Sponge astrocyte model: volume effects in a 2D model space simplification

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Astrocytes are the most abundant and versatile specialized glial cells, which contiguously tile the entire CNS where they may outnumber neurons. Real astrocytes are obviously not binary. There is a graded transition from thick branches to branchlets and to leaflets, primarily determined via the surface-to-volume ratio (SVR). Moreover, leaflet regions of the template contain not only astrocyte itself, but also the neuropil. We encode the astrocyte structural features by means of its color representation.

Mechanisms-based model

Ullah local model [1-2] supplemented with CaEr and glutamate

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\begin{align*}
\frac{dCa}{dt} &= \epsilon_c \left( J_{\text{in}} + J_{\text{磷}} - J_{\text{pmp}} \right) + \epsilon_i \left( J_{\text{st}} - J_{\text{nst}} + k[Glu] \right); \\
\frac{dCa_{\text{er}}}{dt} &= -\epsilon_c J_{\text{st}} - \epsilon_i J_{\text{st}} + k_c (Ca_{\text{er}} - Ca_{\text{er}}) \\
\frac{dIP3}{dt} &= \epsilon_j \left( J_{\text{fas}} + J_{\text{glu}} \right) - \left( IP - IP_3 \right) / \tau_i; \\
\frac{d[Glu]}{dt} &= \epsilon_i \left( J_{\text{fas}} - [Glu] \right) + \epsilon_j [Glu] / t_c.
\end{align*}
\]

1. Ca\textsuperscript{2+} in cytoplasm – Ca\textsubscript{c}
2. Ca\textsuperscript{2+} in endoplasmic reticulum – Ca\textsubscript{ER}
3. IP\textsubscript{3} dynamics – IP\textsubscript{3}
4. Extracellular glutamate – Glu
5. IP\textsubscript{3}R inactivation variable (receptor of IP\textsubscript{3}) – h

Calcium fluxes:
- J\textsubscript{pmp} = n(1 + (k/3)Ca\textsubscript{pmp})
- J\textsubscript{fas} = k_{fas}Ca\textsubscript{fas}
- J\textsubscript{st} = k_{st}Ca\textsubscript{st}
- J\textsubscript{glu} = k_{glu}[Glu]

SVR(AVF) function

Conclusions

Simulations show the formation of calcium waves. In contrast to the binary segmentation model, calcium elevation response in the proposed biophysically more realistic sponge model is greater, i.e. the intensity of the formed waves is higher, but the basal calcium level is lower. The threshold of stable wave existence grows because increasing AVF works like a blocking barrier for a small glutamate release reducing the number of wave sources. Nevertheless, large enough glutamate release leads to a wide-area wave quickly occupying the leaflets moving to the astrocyte soma.

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