The current state of the art in mathematical modelling of neurological and cardiological systems

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The majority of mathematical models of neurological and cardiological systems concern the field of continuum mechanics. And the corresponding state-of-the-art was tackled in a recent publication arising from COST Bioneca (Morin et al, Journal of Applied Mathematics and Mechanics, 2018)

https://onlinelibrary.wiley.com/doi/abs/10.1002/zamm.201700360;

That article is discussing the following situation:

Thermodynamically sound continuum mechanics models for soft tissues, as reviewed and developed over the last decades by Holzapfel and co-workers have resulted in a thriving research community with increasing impact in biomedical engineering and biomedicine, and particularly so in cardiology. In recent years, the importance of tissue anisotropy has been more and more understood and considered, thereby aiming at more and more resolved representation of the collagen and elastin fiber morphologies evolving during tissue deformation. Most of the corresponding contributions tackle the problem of fiber re-orientation through the use of affine transformations, i.e. the fiber movements are directly linked to the “macroscopic” strain tensor characteristics of the representative volume element associated with a piece of tissue. While this concept frequently provided very satisfactory results, in particular so in the context of mitral valve leaflet modeling, one may also note note several experimental observations where the fibers do not follow such a deformation pattern. These observations concern the adventitia layer of carotid arteries, but also tissues beyond the cardiac realm, such as the human liver capsule and murine skin. Typically, the aforementioned deformation patterns are associated with large shear strains in the soft matrix being situated in-between the fibers; and such discrepancies between macroscopic and microscopic strains, being incompatible with affine deformation characteristics, have also been reported for tendon fascicles.

In order to break new grounds in soft tissue modeling, non-affine tissue deformation modeling is a key goal of WG3 of Bioneca; thereby extending continuum micromechanics formulations to the realm of large strains; introducing strain-to-spin concentration tensors and associated hypoelastic formulations as an original, novel concept.

In the neurological field, BIONECA researchers have pioneered a way to make the classical Maxwell equations, a cornerstone in theoretical physics, practically employable for neurological disease etiology and therapy (Isakovic et al, Scientific Reports 2018)

https://www.nature.com/articles/s41598-018-31054-9.

Currently, these developments are being extended towards coupled electro-mechanical models, by integrating electrical forces into the Principle of Virtual Power, which is one of the fundamentals pillars of continuum mechanics. This will allow for literally translating electric stimuli to „mechanical stress“ - thereby providing a new ontology for neurological field.