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Stroke-related Effects on Maximal Dynamic Hip Flexor Fatigability and Functional Implications

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The Stroke-related Effects on Maximal Dynamic Hip Flexor Fatigability and Functional Implications

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Abstract
Introduction: Stroke-related changes in maximal dynamic hip flexor muscle fatigability may be more relevant functionally than isometric hip flexor fatigability.
Methods: Ten subjects with chronic stroke performed 5 sets of 30 hip flexion maximal dynamic voluntary contractions (MDVC). A maximal isometric voluntary contraction (MIVC) was performed before and after completion of the dynamic contractions. Both the paretic and non-paretic legs were tested.
Results: Reduction in hip flexion MDVC torque in the paretic leg (44.7%) was larger than the non-paretic leg (31.7%). The paretic leg had a larger reduction in rectus femoris EMG (28.9%) between the first and last set of MDVCs than the non-paretic leg (7.4%). Reduction in paretic leg MDVC torque was correlated with self-selected walking speed (r^2=0.43), while reductions in MIVC torque were not (r^2=0.11).
Discussion: Reductions in maximal dynamic torque of paretic hip flexors may be a better predictor of walking function than for maximal isometric contractions.

Keywords: stroke, neuromuscular fatigue, hip flexors, dynamic contractions, walking

Introduction

Stroke survivors often have strength deficits[1,2] and increased muscle fatigability in the hip flexors (defined as an acute, exercise-induced reduction in force or power)[3] that are associated with deficits in leg function and walking.[4,5] Previous work has focused primarily on paretic muscle fatigability during isometric contractions.[4,6] However, less is known about stroke-related changes in muscle fatigability during maximal dynamic contractions and the relationship to function. In healthy young and older adults for example, there is limited correlation between muscle fatigability of isometric contractions and muscle fatigability of dynamic contractions.[7–9] Hence in stroke, deficits in the ability of the paretic leg to generate maximal dynamic hip flexion forces repetitively may be more predictive of walking function. Specifically because compared with maximal isometric voluntary contractions (MIVCs), dynamic contractions are (1) more specific to the task of walking, and (2) maximal contractions are more likely to expose power-related deficits in the hip flexors. Further, because individuals with stroke cannot activate musculature fully,[10,11] maximal contractions help account for effort levels between the paretic and non-paretic sides or between individuals without stroke. The purpose of this study was to determine: 1) hip flexor fatigability between the paretic and non-paretic legs during repetitive maximal dynamic voluntary contractions (MDVCs) and 2) the relationship of muscle fatigue (both MDVC and MIVC) with self-selected walking speed.

Materials and Methods

Ten people with chronic (>6 months) unilateral stroke (6 men and 4 women; age 54 ± 6 years, Lower Extremity Fugl-Meyer score mean ± SD = 25 ± 4) performed the Ten-Meter Walk Test to quantify self-selected walking speed. Participants were positioned on a therapy table with both legs secured in a customized robotic apparatus [2 servomotor systems (Kollmorgen, Northampton, MA)] instrumented with 2 torque transducers (S. Himmelstein Company, Hoffman Estates, IL)[4,12]. For details on the setup, please see previous studies.[13,14,4,15,16] Bipolar surface EMG was recorded from the rectus femoris (RF) and the medial hamstring (MH) muscles. The test protocol was performed as follows in the robotic apparatus: 1) 3–5 baseline hip flexion MIVCs, with the test leg held static at 20° hip flexion; 2) 5 sets of 30 hip flexion MDVCs (150 total repetitions); and 3) 1 final hip flexion MIVC. During MDVCs, subjects were instructed to maximally contract the hip flexor muscles while the robotic apparatus oscillated the test leg from 10° hip extension to 40° hip flexion (frequency = 0.5 Hz). Subjects were instructed to relax when the robotic apparatus moved the leg back from 40° hip flexion to 10° hip extension. After a recovery period of at least 15 minutes, the contralateral leg was tested. The order of legs tested was counterbalanced among subjects.

