MOVING AND SHAKING: SOFT TISSUE WORK IN HUMAN WALKING

Karl E. Zelik and Arthur D. Kuo

University of Michigan, Ann Arbor, MI, USA
email: kzelik@umich.edu, web: http://hbcl.engin.umich.edu

INTRODUCTION

Joint work performed by lower-limb muscles and tendons is considered the dominant energetic contributor to walking, but soft tissues elsewhere in the body may also do significant work. Steady level-ground walking requires zero net mechanical work per stride, yet less negative work is performed about the lower-limb joints than positive [1]. This suggests that joint work measures fail to capture some negative work performed by the body. This uncaptured work may be indicative of unmodeled soft tissue deformations, as is recognized in running and jumping impacts, but typically not in walking, when collisions occur after heelstrike. Soft tissue work could influence walking economy or the risk of tissue injury or degeneration. The purpose of this study was to investigate the energetic contributions of soft tissue in human walking. We hypothesized that (1) soft tissue performs significant negative work during the collision of the leg with the ground (Collision phase of gait), and (2) soft tissue dissipates more Collision energy at faster gait speed, as total Collision magnitudes increase.

METHODS

We propose that work performed on the body center of mass (COM), but not captured by rigid-body joint work estimates is an indicator of soft tissue deformations (Fig. 1). We performed standard gait analysis on subjects walking on an instrumented treadmill at various speeds (N=10, 0.7–2.0 m/s). We compared 3D mechanical work estimates from conventional inverse dynamics and COM work analysis during individual phases of the gait cycle, looking for indications of soft tissue work, specifically during Collision phase. The phases of gait – Collision, Rebound, Preload, Push-off, Swing – are defined by fluctuating regions of positive and negative COM work, beginning at heelstrike (Fig. 2). Inverse dynamics calculations were performed using commercial software (Visual3D, C-Motion). We computed COM work rate independently for each limb based on the 3D dot product of each limb's ground reaction force with COM velocity [2]. Statistical analysis of covariance was used to evaluate work trends across speed.

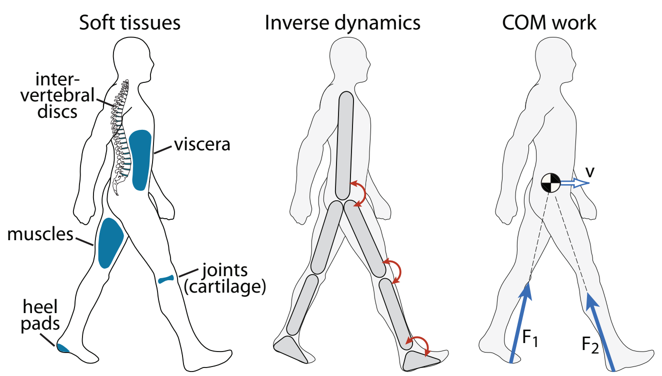

Figure 1: Soft tissues of the body and models for estimating work.

RESULTS AND DISCUSSION

We observed a strong correspondence between COM work rate and summed joint power of the ankle, knee and hip (Fig. 2). No COM vs. joint work differences were found for Pre-load or Push-off phases (P>0.05, Fig. 3). COM work of Collision and Rebound could be largely attributed to the knee joint, and Pre-load and Push-off to the ankle.

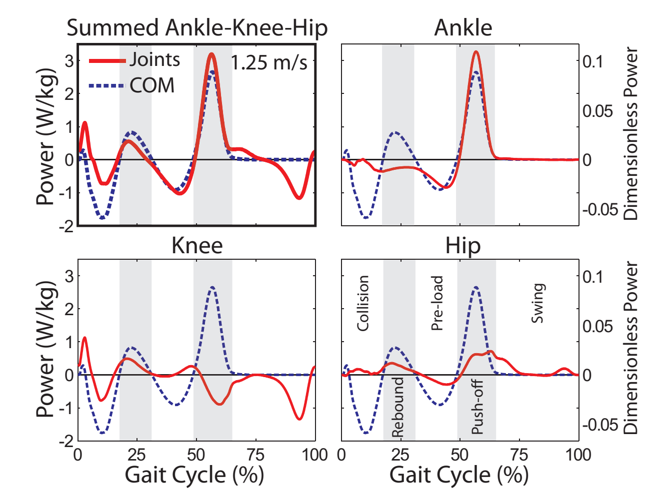

Figure 2: Average COM vs. summed ankle, knee and hip joint power. Gait phases are defined by alternating regions of positive/negative COM work.

The largest difference between COM and summed ankle-knee-hip work was during Collision, with 3.8 J less joint work at 0.7 m/s and 33.0 J less at 2.0 m/s (Fig. 3). These results suggest that substantial negative soft tissue work is performed during Collision, increasing with speed ($P<0.03$). At the nominal 1.25 m/s, ankle-knee-hip negative work fails to capture about 7.5 J during Collision, which amounts to about 31% of the negative work per stride and 60% of the negative Collision work [3].

