Exploratory simulation study on high-frequency detection of cell internal structures

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Abstract:

Introduction:

Cell analysis is important in the diagnosis of several diseases, as the dielectric and morphological properties of the cells can change when diseased. In this context, malaria is one of the most threatening diseases affecting red blood cells (RBCs), leading to their destruction. High-frequency impedance spectroscopy (HFIS) with nanoelectrode arrays has the potential to overcome the Debye screening effect of the electrolyte and surpass the cellular membrane, thus allowing the study of the cell internal structure. In this work, we investigate, by simulation, the potential of the NXP CMOS nanoelectrode array biosensing platform in Widdershoven2018 to study the internal structure of the cells.

Methods:

Simulations were carried out in COMSOL Multiphysics ®, modelling a healthy RBC discocyte with an overall volume of 86 fL. The malaria parasite within the cell was modelled at three different stages of infection: 6 hpi (hours post infection), 12 hpi, and 18hpi. The simulation medium consisted of a physiological solution that does not affect the cell's properties. All simulation parameters were taken from Honrado2018.

Results and Discussion:

The simulations were performed with an RBC positioned in the centre of the array, obtaining ΔC as the difference in capacitance with and without the cell. The capacitance profiles show a change in the ΔC spectrum above 1 MHz, due to the malaria parasite. Analyzing the difference in capacitance between uninfected and infected RBCs at high frequencies, the variation reaches valued as high as 100 aF, measurable with the existing NXP nanoelectrode array platform. This provides a framework for distinguishing between healthy cells and the ones with intracellular inclusions.

Conclusions:

The potential of HFIS analysis with a CMOS nanoelectrode array platform was explored in this work, suggesting the possibility of a label-free and non-invasive method to study and explore the internal structure of a cell.

Keywords: Red blood cells; High frequency impedance spectroscopy; bioelectronics; nanoelectrode arrays; microelectrode arrays