A generalized thermo-hyperelastic constitutive model of cardiac radiofrequency ablation

Speaker: Leonardo Molinari, Emory University

Abstract: Current constitutive models for radiofrequency catheter ablation (RFCA) face notable limitations, such as the absence of a dependable three-dimensional microstructural representation of the myocardium and the complexity of multiphysics interactions during tissue heating. To address these issues and contribute to the refinement of procedure design and optimization, we propose a novel and comprehensive, thermodynamically consistent, transverse isotropic thermo-hyperelastic constitutive model for the myocardium. This model accounts for local anisotropies and multiscale dynamics. In particular, we introduce a biophysically-grounded rationale by formulating a continuum damage approach based on a three-state hyperthermic cell death dynamical model. Additionally, we present a fully coupled thermo-mechanical model that incorporates the multiplicative decomposition of the deformation gradient and defines temperature-dependent material parameters in accordance with the general theory of thermoelasticity. We numerically solve the overall multiphysics and multiscale model within an idealized tissue domain, utilizing a precise finite element scheme and adhering to the constraint of constant power control.

In a supplementary investigation, we have expanded upon our original framework by introducing higher order (phase-lagging) models for heat transfer. We conducted an experimental characterization of myocardial thermal anisotropy, employing multi-point temperature measurements. This empirical data allowed us to develop a finely-tuned thermo-electric material model tailored specifically to cardiac tissue.

Our modeling efforts bridge the existing gap in constitutive modeling for cardiac RFCA, resulting in a stronger correlation between the ablating volumes projected by our model and those detailed in contemporary literature. Notably, we unveil, for the first time, the elliptical shape of the lesion formation attributable to anisotropic thermo-electric conduction and elucidate the persistence of residual strains caused by tissue phase changes subsequent to ablation.