Another substantial difference was in the positive work of Rebound. Summed ankle-knee-hip joint work was consistently less than COM by about 4 J across all speeds ($P=0.001$). At 1.25 m/s, this Rebound difference constitutes about 10% of the positive work per stride performed by the lower extremity joints. Soft tissue contributions to Rebound were not proportional to Collision work, but might nonetheless represent a damped elastic response that cannot be attributed to rotational contributions of the ankle-knee-hip joints.

A limitation of this study is in the degree to which joint work and COM work are comparable. The two types of work are not identical, but substantial energetic differences between them may still provide indirect evidence of soft tissue work. It is possible that the differences could also be attributed to contributions of unmeasured joints or errors in force and torque estimates induced by rigid body assumptions. However, we also observed less negative work about the lower extremity joints than positive work (e.g., -28 vs. +34 J at 1.25 m/s), a separate indicator of negative work by soft tissues, since steady gait requires zero net work per stride.

We believe that soft tissues play an underappreciated role in walking. Not only do they reduce peak impact loads, but they also dissipate, store and even return energy.

REFERENCES

1. DeVita P et al. (2007). *J Exp Biol* 210, 3361-73.
2. Donelan JM et al. (2002). *J Biomech* 35, 117-24.
3. Zelik KE & Kuo AD (2010). *J Exp Biol*, subm.

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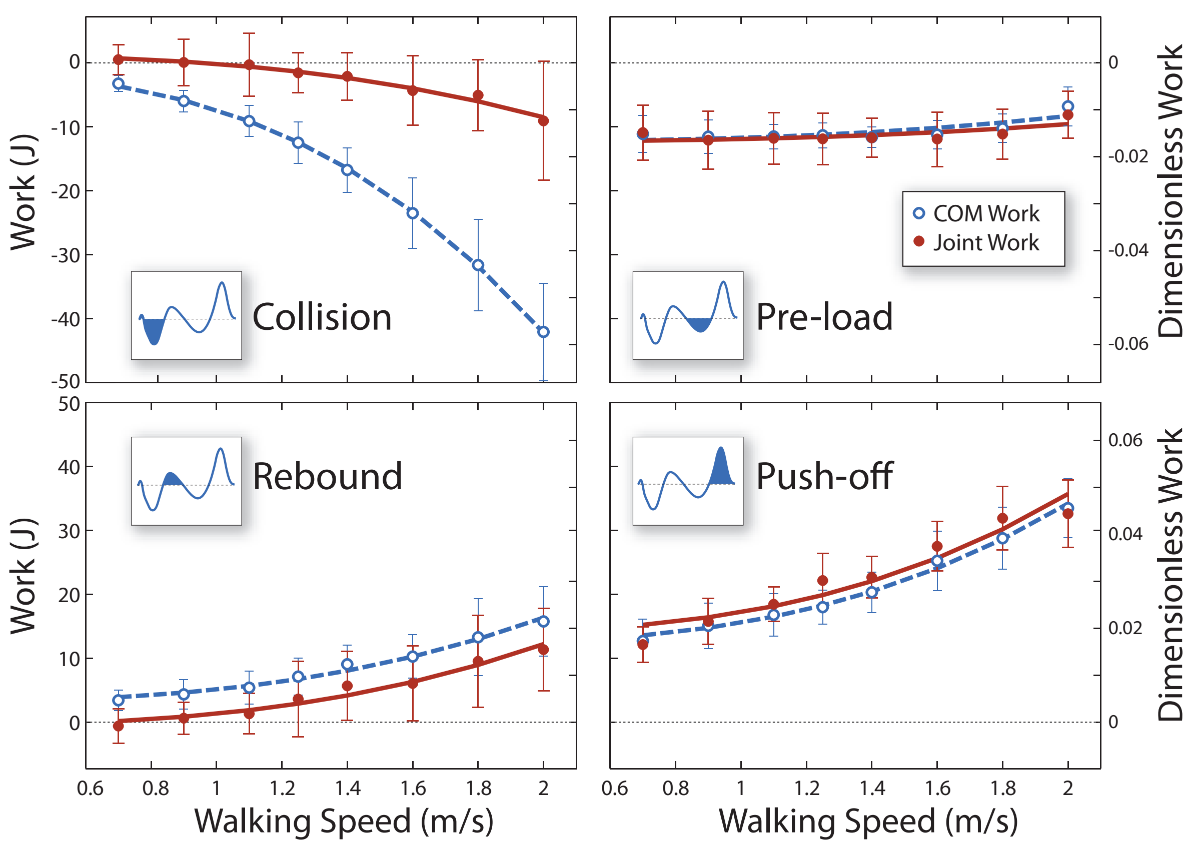

Figure 3: Average COM and summed ankle-knee-hip joint work vs. speed during phases of gait cycle. Work values were integrated from power plots (e.g., Fig. 2) during specified phases of gait.