Using Vibromyography to obtain length-tension curves for a quadriceps muscle (vastus lateralis)

The ability of a muscle to produce force is strongly dependent on the stretched length of the muscle. This is commonly referred to as the length-tension relationship, a relationship which arises as a direct result of the microanatomy of the muscle sarcomere (Figure 1).

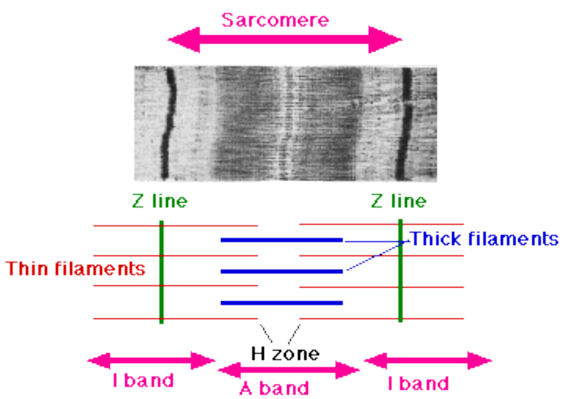

Figure 1. *Microanatomy of a muscle sarcomere. Force generation relies on the interaction between the thin actin microfilaments and the thick myosin filaments. Degree of overlap between these filaments regulates the level of force generation when the muscle fiber is excited.*

When there is either little overlap between the actin and myosin filaments, or maximal overlap, a sarcomere can produce little force. Correspondingly, when there is an optimal overlap between the actin and myosin filaments the sarcomere can produce a maximal contractile force. This relationship extends to all sarcomeres in a muscle fiber, and to the muscle as a whole, such that a parabolic relationship exists between the force that can be produced by a muscle and the length of the muscle, with maximal force generation capability existing at the optimal length. From an alternative perspective, in order to produce a less than maximal force, fewer muscle fibers need to be recruited when the muscle is at its optimal length, that is, reduced muscle effort is required.

In healthy individuals, muscles are typically stretched to close to their optimal length when the limbs are approximately in the middle of their range of motion. For example, the knee has a range of motion of approximately 120 degrees, and in healthy individuals, quadriceps muscles have been shown to produce their peak force near 60 degrees of knee flexion.[1]

However, in the event of muscle or tendon injury, or as a result of excessive tendon laxity or contraction, the muscle body may not be appropriately stretched to produce maximal force at the optimal flexion angle. Moreover, to date it has been difficult to characterize the length-tension curve for a specific muscle in an individual. Recent developments in the application of vibromyographic technology to assess muscle effort permit an accurate determination of the length-tension curve for voluntary muscles, thereby permitting accurate diagnosis and effective rehabilitation of the muscle.

Methods

Vastus lateralis (VL) muscle effort was obtained using the BIOPAC BPS-II VMG transducer. The VMG transducer was placed over the VL just proximal to the patella, and secured in place using a four inch strap (Chattanooga Group) wrapped around the thigh. Knee flexion angle was maintained by having the subject undertake knee extensions in a Biodex (System 3) dynamometer.

Isometric knee extensions to 30 N-m were undertaken at knee flexion angles of 20, 40, 60, 80 and 100 degrees. The resting torque on the dynamometer due to gravitational loading on the lower leg was recorded at each angle and this torque was added to the knee extension torque to obtain total torque generated by the VL. VMG recordings were obtained for four seconds, with three repetitions obtained for each flexion angle. VMG values were converted to muscle effort values using the BIOPAC VMG filter and these muscle effort values were averaged over the four seconds of each trial and for each flexion angle. Average muscle effort values were normalized to the total torque produced at each flexion angle.

Results

During submaximal muscle force generation, fewer muscle fibers need to be recruited to produce a given force at the optimal muscle length, and so the length-tension curve should demonstrate a minimum. Consistent with this observation, a curve fit to the normalized muscle effort data indicates a distinct minimum in the region of 45 degrees (Figure 2).

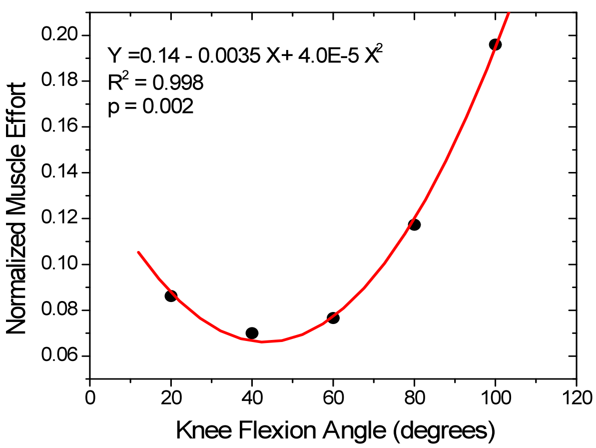

Figure 2. *Vastus lateralis muscle effort (obtained by VMG) as a function of knee flexion angle. Uncorrected for knee anatomy, a minimum in the "length-tension" curve at approximately 45 degrees is evident.*

However, knee angle does not accurately capture muscle length for the quadriceps. A more accurate assessment of the length-tension curve can be obtained by incorporating a correction factor into the muscle effort estimates utilizing established values for the quadriceps muscle force required to produce a constant knee extension torque. Specifically, the force necessary to produce a 30 N-m knee torque is only 600N at 20 degrees of flexion, but is more than 1300N at 100 degrees of flexion.[2] Normalized muscle effort as a function of knee flexion angle is shown in figure 3 following knee kinematics correction.

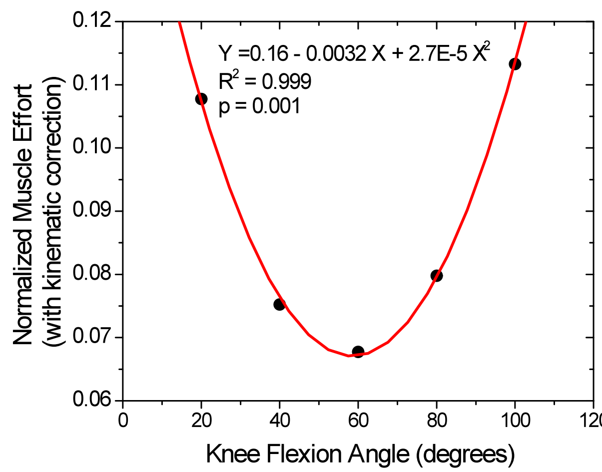

Figure 3. *"Length-tension" curve for the vastus lateralis muscle following correction for muscle length variations due to knee kinematics. An optimal knee flexion angle of 60 degrees can be identified.*

Following correction for knee kinematics, the parabolic relationship which exists between the muscle effort required to produce a constant torque and muscle length is clearly evident in this VL dataset. Further, the optimal muscle force efficiency angle is observed to be 60 degrees in this individual, indicative of a healthy muscle-tendon pair.

References

1) *Huberti H, Hayes, WC, Stone JL, Shybut GT (1984) Force ratios in the quadriceps tendon and ligamentum patellae. J. Orthopaedic Research 2:49-54.*

2) *Ostermeier S, Friesecke C, Fricke S, Hurschler C, Stukenborg-Colsman C. (2008) Quadriceps force during knee extension after non-hinged and hinge TKA. Acta Orthopaedica 79:34-38.*