Smooth Muscle Contraction: An Electro-Chemo-Mechanical Process

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ABSTRACT

Smooth muscles contraction is a complex multi-physics problem including electrical, chemical and mechanical processes. The contraction typically starts by a cell membrane excitation through an electrical, mechanical or chemical stimulus. Although different, all stimuli lead to a change in the transmembrane potential, causing ionic membrane channels to open. The channels allow for ion exchange between the extracellular and intracellular spaces. Among these ions, calcium plays a pivotal role. Through a chain of reactions, it ultimately causes phosphorylation of the myosin head and allow it to form cross-bridges with the actin filament. The actin-bound myosin changes its conformation and generate a pull force (power stroke) on the actin filament. The macroscopic muscle force may therefore be considered as the combined effect of a large number of power strokes.

The conversion of electrical stimuli to a mechanical response is called the excitation-contraction (EC) coupling. Several models exist for separate parts of the EC coupling, e.g., membrane excitation [1], myosin phosphorylation kinetics [2], and muscle mechanics [3]. Few studies have attempted to model the whole EC chain, however. A notable exception is [4], although it is based on a one-dimensional small deformation theory. Our group has developed a multi-physics model which accounts for the whole EC coupling chain and includes a three-dimensional finite deformation continuum model for the mechanical force generation [5]. The electrical, chemical and mechanical processes are coupled using a thermodynamic framework, and the model response is tested for a uniaxial contraction and shows good agreement with published data.

To study a more complex EC coupling problem, the contraction of a human uterus is simulated [6]. The uterus is modelled as a thick-walled ellipsoid filled with an incompressible fluid, and the model is implemented in COMSOL Multiphysics®. The intrauterine pressure is computed and shows good agreement with published data.

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