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Accurate numerical simulation of electrodiffusion and water movement in brain tissue with cortical spreading depression as a case study

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Mathematical modelling of ionic electrodiffusion and water movement is emerging as a powerful avenue of investigation to provide new physiological insight into brain homeostasis. However, in order to provide solid answers and resolve controversies, the accuracy and precision of the predictions are essential. Here, we consider an homogenized model for ionic electrodiffusion and osmosis comprising a non-trivial system of non-linear and highly coupled partial and ordinary differential equations that govern phenomena on disparate time scales. We study numerical challenges related to approximating the system and validate the model against values from experimental studies in the physiologically relevant setting of cortical spreading depression (CSD). CSD is a wave of electrophysiological hyperactivity accompanied by substantial shifts in ionic concentrations and cellular swelling. We evaluate different associated finite element-based splitting schemes in terms of their numerical properties, and find that the schemes display optimal convergence rates in space for problems with smooth manufactured solutions. However, the physiological CSD setting is challenging: we find that the accurate computation of CSD wave characteristics (wave speed and wave width) requires a very fine spatial and fine temporal resolution. Further, the data for several CSD hallmarks obtained computationally, including wave propagation speed, direct current shift duration, peak in extracellular potassium concentration as well as a pronounced shrinkage of extracellular space, are well in line with what has previously been observed experimentally. Finally, we note that the model considered within this work may be applied to study a wide array of phenomena in brain physiology and pathology.

Time Block Preference

Time Block A (09:00-12:00 CET)

References

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