Combining an Artificial Gastrocnemius and Powered Ankle Prosthesis: Effects on Transtibial Prosthesis User Gait

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Introduction

Powered prosthetic ankles can restore the monoarticular function of the soleus muscle during walking, which provides a burst of Push-Off power in late stance. However, the benefits observed from powered ankles (e.g., magnitude of metabolic cost reduction) have often been less than those theorized/expected [1], [2].

One potential explanation is that powered ankles do not restore the biarticular function of the gastrocnemius muscle, which provides a mechanical coupling across the ankle and knee. The gastrocnemius appears to play an important role in transmitting power between proximal and distal body segments. Indeed, simulation [3] and experimental [4] studies provide preliminary evidence that restoring the gastrocnemius ankle-knee coupling to individuals with lower limb amputation (ILLA) may improve walking performance above and beyond restoring soleus function alone. For instance, ILLA demonstrated reductions in prosthesis-side hip and knee joint torques when gastrocnemius function was restored in combination with a powered ankle [4]. However, it is unclear if restoring the gastrocnemius function is only important for prosthetic ankles that generate sufficiently high magnitudes of Push-off power, or whether the gastrocnemius behavior itself (e.g., gastrocnemius stiffness) should to be tuned differently based on the powered ankle behavior. This knowledge gap remains because benefits of an artificial gastrocnemius (AG) have not yet been compared across various levels of powered prosthetic ankle Push-Off.

The objective of this study is therefore to emulate gastrocnemius-like ankle-knee coupling in ILLA, and to characterize its effect on whole-body gait biomechanics across various levels of prosthetic ankle Push-Off power and across various levels of gastrocnemius stiffness. We predict that kinematic and kinetic effects of the artificial gastrocnemius will be larger for higher levels of prosthetic ankle Push-Off power.

Methods

To study the role of the gastrocnemius we are using a robotic emulation system (HuMoTech) that we customized to include: a soleus actuator (to emulate the powered ankle prosthesis), a separate gastrocnemius actuator (to vary behavior of the ankle-knee coupling), a soft conformal leg interface (which attaches to the user's thigh to provide an anchor point for the gastrocnemius), and a foot prosthesis (a modified version of HuMoTech's standard prosthetic hardware, Fig. 1). We have developed a controller that can command the artificial soleus and gastrocnemius in a repeatable, accurate, and precise manner. As subjects walk, we can independently manipulate the dynamics of the soleus and gastrocnemius, in order to systematically analyze how different parameters affect gait.

Otherwise healthy ILLA (N=5) attended an initial familiarization session. Participants then returned for a second session, during which the artificial ankle (soleus) Push-Off power and the artificial gastrocnemius stiffnesses were systematically varied as participants walked at 1.1 $m \cdot s^{-1}$. Ground reaction forces (Bertec), kinematic marker data (Vicon), and electromyography signals (Delsys) were recorded. It is expected that a more complete (e.g., N=10) dataset will be presented at ASB.

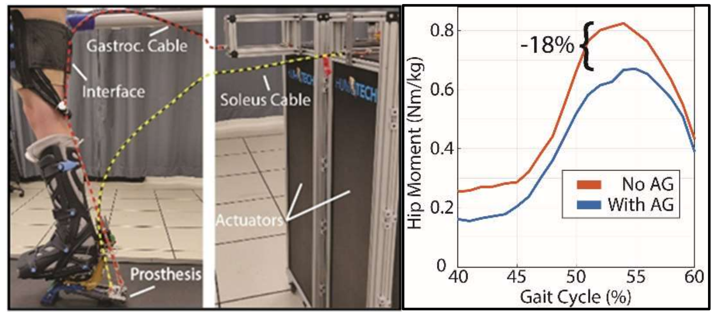

Figure 1: Experimental Set-up (left),
Example of Prosthetic Side Hip Torque with vs. without the AG (right).

Results and Discussion

We have verified the controller's ability to emulate different gastrocnemius spring stiffness profiles during walking as well as its ability to provide various levels of ankle (soleus) Push-Off power while working in tandem with the artificial gastrocnemius. We are partway through our data collection and will continue to test unilateral, transtibial ILLA while we sweep across a range of stiffness values for a passive artificial gastrocnemius, and also sweep across different ankle prosthesis Push-Off powers.

Preliminary results confirm that walking with an artificial gastrocnemius has a considerable effect on gait biomechanics, including reducing prosthesis-side hip moments during Push-Off (Fig. 1). Comparison of how the artificial gastrocnemius affects gait kinematics and kinetics for higher vs. lower magntiudes of prosthetic ankle (soleus) Push-off power is presently underway, and the newest results will be presented at ASB.

Significance

The results from this study will provide deeper understanding of the role of the gastrocnemius and how it interplays with soleus behavior during walking, as well as inform how to improve the benefits ILLAs received from powered prosthetic ankles.

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