Fatigability of the MDVC was determined as the percent reduction in the average of contractions 3–8 in the first set to the last 5 of the fifth set. Fatigability of the MIVC was calculated as the percent reduction in hip flexion MIVC between the peak baseline MIVC and that after the 5 MDVC sets. EMG signals for each muscle during the first and last MDVC sets were rectified. The root mean square (RMS) of the signals was calculated using a sliding 100 ms window. RMS area was calculated for all data points during the first and last MDVC sets that were greater than 10% of that set's maximum RMS value. RF EMG was normalized to the peak RF RMS EMG during MIVC trials and percent change between the first and last sets of MDVCs was calculated. For MH, the ratio between the area during the first and last MDVCs was calculated.

Separate student *t*-tests were used to detect a significant difference between the paretic and non-paretic legs for the following variables: percent change in MDVC hip flexion torque, MIVC hip flexion torque, RF EMG area, and mean ratio for MH ($\alpha = 0.05$).

Results

The paretic leg had a larger percent reduction in MDVC hip flexion torque than the non-paretic leg (Fig. 1A, $P = 0.002$). There was no significant difference in percent reduction of MIVC hip flexion torque between legs (Fig. 1B, $P = 0.08$).

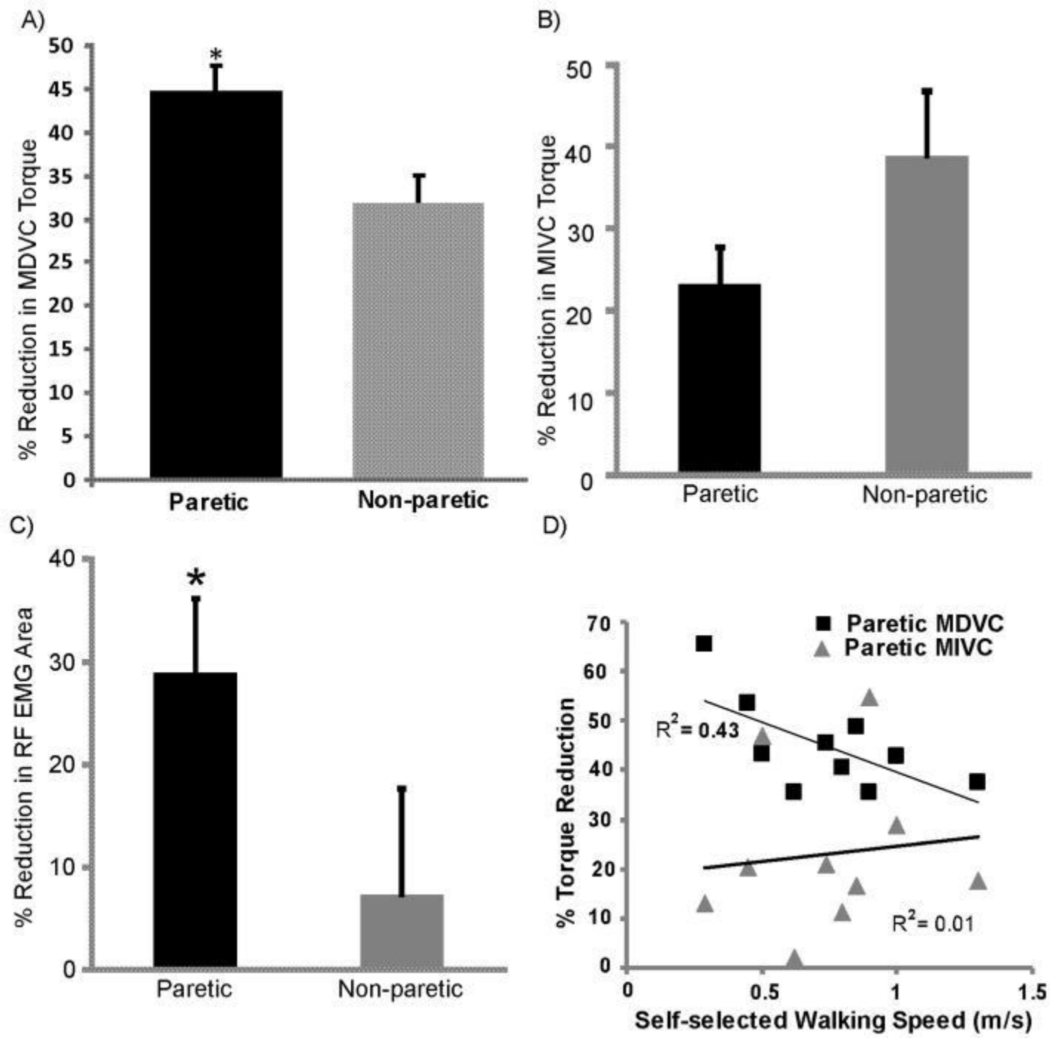

Figure 1. A) Mean (± SE) percent reduction in MDVC torque. The paretic leg had a significantly larger reduction (P = 0.002) in torque when compared to the non-paretic leg. **B) Mean (± SE) percent reduction in MIVC torque.** There was no significant difference in percent torque reduction between the paretic and non-paretic leg (P = 0.08). One subject maximally extended instead of flexing the non-paretic leg following the fatigue protocol, and this measurement was excluded. **C) Mean (± SE) percent reduction in RF EMG area.** The paretic leg has a significantly greater (P = 0.01) change in RF EMG area between the first and last set MDVCs compared to the non-paretic leg. Data were rejected in 2 of the non-paretic leg EMG measurements and 1 of the paretic leg EMG measurements due to poor signal-to-noise ratio. **D) Correlation between percent reduction in MDVC torque and self-selected walking speed.** There was a significant negative correlation (r^2=0.43, P = 0.01) between percent reduction in MDVC torque and self-selected walking speed but not between MIVC torque and self-selected walking speed in the paretic legs (P = 0.33).

The percent reduction in RF EMG area between the first and last set of MDVCs was larger for the paretic than the non-paretic leg (Fig. 1C, P = 0.01). The mean ratio of MH EMG area between the first and last set of MDVC did not differ (*P* = 0.38) between paretic (1.02 ± 0.14) and non-paretic legs (1.45 ± 0.28).

