BIONIC LEG PROSTHESIS EMULATES BIOLOGICAL ANKLE JOINT DURING WALKING

[1,2]Alena Grabowski, [1]Susan D'Andrea and [1,2]Hugh Herr

[1]Dept. of Veterans Affairs Center for Restorative and Regenerative Medicine, Providence, RI, USA
[2]Massachusetts Institute of Technology, Cambridge, MA, USA
email: alenag@mit.edu web: http://media.mit.edu/~alenag

INTRODUCTION

Over time, leg prostheses have improved in design, yet until now, prostheses have been incapable of actively adapting to different walking velocities in a manner comparable to a biological limb. People with a leg amputation (PWA) using such conventional prostheses have abnormal biomechanics during walking compared to non-amputees.

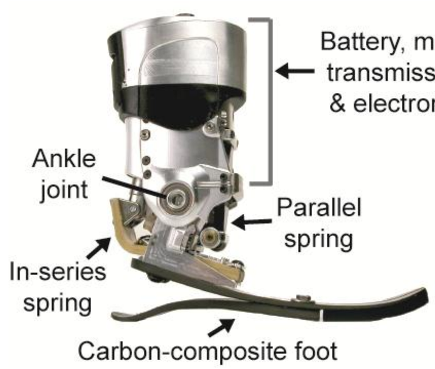

Figure 1. The bionic prosthesis' mass of 2.0 kg is equivalent to a biological foot and partial shank of an 80 kg person. The prosthesis includes a carbon-fiber in-series leaf spring, unidirectional parallel leaf spring, and heel and forefoot leaf springs that provide elasticity. A series-elastic actuator performs negative and positive work. The actuator is comprised of a 200-Watt DC brushless motor and ball screw transmission in series with a carbon-composite leaf spring.

To facilitate normative mechanics during walking, the biological leg must support body weight and accelerate body mass [1-3]. During a single stride, the net mechanical work done on the body's center of mass is nearly zero, but the leg muscles perform both negative and positive work. The biological calf muscles typically perform greater positive than negative work during each stance period [4] and

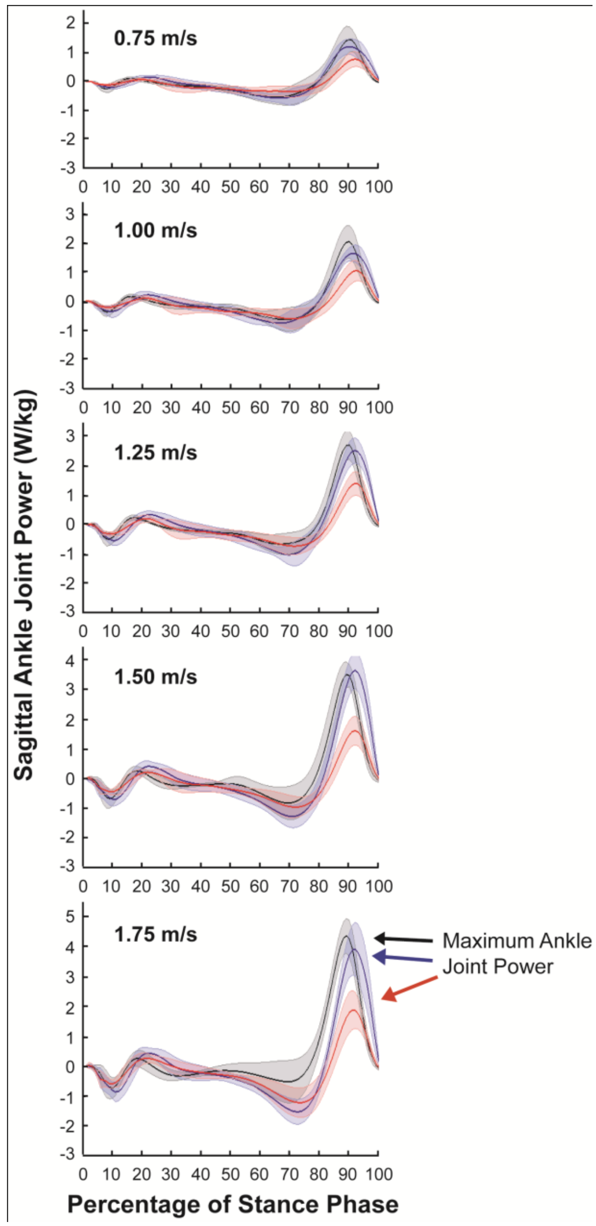

Figure 2. Mean (shaded area +/- S.D.) sagittal ankle joint power during the stance phase of walking was nearly equivalent for PWA using the bionic prosthesis (blue line) compared to non-amputees (black line); whereas PWA using a conventional passive-elastic prosthesis (red line) experienced significantly less peak power from their prosthetic ankle joint during late stance phase.

generate ~80% of the mechanical work required to complete a gait cycle [5]. In contrast, conventional passive-elastic prostheses store and release elastic strain energy while in contact with the ground, but cannot generate net positive work. We have developed a bionic prosthesis capable of performing non-conservative positive work and generating a push-off force (Fig. 1). We hypothesized that if biologically-equivalent ankle stiffness, net positive work, and power were supplied by the bionic prosthesis, PWA using the prosthesis would achieve normative joint kinetics and kinematics compared to those of non-amputees.

METHODS

8 people with unilateral transtibial amputations (PWA) and 8 age-, height- and weight-matched non-amputees participated. PWA completed two experimental sessions; one using the bionic prosthesis (Fig. 1) and one using a conventional prosthesis. Non-amputee participants completed one experimental session. We analyzed ground reaction forces (1000 Hz) and motion (100 Hz) of participants as they walked 0.75, 1.0, 1.25, 1.5 and 1.75 m/s across two force platforms mounted in a 10m level walkway. Then, we calculated joint kinetics using inverse dynamics (Visual 3D, C-Motion, Inc.). We compared results from PWA to non-amputees using one-way ANOVAs and compared results between prosthetic foot conditions using repeated measures ANOVAs.

RESULTS AND DISCUSSION

Across the full range of walking velocities, PWA using the bionic prosthesis normalized sagittal ankle joint power (Fig. 2) and maximum ankle joint power compared to non-amputees (Table 1: $P > 0.13$ at 0.75-1.75 m/s) and substantially increased maximum ankle joint power compared to using a conventional prosthesis (*$P < 0.01$ at 0.75-1.75 m/s).

CONCLUSIONS

We show that a bionic prosthesis can restore normative ankle joint mechanics to people with a leg amputation during level-ground walking. We also found differences in knee and hip joint mechanics in PWA compared to non-amputees. A lack of a biological gastrocnemius in likely led to these differences. Future prosthetic leg designs that allow energy to be transferred across the knee may further improve biomechanics for PWA.

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Table 1: Average Maximum Ankle Joint Power (W/kg) ± S.D.

	Walking Velocity (m/s)				
	0.75	**1.00**	**1.25**	**1.50**	**1.75**
Conventional Prosthesis	0.78 ± 0.25*	1.06 ± 0.35*	1.40 ± 0.41*	1.64 ± 0.49*	1.90 ± 0.65*
Bionic Prosthesis	1.26 ± 0.28	1.66 ± 0.29	2.51 ± 0.42	3.64 ± 0.61	3.94 ± 0.87
Non-Amputee	1.50 ± 0.41	2.10 ± 0.53	2.71 ± 0.50	3.56 ± 0.38	4.38 ± 0.58

* indicates a significant difference ($P < 0.01$) between prosthetic feet and when comparing use of a conventional prosthesis to non-amputees.