A TENDON SLACK LENGTH CALCULATION FROM MUSCULOTENDON EXCURSION

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INTRODUCTION

Many researchers and biomedical engineers dealt with developing of a general method for musculotendon actuator force calculation. In the equation, which express dynamic conditions of muscle and tendon loading, are some input parameters, which are difficult to measured or simply obtain otherwise. One of these input parameters is tendon slack length. From relationships between maximum and minimum length of musculotendon, pennation angle, normalized muscle and tendon slack length has been deduced relation for tendon slack length calculation. The values from this finding are close to experimentally measured and published data.

METHODS

A problem of muscle forces calculation of the elbow during flex/ext movements has been gone before this investigation. We have created simple model of elbow with seven MT actuators, four flexors and three extensors. Each MT actuator was represent as a three element Hill-type muscle in series with tendon, and from experimental collected kinematic and EMG data, …, also from net joint moment calculated from inverse dynamics, were studied behavior of several optimization criteria, EMG-driven and hybrid (EMG-driven with optimization) models. One of the input parameters for tendon dynamic expression is tendon slack length \( L_s^T \).

The muscle force-length property has a limited range of fiber lengths over which a muscle can operate effectively. For representing of this property we use in terms normalized force \( \tilde{F}^M = F^M / F_0^M \) and normalized muscle length \( \tilde{L}^M = L^M / L_0^M \) (Zajac, 1989), \( L_0^M \) represent optimal muscle-fiber length, and peak isometric force is \( F_0^M \). The effective operating range of muscle begins at roughly \( 0.5L_0^M \) and ends at \( 1.5L_0^M \) muscle cannot generate active force beyond these lengths.

Calculation of the length tension is in this case based on next statement: “When tendon slack length is large, muscle-fiber length is small; thus, muscle excursion will be small. Conversely, when tendon slack length is small, muscle-fiber length is large, and muscle excursion will be large. The relationship between optimal muscle-fiber length and MT excursion has been shown to vary widely among muscles, and it cannot be used to definithe value of \( L_0^M \) precisely (Garner & Pandy, 2003; Brand et al., 1988)”. The muscle excursion is defined as the difference between the maximum physiological length \( L_{\text{max}}^M \) and the minimum physiological length \( L_{\text{min}}^M \) of the muscle. So, the relation between optimal muscle-fiber
length and MT excursion is the value of tendon slack length $L_{TS}^T$. We use for expression of $L_{0}^M$ and $L_{T}^T$ in terms two quantities, $\widetilde{L}_{min}^M$ and $\widetilde{L}_{max}^M$, represented the minimum and maximum physiological muscle lengths normalized by $L_{0}^M$ (as well as Garner & Pandy, 2003).

From the relationship between minimum and maximum MT length, $\alpha/\alpha_0$ is pennation angle/optimal pennation angle, equations (1) and (2), and the facts, the values of $\widetilde{L}_{min}^M = 0.5$ and $\widetilde{L}_{max}^M = 1.5$ are known, we can deduced finding (3), relationship between tendon slack length and minimal and maximal MT length.

\[
\widetilde{L}_{min}^M = L_{T}^T + L_{0}^M \widetilde{L}_{min}^M \cos(\alpha) \quad (1)
\]

\[
\widetilde{L}_{max}^M = L_{T}^T + L_{0}^M \widetilde{L}_{max}^M \cos(\alpha) \quad (2)
\]

\[
L_{T}^T = 1.5L_{min}^MT - 0.5L_{max}^MT \quad (3)
\]

RESULTS AND DISCUSSION

The equation (3), can be used for tendon slack length calculation. We used it for seven muscles about elbow, the range of elbow angle was between $0^\circ$ and $145^\circ$. The values are shown in table 1. with optimized values (Garner & Pandy, 2003) and measured data (Winters, 1988). Calculated values are only from one specimen. We can discussed, the tendon slack length value must be greater than zero, equation (4),

\[
L_{T}^T = 1.5L_{min}^MT - 0.5L_{max}^MT \geq 0 \quad (4)
\]

and obtained condition is (5):

\[
\Rightarrow 3L_{min}^MT \geq L_{max}^MT \quad (5)
\]

Table 1: calculated values of $L_{T}^T [cm]$ from eq.(3) and published data.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Brachioradialis</th>
<th>Brachialis</th>
<th>Biceps brachii</th>
<th>Triceps brachii</th>
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</thead>
<tbody>
<tr>
<td>Equation (3):</td>
<td>8.24</td>
<td>4.10</td>
<td>22.45</td>
<td>17.71</td>
</tr>
<tr>
<td>Garner &amp; Pandy:</td>
<td>6.04</td>
<td>1.75</td>
<td>22.98</td>
<td>19.05</td>
</tr>
<tr>
<td>Winters:</td>
<td>7.00</td>
<td>3.00</td>
<td>20.50</td>
<td>19.33</td>
</tr>
</tbody>
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