MODELING 3D KNEE TORQUE SURFACES FOR MALES & FEMALES
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INTRODUCTION

Normative static strength databases are frequently used in the biomechanics, ergonomics and clinical rehabilitation fields. However, dynamic strength has typically been limited to 2D peak torque-velocity curves that do not consider angle-specific torques. Although isolated muscle force-velocity and length-tension relationships have been studied extensively, relatively little work has included three-dimensional (3D) representations of joint torque: torque as a function of angular velocity and position. While limited 3D knee extension torque surfaces for males have been reported (Fuglevand, 1987; Marshall et al, 1990; Signorile & Applegate, 2000), little information exists for knee flexion or for females. This information could have value for modeling applications involving dynamic joint torques as a function of angle and velocity. Thus, the purpose of this study was to develop a database of maximum knee torque (flexion and extension) for men and women – combining velocity and angle-specific measures into a 3D surface. Additionally, our goal was to develop analytical representations of these data for potential implementation with biomechanical models.

METHODS

17 subjects have been recruited to date: 8 males (23 ± 2.5 yrs, 183.0 ± 6.4 cm, 84.8 ± 6.7 kg) and 9 females (23 ± 3.5 yrs; 169.5 ± 6.4 cm; 67.2 ± 12.5 kg). Written-informed consent, as approved by our Institutional Review Board, was obtained prior to all testing. The subjects warmed-up on a cycle ergometer (5 min) prior to all strength testing. Peak torques were measured using an isokinetic dynamometer (Biodex System 3, New York, USA) and the recommended Biodex standard positioning. Range of motion (ROM) limits were set from full extension (~0º) to 120º knee flexion. Isometric torque was measured at 5 randomly-ordered positions: 15, 35, 55, 75, and 100º of knee flexion. At each position, subjects performed four, 3 sec max contractions, alternating between flexion and extension. The isokinetic protocol followed, involving randomly-ordered maximum contractions at 5 angular velocities: 60, 120, 180, 240, and 300º/s. The subjects performed several trial repetitions at each new velocity for familiarization. Subjects completed 4 to 7 maximal repetitions, increasing with velocity, for both flexion and extension.

The raw torque, position and velocity data were sampled at 1000 Hz and further analyzed using Matlab (The Math Works Inc, Natick, MA, USA). Corrections for passive tension and gravity effects were performed. Torque values were calculated for 50 velocity, angle-specific combinations. The mean (SD) male and female peak torque values were calculated and plotted as 3D surfaces (SigmaPlot, SYSTAT Software Inc, CA, USA). Analytical representations using non-uniform rational B-splines (NURBS) were determined (Mathematica, Wolfram Research Inc, USA).
RESULTS AND DISCUSSION

Peak torque values differed between males and females: 242 (± 62.4) Nm vs. 155 (± 34.3) Nm (extension) and 123 (± 19.4) Nm vs. 90 (± 52.7) Nm (flexion), respectively. To demonstrate our results, the female knee extension mean peak torque data and NURBS model are shown in Figure 1a and b, respectively.

The surfaces were consistent with Hill’s (1938) force-velocity relationship, where peak torque decays with increasing velocity. The torque-angle morphology is consistent with muscle length-tension relationships (Close, 1972), despite the inclusion of muscle moment arms and multiple muscles with potentially divergent positions of optimal muscle length. The shape and position of the peak torque curves varied with velocity, demonstrating that 2D representations of strength may miss strength nonlinearities. It is interesting to note that a faint plateau effect is observed at higher velocities, similar to the results seen by Marshall et al (1990).

SUMMARY/CONCLUSIONS

With advances in human modeling, normative dynamic joint torque 3D surfaces may be increasingly valuable. Peak torque varies with both velocity and position, making 3D representations of strength ideal.

REFERENCES


ACKNOWLEDGEMENTS

We would like to acknowledge Dr. Jingzhou Yang for his assistance with the NURBS programming.