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Research paper

A coupled electromechanical model for the excitation-dependent contraction of skeletal muscle

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ABSTRACT

This work deals with the development and implementation of an electromechanical skeletal muscle model. To this end, a recently published hyperelastic constitutive muscle model with transversely isotropic characteristics, see Ehret et al. (2011), has been weakly coupled with Ohm's law describing the electric current. In contrast to the traditional way of active muscle modelling, this model is rooted on a non-additive decomposition of the active and passive components. The performance of the proposed modelling approach is demonstrated by the use of three-dimensional illustrative boundary-value problems that include electromechanical analysis on tissue strips. Further, simulations on the *biceps brachii* muscle document the applicability of the model to realistic muscle geometries.

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1. Introduction

It is well known that the depolarisation of a skeletal muscle fibre results in a free calcium ion concentration increase in the sarcoplasm; see, e.g., Melzer et al. (1984) and Ashley et al. (1991). Further, these free calcium ions bind to troponin to enable cross-bridge attachment and consequently muscle contraction. Although many physiological aspects are known, various mathematical muscle models have been developed considering only single aspects of the excitation–contraction process. Further, they are mostly implemented in so-called ‘stand-alone’ programmes and only capture one-dimensional problems. Hence, no geometry effects can be considered.

One-dimensional examples include, for example, calcium (Ca^{2+}) movements/diffusion (Wallinga-de Jonge et al. (1981), Cannell and Allen (1984), Hollý and Poledna (1989), Bugrim et al. (1997), Baylor and Hollingworth (1998), Novo et al. (2003) and Baylor and Hollingworth (2007)), membrane voltage/calcium sparks (Farnbach and Barchi (1977), Hatze (1977), Dorgan and O'Malley (1997), Rienen and Quintern (1997), Baylor et al. (2002), Chandler et al. (2003) and Baylor (2005)), and different components that link electrical stimulation to contraction (Cannell and Allen (1984), Ríos et al. (1993), Baylor and Hollingworth (1998), Wallinga et al. (1999), Razumova et al. (2000) and Shorten et al. (2007)).

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