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Cardiac electromechanics: the effect of contraction model on the mathematical problem and accuracy of the numerical scheme. (English) Zbl 1250.74019

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Summary: Models of cardiac electromechanics usually contain a contraction model determining the active tension induced at the cellular level and the equations of nonlinear elasticity to determine tissue deformation in response to this active tension. All contraction models are dependent on cardiac electrophysiology but can also be dependent on the stretch and stretch rate in the fibre direction. This fundamentally affects the mathematical problem being solved, through classification of the governing partial differential equations, which affects numerical schemes that can be used to solve the governing equations. We categorise contraction models into three types, and for each consider questions such as classification and the most appropriate choice from two numerical methods (the explicit and implicit schemes). In terms of mathematical classification, we consider the question of strong ellipticity of the total strain energy (important for precluding 'unnatural' material behaviour) for stretch-rate-independent contraction models; whereas for stretch-rate-dependent contraction models, we introduce a corresponding third-order problem and explain how certain choices of boundary condition could lead to constraints on allowable initial condition. In terms of suitable numerical methods, we show that an explicit approach (where the contraction model is integrated in the time step prior to the bulk deformation being computed) is (i) appropriate for stretch-independent contraction models; (ii) only conditionally stable, with the stability criterion independent of time step, for contractions models which just depend on stretch (but not stretch rate) and (iii) inappropriate for stretch-rate-dependent models.

MSC:

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74F15	Electromagnetic effects in solid mechanics
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