How do in vivo knee contact force data affect calibration of muscle-tendon model parameter values?

– ICCB 2015 –

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ABSTRACT

This study utilized a novel two-level optimization method to evaluate how availability of in vivo knee contact force data affects calibration of muscle-tendon model parameter values for walking. An outer-level calibration optimization adjusts muscle-tendon and synergy control model parameter values, while an inner-level muscle force optimization adjusts muscle activations using the current model parameter values. The outer-level optimization is formulated using two approaches – one that matches in vivo knee contact force data (Approach A), and one that does not (Approach B). This methodology makes it possible to evaluate how well model parameter values are defined when knee contact force data are not available.

The experimental data used in this study came from the 4th Grand Challenge Competition to Predict In Vivo Knee Loads [1]. The subject wore an instrumented knee implant in his right leg. An inverse dynamic analysis of six gait trials was carried out in OpenSim [2]. A lower-limb patient-specific model was used to calculate the joint loads. Synergy-based neural commands to be used to control all muscles were obtained from the subject's experimental EMG data. For Approaches A and B, the outer-level optimization adjusted all model parameter values (tendon slack lengths, optimal fiber lengths, moment arm deviations, SV weights for muscles without experimental EMG data, and activation scale factors for muscles with experimental EMG data). Approach A also minimized errors in medial and lateral knee contact forces relative to experimental measurements. The inner-level optimization repeatedly solved a fast quadratic programming problem that minimized the sum of squares of activations subject to the constraints that the six inverse dynamic loads (3 hip, 1 knee, and 2 ankle) must be balanced (equality) and all activations must be close to a linear combination of NCs (inequality).

Approach A predicted contact forces accurately for all 6 gait trials (average $R^2 > 0.88$, average $RMSE < 93$ N, average $r > 0.95$). In contrast, Approach B produced poor contact force predictions (average $R^2 < 0.1$, average $RMSE > 322$ N, average $r < 0.90$). The differences in knee contact forces were due to the changes in muscle parameter calibration. In particular, five muscles were the main responsible. In order to get better accuracy in knee contact force predictions, it was suggested to calibrate muscle parameters using trials where these five muscles have a more important role.

REFERENCES

[1] Fregly, BJ et al., *J Orthop Res*, 30:503-513, 2012.
[2] Delp, SL et al., *IEEE T Bio-Med Eng*, 54:1940-1950, 2007.