10^{-16}$ and propagate in the hole volume of the meat in all possible direction for the meat only and not for the surrounding.

Simulation results ‘figure 3’ show that 9 electrodes with a diameter of Ø 1 mm with 10 mm depth deliver an optimal solution for a homogeneous field distribution and a good shielding to environment at a reduced number of electrodes. Vacuum capacity serves to define the electrode characteristic according the electrodes geometry following equation (2).

$$ C_0 = \frac{\pi \cdot \varepsilon_0 \cdot l}{\ln \left( \frac{d}{2a} + \sqrt{\frac{d^2}{4a^2} - 1} \right)} $$

With d the distance between electrodes with the value 15 mm, l represents the length of electrode inserted into the meat with the value 10 mm and a is the radius of electrode with the value 0.5 mm.
The measurement setup used in in-vitro bio impedance measurement ‘figure 4’ consists of a laboratory impedance analyzer (Agilent 4294 A) connected to a personal computer for data acquisition, at a frequency ranging from 40 Hz to 110 MHz. A calibration of electrode effect is done before measurement. The meat is vacuum packed using a vacuum sealer system and was placed in climate chamber in the temperature of 2°C. The choice of temperature is similar to the meat conservation temperature in supermarket that it is around 2°C. Measurements are made simultaneously regarded to a reference time corresponding to the time of slaughter with a very low fat content during two weeks post-mortem. The vacuum meat avoids the appearance of bacteria and reduces the water loss in meat. This allows getting information about the meat for long period of time and maintains the same state of the meat as in supermarkets.

By using the new electrode configuration and the experimental procedure, it is possible to reduce some difficulties especially bacterial contamination, bad contact between meat and electrodes and the anisotropy dependency. In addition the spectra of the meat samples guarantee a sufficient reproducibility even after two weeks. The three areas of dispersion α, β and γ described in [11-12] are clearly observed in the frequency range [40 Hz-110 MHz] (see ‘figure 5’). At low frequencies in which dispersion α occurs, the meat cells are not conductive and the current flows outside the cells.
The dispersion $\alpha$ describes also the electrode/electrolyte interface and is therefore very sensitive to annoying effects. In the frequency range of the $\beta$ dispersion, the current flows intracellular and extracellular. This allows an accurate assessment of the biological tissue. $\beta$ dispersion includes information about the state of cell membrane integrity and cell aggregations during meat aging. In $\gamma$-dispersion, the dispersion observed at high frequency is mainly due to the permanent dipole relaxation of small molecules such as water. This information is not directly representative for characterization and leads to high costs for electronic development.

3. Conclusion

The theoretical and experimental investigations have proved that the proposed electrode configuration ensure a reduction of the inadequate electrode contact and the influence of anisotropy at the same time. The use of electrodes with a circular geometry allows an independency on the anisotropy so long we measure in the same plane perpendicular to the meat fibres. The use of small needles to contact the meat allows a good contact to meat and shows a good reproducibility over time. The developed measurement method allows a reproducible measurement for a long period of 14 days post-mortem.

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