Electrochemical Methods in Physiology: From Mass Transport to Signalling

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INTRODUCTION

Electrochemical methods offer many advantages for the physico-chemical characterisation of biological tissues including: a wide range of analytes, real-time continuous measurement and tunable spatial resolution.

We have developed a wide range of sensors and techniques for key parameters including dissolved oxygen concentration and diffusivity (O'Hare et al), nitric oxide (Leung et al.) lactate and glucose (Khurana et al.) and more recently for the real time measurement of vesicular release from intact neuronal systems and cultured cells.

Using an electrochemical sensor in a scanning probe configuration allows measurement of solute transport under physiologically representative conditions with sub-cellular resolution. We have used this approach to measure oxygen permeability (Gonsalves et al.2000a) and ion transport (Gonsalves et al.2000b) in articular cartilage.

More recently we have developed a new signal processing approach to electrochemical signals using the Huang-Hilbert transform which, unlike the Fourier and related transforms, is valid for non-linear, aperiodic and non-stationary signals. It is therefore uniquely suited to electrochemical sensors.

VESICULAR RELEASE OF 5-HT IN INTACT NEURONAL SYSTEMS

Carbon fibre microelectrodes (7 µm diameter) were positioned directly on the cell bodies, axons or dendrites in intact dissected neuronal systems of Lymnea stagnalis, water snail. Basal release rates were confirmed by hplc analysis of homogenised tissue. We have been able to observe vesicular release of 5-HT directly in real time. Typical release events are of 5 ms duration. These measurements have revealed changes in the pattern of release due to ageing.

SCANNING ELECTROCHEMICAL MICROSCOPY (SECM)

A microelecctrode mounted on piezo positioners was polarised to reduce dissolved oxygen. As the electrode approaches the substrate, the current falls due to shielding. Fitting the approach curve allows generation of a map of oxygen permeability. Similar approaches have been used to examine the effect of charge on solute transport in tissue.

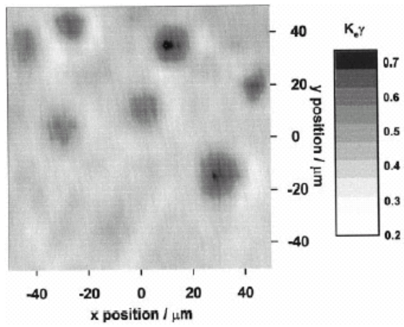

Figure 1. SECMIT map of oxygen permeability is bovine articular cartilage. Note the regions of high permeability in the pericellular regions.

HILBERT TRANSFORM APPROACHES TO ELECTROCHEMICAL DATA

Electrochemical processes are intrinsically non-linear and non-stationary and so the FFT is not applicable to the analysis of these types of data. These strictures have been widely ignored by the scientific community principally due to the dearth of more appropriate signal analysis techniques. Preliminary results have been obtained for three well characterised systems: (i) thermodynamically reversible electron transfer (ii) electrode fouling in phenylene diamine oxidation (iii) growth of a conducting oxide film. We have shown (Arundell et al.) that the Hilbert transform allows separation of the amplitude (related to concentration) from the instantaneous frequency (dw/dt) which can be related to mass transport and electrode reaction.

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