Computer Simulation

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SINERGY-BASED TWO-LEVEL OPTIMIZATION FOR PREDICTING KNEE CONTACT FORCES DURING WALKING

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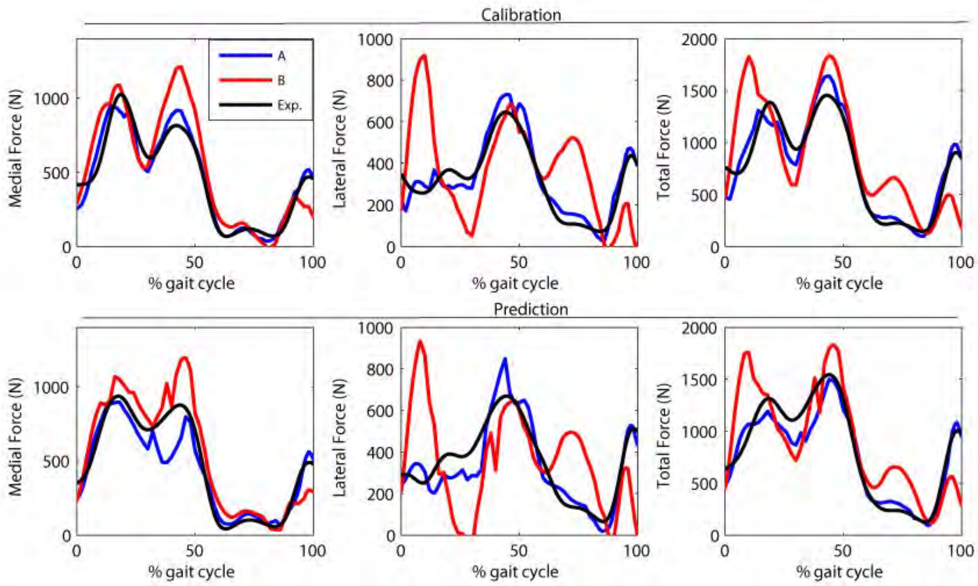
Introduction and Objectives: Musculoskeletal models and optimization methods are combined to calculate muscle forces. Some model parameters cannot be experimentally measured due to the invasiveness, such as the muscle moment arms or the muscle and tendon lengths. Moreover, other parameters used in the optimization, such as the muscle synergy components, can be also unknown. The estimation of all these parameters needs to be validated to obtain physiologically consistent results. In this study, a two-step optimization problem was formulated to predict both muscle and knee contact forces of a subject wearing an instrumented knee prosthesis. In the outer level, muscle parameters were calibrated, whereas in the inner level, muscle activations were predicted. Two approaches are presented. In Approach A, contact forces were used when calibrating the parameters, whereas in Approach B, no contact force information was used as input. The optimization formulation is validated comparing the model and the experimental knee contact forces. The goal was to evaluate whether we can predict the contact forces when in-vivo contact forces are not available.

Methods: 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]. Muscle activations were obtained applying the muscle activation dynamics to the available EMG measurements for all six trials. A muscle synergy analysis was carried out to obtain Synergy Vectors (SVs_{exp}) and Neural Commands (NCs) from experimental activations. A unique set of SVs was obtained for all six trials and one NC for each trial represents the time-activation pattern. Three gait trials were used to calibrate the model. A two-step optimization formulation was developed to calibrate the muscle parameters in the outer level, and to calculate activations at the inner level. In the outer level, SVs of the muscles without experimental data (SV_{model}), scale factors for the SV_{exp}, moment arm deviations, scale factors for the muscle optimal length and the tendon slack length were calibrated. The outer cost function had terms to minimize the passive force and the residual activations and, only in Approach A, it had terms to track the knee medial and lateral contact forces. It also had bound terms to constrain SVs, moment arm deviations, the optimal muscle lengths and the tendon slack lengths. In the inner level, muscle activations were calculated by means of the resolution of a quadratic programming problem. Muscle activations were minimized while inverse dynamics muscle contributions were matched with the calculated ones. Three different gait trials were used to predict the knee contact forces. In this case, muscle parameters previously calibrated in the outer level were used to run the inner level.

Results: Table 1 shows the R^2 values (and RMSE in parenthesis) of the match between experimental and model knee contact forces (medial, lateral and total, respectively) when calibrating the model and when predicting the contact forces, using knee contact forces to calibrate the model (Approach A) and without using them (Approach B). Figure 1 shows the knee contact force prediction in two trials (Approach A and B). The mean RMSE difference of the muscle parameters between Approach A and B for time varying quantities were computed: muscle activations 0.08, muscle forces 65.62, normalized length of the muscles 0.11. The mean absolute difference for muscle parameter values was 0.009 for optimal length of the muscles, 0.010 for slack length of the tendons and 0.290 for scale factors of the experimental activations.

Figure:



Caption: Fig. 1. Contact forces in one calibration and one prediction trial for both approaches and their experimental values

Conclusion: Medial contact forces were better predicted than lateral forces in both approaches, what is in agreement with other studies [3]. Overall, all muscle parameters are similar except some of them that would explain the differences in the contact force predictions. For instance, tensor fasciae latae, a muscle which crosses the knee, had a different activation in both approaches due to the lack of the knee contact force constrains in approach B. In Approach A, the contact force prediction were quite better predicted than in B, what means that for this subject the use of neural commands alone was not sufficient to calibrate the model such that predicted good contact forces.

Table:

	Approach A	Appoach B
Calibration	0.97 (56.97), 0.84 (64.18), 0.95 (110.39)	0.69 (194.64) / -2.07 (284.33) / 0.44 (363.88)
Prediction	0.91 (96.38), 0.76 (85.36), 0.91 (145.13)	0.68 (185.01) / -1.75 (288.64) / 0.44 (353.04)

Caption: Table 1. Mean R2 values of the knee contact force match (medial, lateral and total, respectively).

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[3] Kinney AL et al. J Biomech Eng **135**: 021012, 2013.

Disclosure of Interest: None Declared