Dependence of the Ratio of Fiber Length Strain to Aponeurosis Strain (Gear Ratio) of the Human Medical Gastrocnemius on Anatomical Position and Loading Conditions

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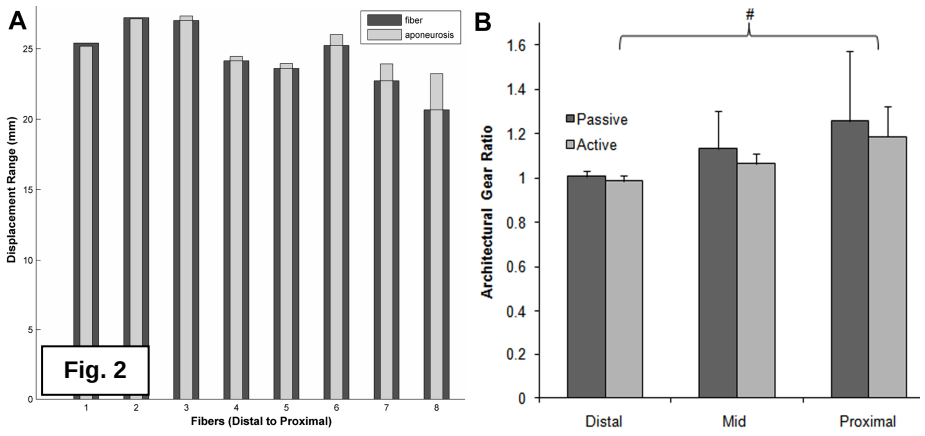
Introduction: One mechanical consequence of pinnate muscle architecture is the gear ratio. This refers to a mechanical advantage wherein the tendon displacement is greater than the length change in muscle fibers[1,2], and which can have a significant functional impact on the muscle output. Azizi et al.[3] demonstrated that the gear ratio may be variable with external load based on an *in situ* experiment on the lateral gastrocnemius (LG) of the wild turkey. We report a velocity-encoded-phase-contrast-MRI (VE-PC-MRI) study using a hydraulic-based MR-compatible ankle rotation apparatus[4] to measure the *in vivo* gear ratio of the medial gastrocnemius (MG) in humans. We hypothesize that the gear ratio is not only load-dependent but may also be spatially varying along the length of the MG as a result of changes in pennation angle and aponeurosis separation[2].

Methods: Six healthy human volunteers (height: 174.8 ± 4.1 cm, weight: 80.5 ± 12.9 kg, age: 31.5 ± 13.5 years) were studied (after IRB approval) under two modes of dynamic ankle rotation, i.e. passive and active eccentric contraction at 40% MVC. Prior to contraction-gated VE-PC-MRI acquisition (FOV: 16.5x30 cm, 141x256 matrix, Slice: 5 mm, TR/TE/FA: 16.5 ms/7.7 ms/20º, BW: ±15.6 kHz, VENC: 10 cm/s in 3 directions, VPS: 4, NEX: 2), water saturated TSE images were acquired on the same oblique sagittal slice (FOV: 18x30 cm, 154x256 matrix, Slice: 5 mm, TR/TE: 2500 ms/17.4 ms, BW: ±15.6 kHz, ETL: 7, NEX: 3) to maximize the contrast from fatty layers of connective tissue aligned in parallel with the fascicle arrangement in the MG. The muscle fiber ends were directly localized along the length of the MG using this image. These end locations were then tracked two-dimensionally using the VE-PC-MRI data after one-to-one image registration (Fig. 1). The gear ratio was determined as the ratio of the vertical displacement of the ends of each fiber to its length change during the ankle rotation cycle. The 2-way ANOVA was used to determine the effects of muscle location (distal, mid, and proximal) and mode of contraction (passive vs. active) on the gear ratio with Bonferroni multi-comparison tests when the significance was detected (p<0.05).

Results & Discussion: Fig. 2A shows the maximum displacement of fiber shortening (light bar) relative to that of the aponeuroses (dark bar), at different positions of fibers from distal to proximal (X-axis), in a representative subject. The result illustrates that the relative contribution of fiber and aponeurosis displacement is spatially varying and that the aponeurosis displacement increases proximally, implying higher gear ratio. Fig. 2B is the summary data from all subjects, presenting the means ± SD of the gear ratio as a function of MG region and the mode of contraction. The gear ratio was statistically different amongst all regions[#] with progressive increase toward the proximal end. The mode of contraction had no significant effect, though less gain was observed under active eccentric mode in all three regions.



Conclusion: For the first time, the architectural parameter of gear ratio and its variation with anatomical position under different loading and movement conditions were measured in vivo using a MR-based technique. Spatially-varying gear ratios contribute to our recognition of inhomogeneous muscle mechanics and provide insights into muscle biology.

References: 1. Otten E. Exerc Sport Sci Rev. 1988;16:89-137. **2.** Hodgson JA, Finni T, Lai AM, Edgerton VR, Sinha S. J Morphol. 2006 May;267(5):584-601. **3.** Azizi E, et al. Variable gearing in pennate muscles. Proc Natl Acad Sci. 2008 Feb 5;105(5):1745-50. **4.** Shin D et al. Proceedings of ISMRM 16th Scientific Meeting and Exhibition, Toronto, 2008; pg 3671.