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# A THREE-DIMENSIONAL FINITE ELEMENT FRAMEWORK FOR INVESTIGATING FUNCTIONAL ELECTRICAL STIMULATION PROTOCOLS

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## ABSTRACT

Functional Electrical Stimulation (FES) is a technique that uses applied electric fields to elicit a functional response from nerve and muscle tissue. It can be used as a movement augmentation tool for people with peripheral nerve damage as well as a rehabilitation technique for stroke patients. Mathematical models are an important tool that can be used to understand the effect of electric fields on the neuromuscular system. In order for a model to be able to represent the effects of specified fibre distributions, different recruitment orders, fibre direction and fatigue, the model must be able to link the propagation of a nerve stimulus along the nerve trunk with the muscle at a cellular level, up through individual fibres, to the response of whole muscles. This has been achieved by integrating a mathematical model of the nerve and incorporating the cellular responses of skeletal muscles within a three-dimensional biomechanical Finite Element (FEM) model that is based on the anatomy of the right lower limb of the Visible Male data set.

The FEM model of the nerve is based on the CRRSS model for warm blooded nerves [1]. The contractile response of the skeletal muscle is modelled using a transversely isotropic constitutive law, the governing equations of finite elasticity theory, and tri-cubic Hermite Finite Element basis functions. To incorporate the cellular properties of skeletal muscle fibres [3] within the whole muscle, homogenized values of key physiological parameters, e.g. the pre- and post-power stroke concentration of crossbridge attachments, are computed at the Gauss points of the FEM integration scheme. These values are then used to modify the stress tensor in such a way that it resembles the contractile response [2].

This framework of an anatomically based lower limb model combined with the above mentioned electromechanical skeletal muscles model has been developed to improve Functional Electrical Stimulation protocols with respect to muscle control and fatigue.

The placement of electrodes and the strength of the current required for various levels of activation at the electrode location play a crucial role. Further, this framework can be used to investigate and study local muscle contraction, muscle recruitment patterns, force generation, or fatigue response of skeletal muscles, and the calculation of surface electromyography (EMG) signals.

Here, we will present the electromechanical skeletal muscle model, the nerve model, and the effects of muscle recruitment based on surface stimulations.

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