Electrode - Fiber Distance and Active Unit Conduction Velocity Estimation

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Abstract

Advanced neuroprosthetic electrodes are indwelling devices that are being developed to create a bidirectional interface to the nervous system. They are a key enabling technology under development to restore function to those suffering from neurological disorders or injury, and have the potential to restore function to paralyzed limbs, sight to the blind, or hearing to the deaf. Their ultimate performance is dictated by keeping the distance between the active sites on the implant structure and the target nerve cell minimized. Currently, there is no analytical way to evaluate the distance between the electrode and the active cell without histologically examining the implanted tissue post-mortem.

We report here on the development of a method to estimate not only the distance, but also the conduction velocity of the action potential. A tissue filter relationship was derived through analysis of the reciprocity equations in the frequency domain and transformation of the spatial frequency to time frequency. The derived function relates how the SFAP is transformed as a function of distance and conduction velocity. A 3-D finite element (FE) volume conductor model of an electrode residing in a nerve fascicle was created to determine the potential distribution in the nerve fascicle, and derive the tissue filter function. Single fiber action currents were filtered using the tissue filter function to simulate the predicted action potential for different fiber-electrode distances and action potential conduction velocities. A power spectral density (PSD) analysis was then implemented for the simulated SFAPs, to quantify changes in the PSD of the recorded simulate SFAPs.

The model shows that a smaller electrode-fiber distance results in the broader bandwidth signal. It further showed that the faster conducting fiber, the fewer weights the spatial filter function and the broader the bandwidth. These factors result in a quantitative change in the PSD of faster conducting fibers, resulting in a peak in modulation in the 2^{nd} peak of the PSD (around 5-6 kHz) which is a function of velocity and distance. Through the use of multiple electrode sites, the conduction velocity can be predicted and differentiated from the effect of distance.