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Parameter identification for a DM model of the active behavior of the rats tibialis anterior

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Introduction

To study the influence of mechanical load on muscle tissue a continuum model of the tibialis anterior (TA) of the rat is developed by Gielen [1]. The contractile properties in this model are described by a distribution-moment (DM) model [2]. The objective of the present research is to identify the unknown DM parameters for the rats TA. Because model simulations will be compared to macroscopic behavior we used a simplified 1D model.

Methods

Distribution-Moment Model

The contractile property of muscle tissue is described by a two-state Huxley cross-bridge model including the calcium activation dynamics [2]. The equation reads

\[ \frac{dn}{dt} = \frac{\partial n}{\partial t} - u(t) \frac{\partial n}{\partial \xi} = r f(\xi)[n - g(\xi)n] \]

where $n$ is the fraction attached cross-bridges with scaled length $\xi$, $u(t)$ is the scaled shortening velocity of a half sarcomere and $r$ and $n$ are respectively the activation and the overlap factor. $f(\xi)$ and $g(\xi)$ represent respectively the attachment and detachment rate parameters defined as

\[ f(\xi) = \begin{cases} 0 & \xi \leq 0 \\ f_1 \xi & ; g(\xi) = \begin{cases} g_2 & -\infty < \xi < 0 \\ g_1 \xi & 0 < \xi < 1 \\ g_1 \xi + g_3 (\xi - 1) & 1 < \xi < \infty \end{cases} \end{cases} \]

Since we are interested in the contractile behavior at regional level it suffices to approximate the solution of the Huxley equation by the DM model. An additional advantage of this approach is that the moments $Q_\lambda = \int_{-\infty}^{\infty} \xi^\lambda n(\xi, t) d\xi$, have a physical meaning. The first moment $Q_1$, for example is proportional to the isometric muscle torque.

Parameter Identification

The rate constants $f_1$, $g_1$, $g_2$ and $g_3$ and two parameters associated with calcium activation, $\rho$ and $\tau_0$ are unknown for the TA of a rat. Identification of these parameters requires experimental data of macroscopic muscle behavior.

Experiment

Experimental data were obtained by inducing isometric contractions by $320ms$ electrical stimulation of the TA at different stimulation frequencies, during which the muscle torque $T$ was measured using a isometric rat dynamometer.

Results

The DM parameters values that appeared to give the best fit to the measured isometric torques were determined interactively by trial-and-error.

<table>
<thead>
<tr>
<th>$f_1$</th>
<th>$g_1$</th>
<th>$g_2$</th>
<th>$g_3$</th>
<th>$\rho$</th>
<th>$\tau_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$60s^{-1}$</td>
<td>$50s^{-1}$</td>
<td>$300s^{-1}$</td>
<td>$20s^{-1}$</td>
<td>$4$</td>
<td>$0.01s$</td>
</tr>
</tbody>
</table>

**Fig. 3** Measured (solid lines) and simulated (dashed lines) isometric torque as fraction of maximum isometric torque.

Discussion

The results in Fig. 3 indicate that the identified parameters of DM model enables reasonable description of the isometric muscle torques of the TA of the rat at different simulation frequencies. Because only one experiment was performed so far, the parameter values are a first approximation. In the near future more experimental data will be collected and automatic parameter estimation procedures will be used.

References