Strength Training for Skeletal Muscle Endurance after Stroke

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Background and Purpose: Initial studies support the use of strength training (ST) as a safe and effective intervention after stroke. Our previous work shows that relatively aggressive, higher intensity ST translates into large effect sizes for paretic and non-paretic leg muscle volume, myostatin expression, and maximum strength post-stroke. An unanswered question pertains to how our unique ST model for stroke impacts skeletal muscle endurance (SME). Thus, we now report on ST-induced adaptation in the ability to sustain isotonic muscle contraction. *Methods:* Following screening and baseline testing, hemiparetic stroke participants were randomized to either ST or an attention-matched stretch control group (SC). Those in the ST group trained each leg individually to muscle failure (20 repetition sets, 3× per week for 3 months) on each of three pneumatic resistance machines (leg press, leg extension, and leg curl). Our primary outcome measure was SME, quantified as the number of submaximal weight leg press repetitions possible at a specified cadence. The secondary measures included one-repetition maximum strength, 6-minute walk distance (6MWD), 10-meter walk speeds, and peak aerobic capacity (VO_2 peak). *Results:* ST participants (N = 14) had significantly greater SME gains compared with SC participants (N = 16) in both the paretic (178% versus 12%, $P < .01$) and non-paretic legs (161% versus 12%, $P < .01$). These gains were accompanied by group differences for 6MWD ($P < .05$) and VO_2 peak ($P < .05$). *Conclusion:* Our ST regimen had a large impact on the capacity to sustain submaximal muscle contraction, a metric that may carry more practical significance for stroke than the often reported measures of maximum strength. **Key Words:** Stroke recovery—stroke rehabilitation—strength training—exercise—endurance.
Published by Elsevier Inc. on behalf of National Stroke Association.

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Received August 22, 2016; revision received October 5, 2016; accepted October 19, 2016.

Sources of funding: Dr. Ivey was supported by a VA Rehabilitation Research and Development (RR&D) Merit Award and VA ORH funding. Dr. Ryan was supported by a VA Senior Research Career Scientist Award. Dr. Prior was supported by a VA Career Development Award and K23-AG040775 (NIH and American Federation for Aging Research). The authors also wish to acknowledge support from the VA RR&D Maryland Exercise and Robotics Center of Excellence (MERCE), Department of Veterans Affairs and Veterans Affairs Medical Center, Baltimore Geriatric Research, Education and Clinical Center (GRECC), and the National Institute on Aging (NIA) Claude D. Pepper Older Americans Independence Center (P30-AG028747).

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1052-3057/$ - see front matter
Published by Elsevier Inc. on behalf of National Stroke Association.
http://dx.doi.org/10.1016/j.jstrokecerebrovasdis.2016.10.018

Introduction

Paretic-side skeletal muscle abnormalities contribute to poor strength, fitness, and function, with serious implications for both disability and ongoing cardiometabolic risk after stroke.[1-4] Our group designed a unique strength training (ST) model for stroke, showing great potential for reversing both paretic and non-paretic-side skeletal muscle wasting.[5] These ST-induced adaptations carry high clinical relevance, resulting in altered tissue composition and improved insulin sensitivity to affect whole body metabolic health.[5,6]

Of the trials completed to date after stroke, success of ST interventions has often been gauged by impact on maximum strength.[5,7-17] Although measures of one-repetition maximum (1-RM) and peak torque generating capacity strength are clearly important measures through which to evaluate the effectiveness of a training stimulus, the ability to sustain submaximal muscle contraction may be even more relevant to everyday function.[18,19] This is especially true in stroke disability, wherein activities of daily living are more often contingent upon submaximal sustainment than maximal exertion.[20-23] For this reason, it would seem logical to target and design interventions with an eye toward maximizing skeletal muscle endurance (SME) in addition to maximum strength. To our knowledge, the general concept of training for SME has not yet emerged in stroke rehabilitation.

Hence, our objective was to apply an ST intervention tailored for muscle endurance gains after stroke. We sought to assess bilateral capacity for improving maintenance of submaximal muscle contraction at a specified cadence. In addition, we determined whether our endurance-based ST regimen for stroke changed other widely reported functional metrics, some of which do not consistently respond to more standard ST regimens.[7,17] The designated primary assessment (SME) was compared between ST and stretch control (SC) groups in both the paretic and non-paretic legs across a 3-month period. Likewise, the chosen secondary functional measures (1-RM, 6-minute walk distance [6MWD], VO_2 peak, and 10-meter walk speeds [10MWS]) were assessed and compared between groups. We hypothesized that ST would show between-group superiority and large effect sizes for SME, and that secondary functional measures would also improve based on the unique features of the training protocol.

Materials and Methods

Subjects

Recruits came from the University of Maryland Medical System and the Baltimore VA Medical Center referral networks. Patients with chronic hemiparesis (>6 months post-stroke) were identified and invited to participate after completion of all standard physical therapy. Potential participants presented with mild to moderate hemiparetic gait and preserved capacity for ambulation either with or without an assistive device. This study was approved by the institutional review board for research involving humans at the University of Maryland, Baltimore. Written informed consent was obtained from each participant.

Screening

Baseline evaluation included a medical history and examination, ensuring that all specified entry criteria were met. Additionally, a physician-supervised treadmill tolerance test at no incline was first performed to assess gait safety and to select walking velocity for subsequent peak exercise testing as previously described.[24,25] Participants minimized handrail support, and a gait belt was worn for safety. For the graded treadmill screening test, all participants who achieved adequate exercise intensities without signs of myocardial ischemia or other contraindications for participating in exercise training were deemed suitable for safe entry.

Outcomes Testing

SME

Endurance for both paretic and non-paretic legs was assessed individually on a leg press device that allowed for unilateral movement (Keiser K-300, Fresno CA). Using a standardized protocol, the objective was to determine the maximum number of leg press repetitions possible at 70% of 1-RM according to a fixed metronome cadence (60 bpm, 0°-90°). The non-paretic leg was always assessed first, followed by separate testing on the paretic leg. Participants were instructed to perform the concentric and eccentric movements of the leg press in a highly controlled manner, moving out with one metronome click and back with the subsequent metronome click, repeating as many times as possible until either complete muscle failure or disruption of the specified cadence. In this way, we could ascertain the capacity of the quadriceps to sustain controlled contraction on the paretic and non-paretic sides, both before and after the interventions. The 3-month post-test used the same absolute level of resistance (70% of baseline 1-RM), enabling us to properly gauge the enhanced efficiency of sustaining leg press movement with the original pretraining level of resistance. This is somewhat analogous to studies assessing gait economy on a treadmill, during which the same absolute treadmill speed (i.e., level of work) is utilized for both baseline and post-training testing.[26] The number of repetitions at the required cadence was the outcome value compared across time and between groups for both the paretic and non-paretic legs.

1-RM

The 1-RM strength testing was conducted separately on each side to account for sizeable strength discrepancies

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