From muscle-tendon to whole-body dynamics: towards a multi-scale empirical understanding of human movement biomechanics

BACKGROUND AND AIM: A grand challenge in the field of biomechanics is to develop a cohesive, multi-scale understanding of human movement that links muscle-tendon, joint and whole-body dynamics. Musculoskeletal simulations have been developed to help bridge these gaps; however, these computational models are difficult to validate due to parameterization complexity and anatomical/physiological uncertainties. Empirical methods could potentially overcome these limitations by more directly measuring human biomechanics, but the challenge remains to improve quantitative agreement between our various experimental estimates. Using traditional 3D analysis, biomechanical estimates at one scale often do not agree with estimates at another. For instance, net mechanical work computed about the joints when a person climbs a set of stairs overestimates the work performed to raise the center-of-mass against gravity (Duncan et al. 1997). Even for level ground walking, work discrepancies of 25-35% have been observed (Zelik et al. 2015). Likewise, muscle-tendon work estimates derived from ultrasound and force transducers may not be fully consistent with joint work estimates from inverse dynamics. It is critical to resolve these discrepancies in order to develop a comprehensive, multi-scale understanding of movement. This abstract summarizes our recent efforts to coalesce multi-scale estimates. METHODS: In one study we integrated various empirical estimates of work and energy in order to synthesize whole-body dynamics (from Fenn 1930, and Cavagna et al. 1963 traditions) with joint- and segment-level kinetics (from Braune and Fischer 1895, and Elftman 1939 traditions). In a second study we focused on developing and validating an EMG-driven musculoskeletal analysis to partition joint kinetics into contributions from individual muscle-tendon units. We are now working to parse muscle fiber vs. tendon work by incorporating ultrasound. RESULTS AND CONCLUSIONS: We demonstrated, for the first time, that joint-segment estimates could fully capture whole-body gait dynamics (work done on/about the center-of-mass, Zelik et al. 2015). We found that the key to resolving work discrepancies was using 6 degree-of-freedom (rotational and translational) analysis of the hip, knee, ankle and foot. Next, we demonstrated that a new EMG-driven analysis could reproduce inverse dynamics sagittal ankle power with high fidelity during walking ($R2=0.98$, Honert and Zelik 2016, in review), while providing estimates of individual muscle-tendon contributions. Future work remains to validate this approach for different joints, activities, and planes (non-sagittal). The next challenge is to parse muscle fiber vs. tendon work. Although historically difficult, advances in medical imaging (e.g., ultrasound) offer promise. We will discuss ongoing efforts to reliably quantify muscle-tendon length changes and forces during movement, and to synthesize these with our multi-scale biomechanical understanding.