Self-selected walking speed correlated negatively with the percent reduction in MDVC torque of the paretic leg (Fig. 1D, r^2 = 0.43, *P* = 0.04), and not with the non-paretic leg (r^2 = 0.11, *P* = 0.33). Individuals with the largest reductions in MDVC hip flexion torque were also the slower walkers. There was no significant correlation between the reduction in MIVC hip flexion torque and self-selected walking speed in paretic (r^2 = 0.01, *P* = 0.79) or non-paretic (r^2 = 0.26, *P* = 0.20) legs.

Discussion

The novel findings of this study are: 1) there was a greater reduction in hip flexion torque from the paretic leg compared with the non-paretic leg during MDVC, with no difference in torque between legs during MIVC; 2) the reduction in torque of the paretic leg during MDVC was associated negatively with self-selected walking speed; and 3) neither torque reductions in the non-paretic leg MDVC and MIVC, nor reductions in the paretic leg MIVCs correlated with walking speed. Thus, muscle fatigability in the paretic leg induced with dynamic contractions is more predictive of functional tasks that require dynamic contractions (i.e. walking) than when it is assessed with maximal isometric contractions. These findings are important, because much of the literature reports the use of isometric contractions as the main tool for quantifying fatigability[3,17] in healthy and clinical populations.

We also found that the paretic RF EMG was reduced with a negligible increase in MH EMG during dynamic contractions. This suggests that reductions in paretic limb torque may be related to diminished central drive to the hip flexor muscles rather than increased co-activation of antagonist muscles. A reduction in RF EMG during repeated maximal dynamic contractions indicates that muscle activation declined either due to dropout of motor units or decreases in rate coding as the muscle fibers became fatigued.[18] It is likely that both mechanisms contribute post-stroke, as recent work has shown that paretic motor rate coding during brief contractions is impaired.[19,20] In addition, sarcopenia post-stroke would likely compound impairments in activation of paretic muscle[21] and therefore functional ability. Our findings suggest the need for: 1) high intensity stroke rehabilitation paradigms that focus on improving the generation of sustainable power in paretic hip flexors to optimize walking function and 2) evaluation tools to assess dynamic hip flexor fatigability.

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Abbreviations

MDVC	maximal dynamic voluntary contractions
MIVC	maximal isometric voluntary contraction
RF	rectus femoris
EMG	electromyography
RMS	root mean square

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