Effect of Muscle Passive Force Minimization on EMG-driven Model Calibration

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I. Introduction

EMG-driven musculoskeletal modeling uses optimization to calibrate musculotendon model parameter values to subject movement and EMG data. The objective function inimizes the sum of squares of errors between inverse dynamic joint moments and the joint moments estimated by the EMG-driven model. While necessary, this objective function is not sufficient to produce unique model parameter values. Consequently, unrealistic solutions sometimes occur where a muscle generates unreasonably large passive force, even when published passive joint moments for sagittal plane joints are also tracked in the cost function [1]. Previous research has shown that to avoid injury during walking, muscles likely operate primarily on the ascending or early descending region of their active force-length curves, thereby producing relatively low passive forces [2,3]. To address over-estimation of passive muscle force, this study investigated whether EMG-driven model calibration can provide reasonable estimates of musculotendon parameter values through the addition of passive muscle force minimization to the optimization cost function.

II. Methodology

Previously published gait data collected from the non-paretic leg of a subject post-stroke performing treadmill walking were used to scale a generic OpenSim model [1] and calibrate lower body joint positions and orientations [1]. The OpenSim model possessed N_m = 35 muscles controlling N_J = 5 degrees of freedom (DOFs) (2 hip DOFs, 1 knee DOF, and 2 ankle DOFs), where muscles were treated as Hill-type models with a rigid tendon. EMG-driven model calibration was performed using 10 gait cycles collected at the subject's self-selected and fastest speeds (5 gait cycles for each speed) by optimizing activation dynamics and Hill-type model parameter values (P). The optimization cost function was formulated as:

$$\min_{P} J \triangleq (1-\mu)J_{TrackMom} + \mu J_{PassiveF} \quad (1)$$

$J_{TrackMom}$ minimizes for errors in matching joint moments from inverse dynamics, $J_{PassiveF}$ minimizes total normalized passive force cost, and μ is a weighting factor that defines the relative importance of each sub-objective. The sensitivity of the solution to μ was investigated when μ was increased incrementally from 0 to 0.9.

$$J_{TrackMom} \triangleq \frac{1}{N_J}\sum_{i=1}^{N_J}\left((M_i^{mod} - M_i^{exp}\right)^2 \quad (2)$$

$$J_{PassiveF} \triangleq \frac{1}{N_m}\sum_{j=1}^{N_m}(F_j^{Passive}/F_j^{mo})^2 \quad (3)$$

M_i^{mod} and M_i^{exp} represent calculated and experimental joint moments around joint i respectively. $F_j^{Passive}$ defines model-predicted passive force of muscle j, which was normalized to maximal isometric muscle force (F_j^{mo}). For each solution, the resulting joint passive moments for the three sagittal joints were also compared with the passive joint moment measurements reported in the literature [1,4].

III. Results

A Pareto front (Fig.1 (A)) showed the trade-off between joint moment tracking error and passive force cost, where increasing the weight factor μ led to decreased passive force magnitude and increased joint moment tracking error (Fig.1 (B)). Furthermore, passive moment difference relative to published passive joint moments for different values of μ followed a v-shaped curve with a minimum near μ = 0.5 (Fig.1 (C)), which was close to the elbow of Pareto front. Passive force minimization reduced passive force cost and joint moment tracking errors simultaneously relative to a solution that tracked published sagittal plane passive joint moments in the cost function (see 'Tracking' in Fig.1 (B)).

EMG-driven model calibration was influenced by passive muscle force minimization, which tended to increase optimal muscle fiber lengths while decreasing joint moment tracking errors. Matching published average passive joint moments during model calibration may hinder EMG-driven model calibration [1, 4]. The proposed approach may reduce the occurrence of unrealistically high passive muscle forces while simultaneously producing passive joint moments that exhibit trends consistent with published data (Fig.1 (D)).

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References

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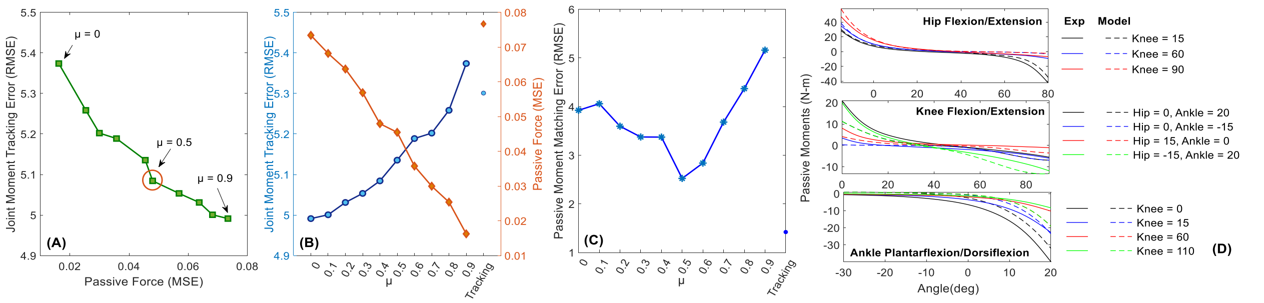

Fig.1 (A) Pareto front comparing joint moment tracking errors and passive force cost as a function of μ. (B) The influence of μ on joint moment tracking errors (blue) and passive force cost (red). (C) Passive joint moment matching differences relative to published data as a function of μ. (D) Predicted and experimental passive moments for $\mu = 0.5$. 'Tracking' indicates results when passive moment tracking for 3 sagittal plane joints is included in cost function.