

Age effects on the mechanical gain system of the skeletal muscle

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Introduction: One of the important architectural parameters of the musculoskeletal (MSK) system that modulate the force output of the muscle fiber is the gear ratio. This parameter refers to the mechanical advantage provided by the pennate muscle architecture and is the factor by which a unit length change in fiber is amplified to yield the final tendon displacement. This gain of the system has been suggested to vary with the pennation angle and to be proportional to $1/\cos(\text{pennation angle})$ (1). Consequently, the gear ratio should decrease for a lower pennation angle. The changes in the gain within the MSK system concomitant with aging is a poorly understood phenomenon, but an extremely significant one clinically, given the rapidly increasing geriatric population. We hypothesized that older adults would have a lower gear ratio than younger ones based on earlier studies which, using relatively sub-optimal techniques, have revealed that the pennation angle is significantly reduced in older individuals compared to younger adults (2). The gear ratio is a more directly relevant parameter to force output than the pennation angle. Hence, in the present study, using gated velocity-encoded phase contrast (VE-PC) imaging, we investigate the differences in gear ratio between two cohorts of old and young adults by measuring the strains in muscle fibers and those in the aponeurosis during plantarflexions of the lower leg.

Methods: Two groups of old [Number of subjects = 9 (all female), Mean age = 79 years] and young [N = 3 (one female, two males, 30 years)] subjects were recruited into the study after Institutional Review Board approval. Using a 1.5-T GE whole-body scanner and a spine coil, water-saturated T1-weighted images (2000 ms TR, 12.9 ms TE, 90° FA, 192 × 320-mm image matrix, 300 × 180-mm FOV, 3-mm slice thickness, 244 Hz/pixel bandwidth, 3 excitations, 1 slice, and 2:30 scan time) were used to visualize fatty tissues running parallel to muscle fascicles and determine the starts and ends of the muscle fascicles. Subsequently, gated VE-PC (water) imaging (16.5 ms TR, 7.7 ms TE, 20° FA, 122Hz/pixel bandwidth, 10 cm/s velocity encoding in three directions, 4 views per segment, 22 phases, 2 excitations, 154 × 256-mm image matrix, 300 × 180-mm FOV, 1 slice, and 1:53 scan time) in an identical oblique-sagittal orientation as the fat-image, was used to acquire tissue velocity encoded dynamic images of the lower leg during ankle plantarflexion. Because of the age of the older subjects, these experiments were carried out under passive conditions. Regions of interest (ROIs) were drawn at the origin and insertion points of the MG fascicles selected on the water-saturated T1-weighted image and then registered on to the VE-PC image. Measurements were made for the fascicle length, pennation angle, and aponeurosis displacement and strain from the VE-PC images. The ratio between fascicle length change and aponeurosis displacement were used to calculate the gear ratio.

Results: The gear ratio was less (~0.92) in older than in young subjects (~1.15) (Fig. 1-left). Fig. 1-(middle and right) show the model we used to calculate the relationship between fascicle length change and aponeurosis displacement in a pennate muscle. A gear ratio less than unity in the older cohort indicates, as Fig. 1 depicts, that the aponeurosis displacement is less than the fascicle length change.

Therefore these experiments reveal for the first time that while there was amplification of muscle fascicle length changes into aponeurosis displacement in the younger adults, there was a corresponding REDUCTION of aponeurosis displacement from unit length change in muscle fiber (gear ratio) in the older adults! This may be due to the lower pennation angle and lesser aponeurosis separation in the older compared to the younger subjects. This provides an architectural premise to partially account for the loss of limb excursion and consequently muscle force production with ageing.

Conclusions: The results indicate that older adults have a reduced ability in the translation of work from muscle fascicle shortening to the movement of the aponeurosis. Such non-invasive, high-SNR, large Field-of-view imaging with VE-PC techniques allow determination of physiological, clinically significant parameters with good accuracy and reliability. **References:** (1) Gans. *Exerc Sport Sci Rev* 1982; (2) Narici et al. *J Appl Physiol* 2003.

