A polyconvex computational formulation for electro-activation in cardiac mechanics

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ABSTRACT

Cardiovascular diseases, such as heart infarction or dysrhythmia, represent the main cause of death in the world and its prevalence is more significant in developed countries. Research in cardiology is not only devoted to build a body of knowledge about the physiology of the heart but also to contribute to cardiovascular medicine, offering patients more advanced treatments and personalised diagnosis. Regarding the latter aspect, the computational modelling of the complex physical phenomena occurring in the human heart has become an area of increasing scientific interest over the last decade. This facilitates the better understanding of the mechanisms driving the behaviour of the system from both physiological and pathological standpoints and provides augmented diagnostic tools for clinicians. This paper is related to the first aspect, namely mimicking the heart's physiological behaviour, which can be modelled by means of well-posed mathematical equations predicting the evolution of the cardiac action potential and cell dynamics. The aforementioned coupling phenomenon can be succinctly explained in two steps: first, the linear momentum equation is strongly linked to the hasty uprising of the electric potential through cardiac fibres activation, which can be mathematically characterised as fibre shortening, known as active strain **[3]** or internal fibre stresses, namely active stress **[4]**; secondly, the potential wave evolution is predicted by the reaction-diffusion equation which source term is described by two widely accepted ionic models describing the cellular ion exchange, known as Minimal model **[3]** and Ten-Tusscher model **[4]**. From the numerical standpoint, the series of papers published by Gil and Ortigosa **[1,2]** introduces a polyconvex computational framework, overcoming the shortcomings of classical displacement-based formulations that has been developed for the first time in this context. Specifically, the concepts of extremely large deformations, fibre orientation anisotropy, nearly incompressible behaviour and realistic three-dimensional geometries have been considered. Finally, an extensive set of numerical examples is presented to assess the robustness, applicability and accuracy of the proposed formulation.

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