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14. ABSTRACT

Exotendons may offer an unpowered, low-cost way to reduce the muscular effort required to walk. We have developed a computational model to inform the design of an exotendon system, developed a beta prototype, and have tested the system with healthy human subjects. Walking performance was hindered for healthy subjects using the device. Performance is more likely to be improved for individuals for whom walking is very difficult.

15. SUBJECT TERMS
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Introduction

Exotendons [1, 2] may represent a cost-effective way to augment human performance and facilitate ambulation for those with mobility-impairments. Borrowed from equine anatomy where large muscle groups exist proximally and articulate joints via long tendons (Fig 1)[3], exotendons are parallel passive elastic structures that extend across multiple joints (Fig 2). Wrapped around pulleys at the joints, exotendons stretch with joint motion and can store energy for later return, transfer energy to different joints, and even contribute to muscular force production without adding to the metabolic cost of walking. Theoretical models have shown that exotendons can reduce joint moments and powers by about 75% [1], yet exotendons have not been used in a physical system to assist gait. Therefore, the purpose of the work proposed in this application is to develop a physical system, evaluate its performance with human subjects, and model advanced exotendon designs to inform future generations of the device.

Body

The research proposed for this project included three specific aims: 1) Design and fabricate an exotendon system, 2) Test the exotendon system with healthy human subjects, and 3) Model advanced exotendon systems. During the actual project, we were able to accomplish Specific Aim 3 first followed by 1 and then 2.

Early prototyping of a physical system found that a design following [1] would have exotendons so stiff that it would be impossible to recreate human gait. Therefore, we sought out to model new configurations that would allow the use of softer exotendons. To accomplish this, we would need to use larger pulleys to wrap the softer exotendons around, and as such we would need to explore whether pulleys centered away from the joint centers could function appropriately. A new computational model was developed by Orchard Kinetics to explore these issues and it was found that larger pulleys centered away from the hip and ankle joint centers, coupled with softer springs, could replicate a system with stiffer springs and smaller pulleys centered at the joint centers.

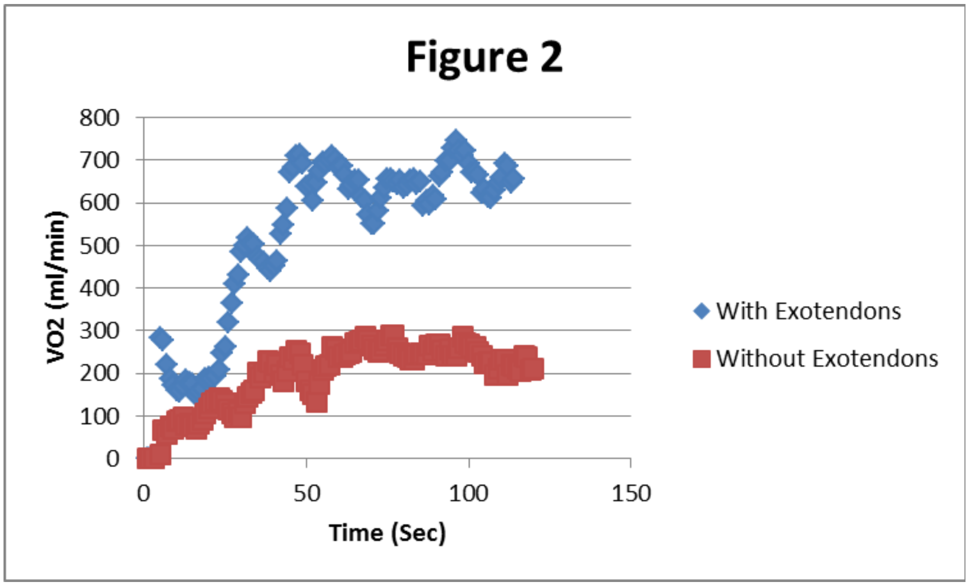
With this new knowledge, Empowering Engineering Technologies set out to build a system based on the new computational model (Fig 1). Parts were machined from local machine shops and assembled in house to create adjustable devices that could be fit to a wide variety of human subjects.

Human subjects research was performed at the Cleveland Clinic Learner School of Medicine under an IRB-approved protocol. Eight healthy volunteer performed six-minute-walk tests, oxygen consumption, and 3-D biomechanics tests with and without the exotendon system.

The main findings are that heathly subjects performed better without the exotendon orthosis than with. Fig 2 depicts the volume of oxygen consumed while walking with and without the exotendon orthosis for a representative subject. Each subject consumed equal to or more oxygen per minute walking with the exotendon orthosis than without. During the six minute walk test, subjects walked further without the exotendon orthosis (Mean: 2034.81 ft, std dev 166.89) than with (Mean: 1715.64 ft, std dev 253.5). Borg perceived exertion showed no difference with (Mean 2.09 std dev 0.92) than without (Mean 2.09 std dev 0.89). No discernible difference could be seen in joint moments from the 3D biomechanics tests.

Figure 1. Kinetic Orthosis. A long elastic element stretches around cams at the hip and the ankle to store energy in the beginning of a step, then return that energy at the end of a step to facilitate ankle plantarflexion and hip flexion.

On the surface, these results are disconcerting. However, after examining the data we feel that it is less a failure of the exotendon technology and more a failure of the wrong tests with the wrong types of subjects. Overgound walking clearly was not challenging enough of a task for healthy subjects to truly test the system, as indicated by the Borg perceived exertion results. Subjects barely registered on the scale both with and without the device. Furthermore the metabolic data showed more oxygen being consumed with the device than without. However, this is more likely due to the constraints imposed by the external structure than a failure of the exotendons to assist gait. As Walsh et al. found with their passive exoskeleton, human gait is highly optimized for healthy individuals with many subtle movements that exist to maximize walking efficiency. However, when one adds a device that constricts degrees of freedom in the leg these subtle efficiencies are disrupted and result in increases in metabolic cost [4, 5]. We believe this to be the case with our results as well.



Instead of measuring the performance of the exotendon device with healthy subjects doing an easy task, it appears that a better experiment is to measure the performance of the device either with more demanding tasks or with the same task performed by individuals who have great walking completing that task. As such, in a self-funded pilot study we tested the exotendon orthosis with a man who was three months post-stroke walking overground. With the device, he walked 29.7% faster (.248 m/s without vs. .336 m/s with) suggesting that the exotendon orthosis has the potential to dramatically improve walking for people with severe disabilities[6].

Key Research Accomplishments

- New computational exotendon model was developed
- Completion of beta prototype system
- Completion of human subjects data collection.

Reportable Outcomes

We have applied for one new grant through the Congressionally-Directed Medical Research Program based on this work. This grant is a clinical trial to examine the use of an exotendon orthosis for Soldiers recovering from incomplete spinal cord injuries. Additionally, a proposal to the National Institutes of Health seeking to develop an exotendon prosthesis for lower limb amputees was awarded 9/13/11.

We have also filed a provisional patent application for the new exotendon system that was developed.

Conclusion

We have developed a new computational model and a physical exotendon device, and have collected data with healthy subjects to explore its effectiveness in assisting walking. The exotendon orthosis causes decreased walking performance with healthy subjects. It is more likely to improve gait for individuals for whom walking is very difficult.

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Appendices

None