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FINITE ELEMENT SOLUTION FOR CARDIAC MUSCLE CONTRACTION IN WHOLE HEART

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The simulation of a whole heart, even over a single heartbeat of 700 ms, is a big challenge in terms of the development of numerical algorithms that can translate the effects of specific mutations associated with heart diseases. The MUSICO platform [1] enables detailed translation of structural and kinetics changes of mutated sarcomeric proteins up to the level of cardiac muscle fibre and multicellular structures such as trabeculae. However, these simulations require huge computation time to trace all molecular interactions. Thus, direct use of MUSICO module is not suitable for characterizing active tension and local muscle stiffness in finite element (FE) simulations of complex muscular structures such as a whole heart. The mass action models can be an intermediate approach capable to translate the effects of mutations to higher length scales and such approach is tested on FE simulations of swallowing [2]. However, for the simulations of a whole heart this approach is still computationally intensive, thus even simpler models are needed.

One of the simplest models that can incorporate the features of cardiac muscle mechanical behaviour, translatable from MUSICO to FE packages such as Alya or PAK, had been developed by Rice et al. [3] based on model of Campbell et al. [4]. We implemented this model in FE program connecting the action potentials driving local calcium transients to tension response in whole cardiac muscle. In each FE iteration, the Rice model module requires shortening velocity and sarcomere length as an input from FE integration points (IP), and provides local tension and stiffness at each IP as an output. The solution of FE equilibrium equations for instantaneous material characteristics and the prescribed boundary conditions, defines the relationship to external constraints, e.g. heart pressure and volume, and speed of local deformation. The FE simulations replicated the twitch contractions in trabeculae observed by Janssen et al. [5] and showed contraction in a long FE strip with traveling action potential wave as observed along the layer of cardiac muscle in the heart. Using the proposed methodology, the memory and computational time required for the multiscale simulations were significantly reduced comparing to previous approaches, making simulation of whole heart feasible.

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