AN EMG DRIVEN OPTIMIZATION MODEL FOR ESTIMATING DYANAMIC KNEE MUSCLE FORCES WITHOUT MAXIMUM VOLUNTARY CONTRACTION TESTS

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INTRODUCTION

Anterior cruciate ligament (ACL) injuries are common in sports. Women are at a greater risk for ACL injuries than men. Previous studies show significant gender differences in lower extremity kinematics and kinetics when performing athletic tasks, but have not establish the relationship between the observed gender differences in motion patterns and the risk for ACL injuries. To investigate the biomechanical risk factors for ACL injuries, a musculoskeletal model is needed to estimate dynamic knee muscle forces in athletic tasks. The purpose of this study was to develop an EMG driven optimization model to estimate dynamic knee model forces in athletic tasks without maximum voluntary contraction tests.

METHODS

The muscle fiber force was expressed as the sum of forces generated by the contractile and parallel elastic elements. The force generated by the contractile element was expressed as a function of dynamic EMG, EMG-to-force gain, muscle specific stress, muscle physiological cross section area, muscle length-tension adjustment, and velocity-tension adjustment. The force generated by the parallel elastic element was expressed as a function of muscle specific stress, muscle physiological cross section area, and parallel elastic length-tension adjustment. The muscle origin and insertion coordinate, physiological cross section area, optimum fiber length, muscle tendon length, muscle maximum contraction velocity, and muscle pinnation angle data, and length-tension and velocity-tension relationships in the relevant literature were used in the model to determine muscle length, PCSA, length-tension adjustments and velocity adjustments. Force fiber force was converted to the muscle tendon force using the muscle pinnation angle. Vastus medialis, lateralis, and intermedius, rectus femoris, semimembranosus, semitendinosus, biceps femoris long and short heads, medial and lateral gastrocnemius were considered as the knee flexion-extension moment generators. EMG-to-force gains and muscle specific stresses were optimized to minimize the sum of squares of the differences between the muscle generated knee flexion-extension moment and knee resultant flexion-extension moment, subject to the constraints to the muscle EMG-to-force gains and muscle specific stresses.

Five male and five female recreational athletes were recruited as the subjects. Three-dimensional (3D) kinematics and kinetics, and EMG were collected for a stop-jump and a running task. The kinematics data were collected at 120 frames/second while the kinetic and EMG data were collected at 1200 sample/channel/second. The raw coordinate data of critical body landmarks were filtered at the estimated optimal cutoff frequencies. Knee joint resultants were estimated using an inverse dynamic procedure. EMG signals were band-pass filtered (10 – 300 Hz) and then low-pass filtered (6 Hz) for linear enveloped EMG. The stop-jump and running tasks were rotated as calibration and validation tasks to validate the estimated EMG-to-force gains and muscle specific stresses. Regression determinant (R^2) and mean error (e) between muscle generated knee flexion-extension moment and knee resultant flexion-extension moments were used to evaluate the quality of predicated knee flexion-extension moment. Paired t-tests were performed to compare the regression determinants and mean errors between calibration and validation tasks.

RESULTS AND DISCUSSION

The proposed EMG driven optimization model predicted knee flexion-extension moment for calibration and validation tasks with a good accuracy (Table 1). Although the accuracy of the predicated knee flexion-extension moment was lightly decreased for validation tasks, there was not statistically significant difference in the regression determinant of the predicted knee flexion-extension moment between calibration and validation tasks (Table 1).

The ability of the proposed EMG driven optimization model to predict knee flexion-extension moment for the calibration task was comparable to the similar models in literature. The decreased ability to predict knee flexion-extension moment for the validation task is likely due to assumed linear EMG-to-force relationship. The lack of consideration of the relationship between muscle activation level and muscle length-tension relationship did not seem to have critical effects on the ability to predict knee flexion-extension moment for the validation task. Further studies may be needed to further validate estimated muscle forces and joint structure loadings.

REFERENCES

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Table 1. Regression determinant between predicted knee flexion-extension moment and knee resultant flexion-extension moment.

Calibration Task	Gender	Validation Task	
		Jump	Run
Jump	M	0.9118	0.8346
	F	0.9282	0.8511
Run	M	0.8539	0.9368
	F	0.8409	0.8986
Jump and Run	M	0.8946	0.8849
	F	0.8807	0.8628