PARETIC MUSCLE WORK IS INCREASED IN PRE-SWING DURING HEMIPARETIC WALKING

Carrie L. Peterson, Steven A. Kautz and Richard R. Neptune

Rehabilitation Institute of Chicago, Chicago, IL, USA
Ralph H Johnson VA Medical Center, Medical University of South Carolina, Charleston, SC, USA
The University of Texas at Austin, Austin, TX, USA
email: cpeterson@ric.org, web: http://www.me.utexas.edu/~neptune

INTRODUCTION

Muscle mechanical work, a quantity that cannot be directly measured during walking, is likely affected by abnormalities observed in hemiparetic walking. Increased co-contraction between antagonist muscles and increased reliance on muscles that contribute to medial-lateral stability in hemiparetic subjects each can result in increased mechanical work without a corresponding increase in walking speed. A simulation analysis of nondisabled walking found that musculotendon (i.e., muscle fiber and in-series tendon) work was consistent with metabolic cost estimates during each region of the gait cycle (Umberger, 2010). Since musculotendon work may partly explain the increased metabolic cost of walking in hemiparetic subjects compared to nondisabled controls at matched speeds (Zamparo et al., 1995), understanding differences in musculotendon work between hemiparetic and nondisabled subjects may provide insight into the energetic cost of hemiparetic walking.

The purpose of this study was to use musculoskeletal modeling and simulation analyses to compare individual musculotendon work generated by representative hemiparetic subjects classified according to functional walking status (i.e., limited community = 0.4-0.8 m/s and community walkers = > 0.8 m/s) to a representative speed and age-matched control subject. Musculotendon work was analyzed at two speeds because metabolic cost is more increased compared to speed-matched controls for hemiparetic walkers with slower self-selected speeds than for hemiparetic walkers with faster self-selected speeds (Zamparo et al., 1995). As a first step in understanding differences between the hemiparetic and control subjects, the paretic leg pre-swing phase was analyzed because many abnormalities secondary to stroke that limit walking speed occur during this important double support phase of the gait cycle.

METHODS

Experimental data were collected from 51 hemiparetic subjects walking at self-selected speeds and 21 nondisabled elderly subjects walking at self-selected and slow speeds on a split-belt instrumented treadmill as part of a larger study. From this data set, we selected a representative subject from the limited community walker (age = 53 years, self-selected treadmill speed = 0.45 m/s) and community walker (age = 60 years, self-selected treadmill speed = 0.9 m/s) functional groups and an age matched control subject (female, age = 59 years) walking at speeds of 0.6 and 1.0 m/s for the simulation analyses.

A previously described 3D musculoskeletal model (Peterson et al., 2010) with 23 degrees-of-freedom was developed using SIMM. The model was driven by 43 Hill-type musculotendon actuators per leg with muscle contraction dynamics governed by Hill-type properties and activation dynamics modeled using a nonlinear first-order differential equation. Forward dynamics simulations from paretic midstance to paretic toe-off (right leg for control simulations) were generated using a simulated annealing optimization algorithm that varied the muscle excitation patterns until the difference between simulated and experimentally measured walking data and total muscle stress (muscle force divided by muscle cross-sectional area summed across all 86 muscles) was minimized. Net MT, fiber and tendon work were computed by integrating the corresponding power over the pre-swing phase. Positive and negative work were computed by integrating the positive and negative portions of the power trajectories over pre-
swing and summed (i.e., positive work plus absolute value of negative work) to determine the total MT, fiber and tendon work.

RESULTS AND DISCUSSION

Simulated joint angles and normalized ground reaction forces emulated well the experimental data with an average error of 1.77 degrees and 2.89 %BW, respectively. The right leg of the control simulations are referred to as the ipsilateral leg for comparison with the paretic leg.

Figure 1: Musculotendon (MT), muscle fiber, and tendon work done by all paretic (ipsilateral for control) muscles during pre-swing for the limited community (A) and community hemiparetic walkers (B) compared to the speed-matched control.

For the limited community walker, net MT work by the paretic leg was decreased relative to the ipsilateral leg of the control subject walking at 0.6 m/s (Fig. 1A), which was consistent with a previous experimental study that found decreased net paretic joint moment work during paretic pre-swing compared to speed-matched controls (Chen and Patten, 2008). However, total paretic fiber work was increased (Fig. 1A). More fiber work was done by the paretic muscles of the limited community walker to achieve a similar speed, largely due to decreased paretic plantar flexor activation. While soleus and gastrocnemius recovered the most elastic energy (i.e., positive tendon work) among the paretic muscles for the limited community walker, they recovered much less energy than the control plantar flexors. Because tendon is a passive tissue that uses little metabolic energy, the limited community walker’s decreased ability to exploit elastic energy recovery via the paretic ankle plantar flexors would increase their metabolic cost of walking compared to the speed-matched control.

For the community walker, net paretic MT work was similar to the ipsilateral leg of the control subject (Fig. 1B). However, total paretic fiber work was increased (Fig. 1B) as the paretic hip abductors and adductors did more positive fiber work and paretic gastrocnemius did more positive fiber work while recovering less elastic energy compared to the control.

CONCLUSIONS

Total paretic fiber work was increased in both the limited community and community hemiparetic walkers compared to the age-matched control subject walking at similar speeds. Increased fiber work in the limited community walker was primarily related to decreased fiber and tendon work by the paretic plantar flexors requiring compensatory work by other muscles. Increased fiber work in the community walker was primarily related to increased work by the paretic hip abductors and adductors. Thus, if the hemiparetic and control subjects were to perform work with the same mechanical efficiency, the hemiparetic walkers would expend more metabolic energy during pre-swing. These results may partly explain why hemiparetic walkers have an increased metabolic cost compared to nondisabled walkers at matched speeds.

REFERENCES


ACKNOWLEDGEMENTS

This work was funded by NIH grant RO1 HD46820 and the Rehabilitation Research & Development Service of the VA.