Soft tissue contributions to energy absorption in the foot

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Summary

We quantified the energy absorbed by soft tissues in the foot across different walking speeds. We found that whilst the muscles, tendons and plantar aponeurosis absorb some energy during early stance, most of the energy in the foot is dissipated by the plantar fat pads, located in the heel and forefoot.

Introduction

Soft tissues in the foot play a critical role in dissipating energy as the heel collides with the ground and as the forefoot pushes off during propulsion. In the foot, muscle-tendon structures absorb energy as they generate joint moments and rotate whilst the plantar fat pads compress passively to dissipate energy; yet the influence of the plantar fat pads on the foot's energy absorption requirements remains largely unknown. This study aims to quantify the contribution of soft tissues in the foot, particularly the plantar forefoot fat pad, hypothesising that it would increase at faster walking speeds, as higher forces increase deformation and energy dissipation.

Methods

Nine participants [4 females and 7 males] walked at comfortable (1m/s) and fast (2m/s) speeds on a force-instrumented treadmill as 3D-motion capture and ground reaction forces (GRF) were simultaneously recorded.

Total foot power: We applied unified deformable segment analysis to calculate the total power of all structures distal to the calcaneus, referred to as foot power henceforth [1]. This was calculated using a multi-segment foot model with 6 degrees of freedom (DOF) between each segment. Foot power represents the total mechanical contribution of the plantar heel and forefoot fat pad, the plantar aponeurosis and the muscles and tendons surrounding the midtarsal (MTJ), tarsometatarsal (TMJ), metatarsophalangeal (MTPJ) joint and digits.

Joint power. Joint power was calculated using a validated multi-articular foot model in OpenSim (Maharaj, 2022). Joints in the foot model include the subtalar, MTJ, TMJ, MTPJ joints. Each joint was prescribed an oblique joint axis, allowing these 1DOF joints to move around 3 planes of motion simultaneously. Forces and moments were segmented to the multiple segments in the foot using the location of the centre of pressure (CoP) prior to inverse dynamic analysis. Joint power of the MTJ, TMJ and MPJ were summed and integrated with respect to time over the gait cycle.

Soft tissues: The contribution of the muscles, tendons and plantar aponeurosis was inferred from joint powers and work. The contribution of the plantar fat pads was quantified as the difference between foot power and summed joint powers [2].

Results and Discussion

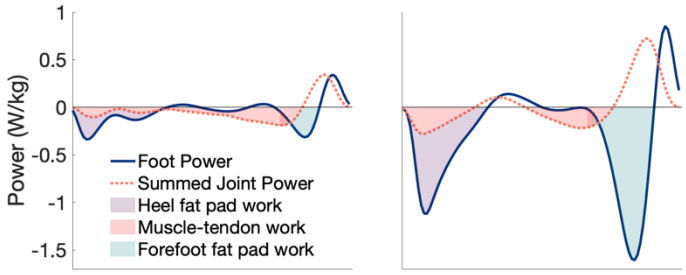

Figure 1: Foot and summed joint powers during walking at comfortable (left) and fast speed (right). Soft tissue energy absorption is highlighted by the shaded areas

Energy absorption in the foot occurs during early and late stance. Muscles, tendons and the plantar aponeurosis absorb some of this energy, see orange shading in Figure 1. However, more than half the energy is dissipated by heel fat pad during early stance (purple shading) and most of the energy in late stance is dissipated by the forefoot fat pad (green shading). At the faster walking speed, energy dissipation by both the plantar fat pads increased due to greater overall energy absorption in the foot.

The plantar fat pads dissipate more energy in the foot than the the muscles, tendons and the plantar aponeurosis absorb. Furthermore, the forefoot fat pad appears to dissipate more energy than the heel fat pad. Future studies are needed to validate the measures of fat pad energy dissipation, as some energy may be absorbed by the digits or result from errors.

Conclusions

The contribution of the fat pads at the heel and forefoot, was represented by the negative work not captured by the joint work performed by muscles and tendons. power. The key contributors to energy dissipation are the forefoot fat pad and the digits, including the interphalangeal joints and their soft tissues. Whilst our estimates of forefoot fat pad energy dissipation are aligned to the literature and the heel pad, future studies are needed for validation.

References

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