

Model of Extracellular Potential Describes Waveforms of Single Units Recorded in Vivo

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We use the “Line Source Approximation” [1] to compute the extracellular voltage waveform resulting from the spiking activity of a 1-D cable model of a reconstructed neuron. We compare simultaneous intracellular and extracellular recordings of CA1 pyramidal cells recorded in vivo [2] with predictions for the same cells reconstructed and simulated with compartmental models. Simulations include ionic channel properties and densities based on data collected in studies of CA1 pyramidal cells in vitro (I_{na}, I_k, I_d, I_c, I_a, I_m, I_{ahp}, I_n, I_l, I_r, I_t, I_h), along with a detailed spine distribution.

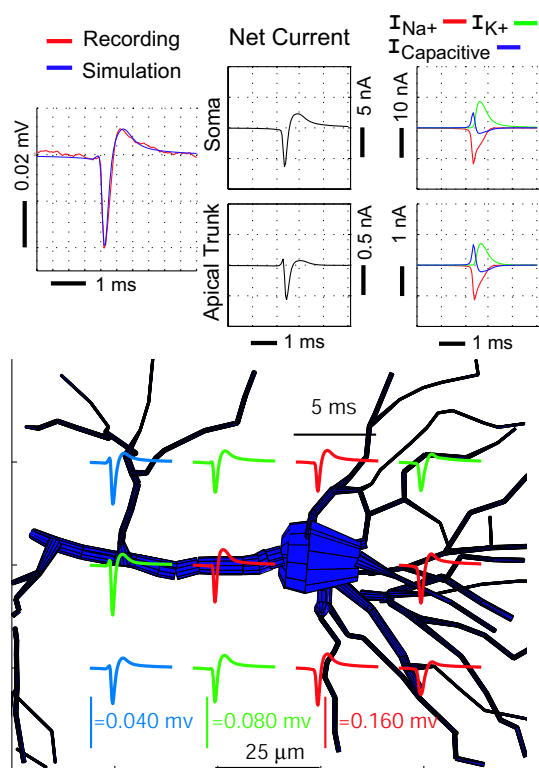


Figure 1: Comparison of recording and simulation, details of simulated membrane currents, and prediction of extracellular potential waveforms around the cell.

The model confirms and explained some previously observed features of extracellular potentials. At the same time, the model provides new insights into in vivo physiology.

We find that the primary determinant of the shape of the extracellular potential waveform is variability in the activity level of the K⁺ currents which repolarize the action potential (A, C, D and K type K⁺ channels.) It is assumed that the Hodgkin-Huxley style kinetics of the different ionic membrane currents do not vary from cell to cell. However, in order for the model to reproduce the variety of extracellular potential waveforms seen in the in vivo recordings, the density of the various ion channels must vary from cell to cell. From this we conclude that different combinations of active ionic currents on different cells explains much of the observed variety in the shape of the extracellular potential waveform.

Another factor contributing to the shape of the extracellular potential waveform is the position of the electrode relative to the cell. For example, it has been previously observed that recordings made close to the apical trunk often show an initial positive peak before the main negative peak of the waveform. The model reproduces this phenomena and provides a clear explanation: The initial positive peak in the waveform is produced by the membrane capacitive current (i.e. $i=C dV/dt$.) which is mainly observable in dendritic recordings. As illustrated in figure 1, at the soma, Na⁺ channel openings precede and drive the membrane potential change, and thus the Na⁺ current masks the capacitive current. Consequently the initial positive peak is usually not observed in somatic recordings.

From these results we conclude that the combination of compartmental modeling with the Line Source Approximation provides an accurate and useful new

[1] G Holt, C Koch. Electrical interactions via the extracellular potential near cell bodies. *Journal of Computational Neuroscience*. (1999) 6: 169-184

[2] D A Henze, Z Borhegyi, J Csicsvari, A Mamiya, K Harris, G Buzsáki. Intracellular Features Predicted by Extracellular Recordings in the Hippocampus In Vivo. *Journal of Neurophysiology* (2000) 84: 390-400