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IN VIVO ACHILLES TENDON FORCES DURING CYCLING DERIVED FROM 3D ULTRASOUND-BASED MEASURES OF TENDON STRAIN

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Introduction and Objectives: Traditional motion analysis provides limited insight into muscle and tendon forces during movement. This study used B-mode ultrasound, in combination with measured joint angles and scaled musculoskeletal models, to provide subject-specific estimates of *in vivo* Achilles tendon (AT) force. Previous studies have used ultrasound images, tracked in 3D space, to estimate AT strains during walking, running, and jumping [1,2]. Our approach extends this work in one novel way. Specifically, we characterized AT stiffness on a subject-specific basis by recording subjects' ankle moments and AT strains during a series of isometric tests. We then used these data to estimate AT force during movement from *in vivo* measurements of tendon strain.

To demonstrate this approach, we report AT forces measured during cycling. Cycling offers a unique paradigm for studying AT mechanics. First, because the crank trajectory is constrained, joint angles and muscle-tendon unit (MTU) lengths of the gastrocnemius (MG, LG) and soleus (SOL) are also constrained. By varying crank load, subjects' ankle moments can be altered without imposing changes in MTU lengths. For this study, 10 competitive cyclists were tested at 4 different crank loads while pedaling at 80 rpm. Based on published EMG recordings (e.g., [3]) and on *in vivo* tendon force buckle data from one subject [4], we hypothesized that the cyclists' AT forces would increase systematically with crank load.

Methods: We coupled B-mode ultrasound with motion capture, EMG, and pedal forces to estimate *in vivo* AT forces non-invasively during cycling and during a series of isometric ankle plantarflexion tests. Marker trajectories were tracked using an optical motion capture system. Joint angles and MTU lengths were calculated based on scaled musculoskeletal models [5] using *OpenSim* [6]. A 50 mm linear-array B-mode ultrasound probe was secured over the distal muscle-tendon junction (MTJ) of the MG and was tracked using rigid-body clusters of LEDs. AT lengths were calculated as the distance from a calcaneus marker to the 3D coordinates of the MG MTJ. Subject-specific AT force-strain curves were obtained from isometric tests using ultrasound to track the MTJ, markers to track both the ultrasound probe and the AT insertion, and a strain gauge to measure the net ankle torques generated by each of the subjects at ankle angles of -10° dorsiflexion, 0°, +10° plantarflexion, and +20° plantarflexion. AT strain during cycling was converted to AT force using each subject's force-strain relation. Subject-specific tendon slack lengths were calculated as the mean tendon length at 310° over all pedal cycles, based on examination of the AT length changes and on published data showing that this position in the pedal cycle precedes tendon loading across multiple pedalling conditions [4].

Results: Peak AT forces during cycling ranged from 1320 to 2160 N ± 400 N (mean± SD) and increased systematically with load (p<0.001; Fig. 1A/B). At the highest load, the peak AT forces represented, on average, 50 to 70 % of the combined MG, LG, and SOL muscles' maximum isometric force-generating capacity, as estimated from the muscles' scaled volumes [7], the muscles' scaled optimal fiber lengths [5], and a specific tension of 20-30 N/cm^2. Peak AT forces occurred midway through the pedaling downstroke, at about 80°, which is consistent with the AT forces directly measured from one subject [4] and with patterns of EMG during cycling [3]. Peak AT strains during cycling were uncoupled from the MG MTU strains and ranged from 3 to 5 % across the different loads examined, measured at the MG MTJ.

Conclusion: Our results are consistent with published data from a single subject in which AT force was measured using an implanted tendon buckle [8]; however, our results were obtained non-invasively using ultrasound and motion capture. These methods substantially augment the experimental tools available to study muscle-tendon dynamics during movement.

Figure:

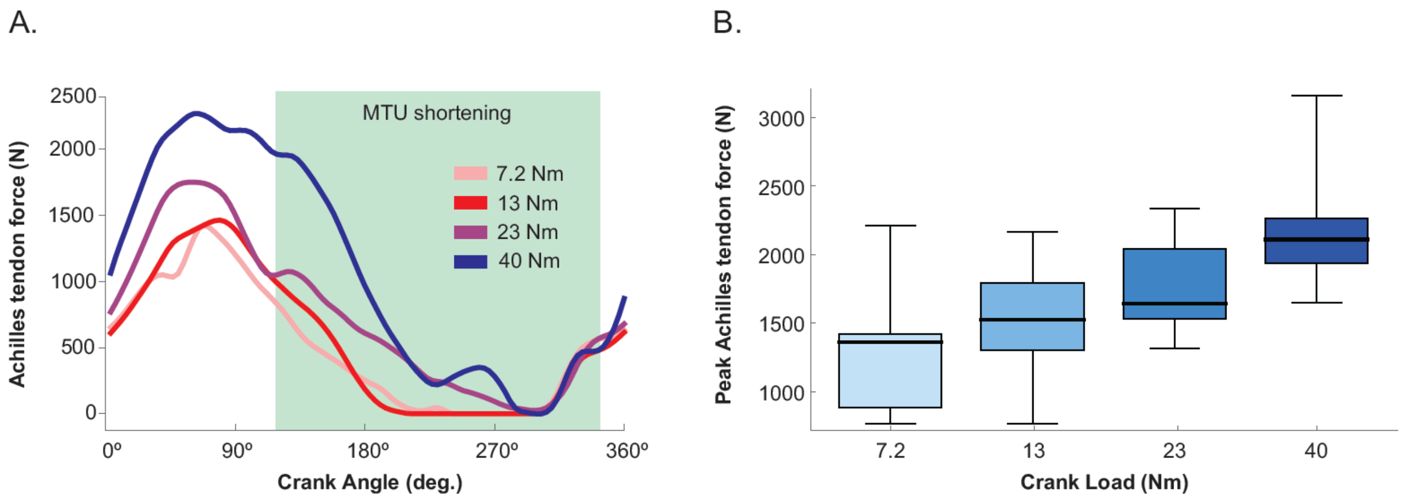

Fig 1. Evaluation of cyclists' *in vivo* AT forces using B-mode ultrasound and motion capture confirms that AT force increases with load. (A) Average AT force and MG MTU length over the pedal cycle for a representative subject cycling at 80 r.p.m and increasing crank loads. (B) Boxplots showing peak AT force for n=10 subjects cycling at 80 r.p.m. and crank loads of 7.2, 13, 23, and 40 Nm.

References:

[1]Lichtwark and Wilson, 2005, J Exp Biol, 208(24), 4715-4725.

[2]Lichtwark et al., 2007, J Biomech, 40(1), 157-164.

[3]Wakeling and Horn, 2009, J Neurophysiol, 101(2), 843-854.

[4]Gregor et al., 1987, Int J Sports Med, 8(S1), S9-S14.

[5]Arnold et al., 2010, Ann Biomed Eng, 38(2), 269-279.

[6]Delp et al., 2007, IEEE Trans Bio Med Eng, 54(11), 1940-50.

[7]Handsfield et al., 2014, J Biomech, 47(3),631-638.

[8]Gregor et al. 1991, J Biomech, 24(5), 287-297

Disclosure of Interest: None Declared