QUANTITATIVE CHARACTERIZATION OF LATERAL FORCE TRANSMISSION IN PASSIVE SKELETAL MUSCLE

Carina J. Bender, M.S. and David A. Hawkins, Ph.D.

Human Performance Laboratory, Exercise Science Graduate Group
University of California, Davis
E-mail: dahawkins@ucdavis.edu Web: http://www.exb.ucdavis.edu/faculty/hawkins/index.htm

INTRODUCTION

Muscle-tendon research is critical for advancing preventative, surgical and rehabilitative techniques in orthopedic and sports medicine. Depending on architectural arrangements within individual muscles and between adjacent structures, a number of force transmission pathways are available. Traditionally, the myotendinous pathway is considered the exclusive means for muscular force transmission, but alternate pathways may employ intramuscular and inter-muscular connective tissues to transmit force laterally (lateral force transmission, LFT) (Huijing, et. al., 1998). Lateral force transmission was investigated in normal and partially compromised passive skeletal muscle systems in order to identify contributing factors and to quantify the fraction of total system force that can be transferred laterally.

METHODS

Tensile tests were performed for simulated tenotomy and fasciotomy conditions. The peroneus longus (PL) and middle gastrocnemius (MG) muscles of the chicken were selected for their similar architecture and the intermuscular fascial interface connecting the muscles along 50-80% of their lengths. The muscle system was mounted to a testing fixture (Figure 1) that allowed removal and reattachment of the distal end of the muscles to simulate tenotomy. The distal clamps were connected to a modified Cambridge

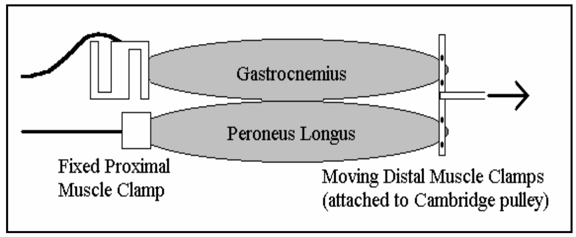

Figure 1. Diagram of testing setup.

Technology Model 300B Lever System. The proximal end of MG was clamped to a 222-N force transducer (Omega Engineering). A computer with analog to digital converter and custom LabVIEW software (National Instruments) controlled the Cambridge system to produce 20% strain in the muscle(s) at 1% strain per second while recording displacement and force data at 10 Hz and digital images of the muscle deformation at 1 Hz.

Tests were conducted under three levels of tenotomy (both muscles attached, only PL attached, only MG attached) and three levels of fasciotomy (100% intact, 33% transected distally, 66% transected distally). Release of the distal end of one muscle (unattached) followed by deformation of the distal end of the other (attached) muscle allowed the magnitude of LFT (F_{LFT}) to be quantified, defined as the force transmitted via the intermuscular fascia from the distally attached muscle to the proximal end of the distally unattached muscle. F_{LFT} was normalized to total force measured at the distal end (F_{Total}) to determine the fraction of total force that was transmitted laterally (F_{LFT}/F_{Total}).

The elastic moduli (slope of the linear portion of the force-deformation curve) for each muscle and the fascia were determined. The elastic modulus of the fascia was determined using system and individual muscle moduli. The ratio of the modulus of the muscle receiving force divided by the modulus of the muscle transmitting force (E_R/E_T) provided the relative stiffness of the two muscles. The ratio of elastic moduli of the fascia and transmitting muscle (E_F/E_T) provided a measure of the relative stiffness of these two components.

The influences of three covariates (fraction of initial fascia intact (*"Fascia"*), ratio of elastic moduli of the muscles (E_R/E_T), and ratio of elastic moduli of the fascia and transmitting muscle (E_F/E_T)) were evaluated by ANCOVA to determine their relative importance to the occurrence of LFT.

RESULTS AND DISCUSSION

The magnitude of lateral force transmission was affected by the extent of fascia and the relative properties of the muscles and fascia. With the fascia intact, 16% to 32% of the force applied distally to one muscle was transferred laterally to the other muscle. The relative amount of force transmitted laterally (F_{LFT}/F_{Total}) decreased with increased fasciotomy (Figure 2) and depended on which muscle was attached.

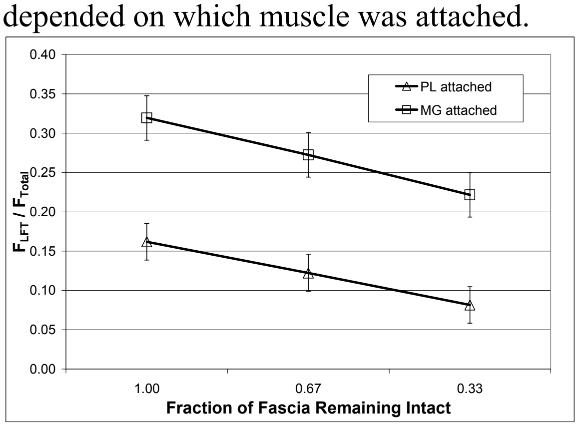

Figure 2. Relative lateral force transmission with progressive fascia removal.

There was no clear relationship between LFT and the relative stiffness of the two muscles. However, the relative stiffness of the fascia was important. As the elastic modulus of the fascia increased relative to that of the transmitting muscle, the fraction of the total force transmitted through the interface increased. The relationship between relative F_{LFT} and E_F/E_T was statistically significant ($p < 0.001$), with 21-95% of the variability in F_{LFT}/F_{Total} accounted for by variability in E_F/E_T.

Analysis of the effects of relative tissue properties and interface quantity by ANCOVA revealed the relative importance of each of these factors. F_{LFT}/F_{Total} can be expressed as a function of these significant contributors ($R^2 = 0.83$) as:

$$F_{LFT}/F_{Total} = 0.024 + (0.156 \bullet Fascia) - \left(0.014 \bullet E_R/E_T\right) + \left(0.032 \bullet E_F/E_T\right)$$

SUMMARY

Lateral force transmission between the muscles tested was sizeable and showed directionality (32% of the force applied distally to the gastrocnemius muscle was transferred laterally to the peroneus longus muscle while only 16% of the force applied distally to the peroneus longus was transferred laterally to the gastrocnemius). There was poor correlation between LFT and the relative stiffness of muscles transmitting and receiving force. Results suggest that contact area and fascia stiffness were the greatest contributors to LFT and that the architectural arrangement of fascia and muscle may play an important role.

REFERENCES

Huijing, P.A., et al. (1998). *J Exp Bio*, **201**, 682-691.

Monti, R.J., et al. (1999) *J Biomech*, **32**, 371-380.