ORIGINAL ARTICLE

Muscle Changes Following Cycling and/or Electrical Stimulation in Pediatric Spinal Cord Injury

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ABSTRACT. Johnston TE, Modlesky CM, Betz RR, Lauer RT. Muscle changes following cycling and/or electrical stimulation in pediatric spinal cord injury. Arch Phys Med Rehabil 2011;92:1937-43.

Objective: To determine the effect of cycling, electrical stimulation, or both, on thigh muscle volume and stimulated muscle strength in children with spinal cord injury (SCI).

Design: Randomized controlled trial.

Setting: Children's hospital specializing in pediatric SCI.

Participants: Children (N=30; ages, 5–13y) with chronic SCI.

Interventions: Children were randomly assigned to 1 of 3 interventions: functional electrical stimulation cycling (FESC), passive cycling (PC), and noncycling, electrically stimulated exercise (ES). Each group exercised for 1 hour, 3 times per week for 6 months at home.

Main Outcome Measures: Preintervention and postintervention, children underwent magnetic resonance imaging to assess muscle volume, and electrically stimulated isometric muscle strength testing with the use of a computerized dynamometer. Data were analyzed via analyses of covariance (ANCOVA) with baseline measures as covariates. Within-group changes were assessed via paired *t* tests.

Results: All 30 children completed the training. Muscle volume data were complete for 24 children (8 FESC, 8 PC, 8 ES) and stimulated strength data for 27 children (9 per group). Per ANCOVA, there were differences between groups ($P<.05$) for quadriceps muscle volume and stimulated strength, with the ES group having greater changes in volume and the FESC group having greater changes in strength. Within-group analyses showed increased quadriceps volume and strength for the FESC group and increased quadriceps volume for the ES group.

Conclusions: Children receiving either electrically stimulated exercise experienced changes in muscle size, stimulated strength, or both. These changes may decrease their risk of cardiovascular disease, insulin resistance, glucose intolerance, and type 2 diabetes.

Clinical Trials Registration Number: NCT00245726.

Key Words: Electrical stimulation; Muscles; Pediatrics; Rehabilitation; Spinal cord injuries.

MUSCLE ATROPHY OCCURS rapidly after spinal cord injury (SCI), with decreases in lower extremity muscle cross-sectional area (CSA) up to 45% reported 6 weeks post-SCI for adults.[1] These values then decrease approximately 3.2% per decade compared with 1% per decade in the general male population.[2] Other muscle alterations seen in adults with SCI include increased intermuscular fat[3]; decreased fiber size, contractile proteins, force-generating capacity, and fatigue resistance; and increased percentage of fast fatigable fibers and myosin heavy-chain isoforms, which impact muscle's response to exercise.[4] The extent of muscle alterations after pediatric SCI is unknown; however, muscle of children with cerebral palsy (CP) shows some similarities to muscle of adults with SCI, including increased intermuscular fat, decreased fiber length and CSA, atrophy, and altered myosin expression, along with altered length-tension relationships.[5,6] Spastic gastrocnemius muscles are 10% shorter in children with CP compared with children with typical development.[5] It is not known whether shortening of spastic muscle occurs for children with SCI.

Muscle atrophy has negative health effects for people with SCI. Along with an increased risk for cardiovascular disease, atrophy is associated with insulin resistance, glucose intolerance, and type 2 diabetes.[7,8] Thigh muscle atrophy in particular is associated with metabolic syndrome, and people with incomplete SCI have 33% less thigh muscle CSA compared with people without disability.[3] Because people with SCI are at risk for metabolic syndrome as a result of atrophy and other risk factors such as inactivity, hyperlipidemia, and increased adiposity,[7] interventions to minimize these risks are important. Children with SCI also have risk factors for metabolic syndrome, and Nelson et al[9] reported metabolic syndrome in 11 of 20 children with SCI (ages, 11–20y). Therefore, intervening at an earlier age may be beneficial.

Cycling with functional electrical stimulation has been used by people with SCI for health and fitness benefits. In addition,

List of Abbreviations

AIS	American Spinal Injury Association Impairment Scale
ANCOVA	analyses of covariance
BMD	bone mineral density
CP	cerebral palsy
CSA	cross-sectional area
ES	electrical stimulation
FESC	functional electrical stimulation cycling
MRI	magnetic resonance imaging
PC	passive cycling
rpm	revolutions per minute
SCI	spinal cord injury

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functional electrical stimulation cycling (FESC) can increase muscle mass and strength in adults with SCI.[10] Studies[11-16] have reported increases in muscle CSA, ranging from 9% to 40%, within 8 weeks.[15,16] Increases in electrically stimulated muscle contractions have also been reported.[17,18] CSA improvements of 35% to 39% have been shown after a 12-week electrically stimulated resistance training program for adults with SCI, suggesting that the effect may be obtained without cycling.[19] Muscle changes may also be possible through the cycling motion itself. After a 12-week program of passive cycling, no changes were reported in thigh girth for adults with SCI; however, decreases were found in proteolytic activity associated with muscle degradation,[20] suggesting possible effects on muscle.

While studies with adults with SCI have indicated improvements in muscle mass and strength, there are no reports in children, whose muscles may respond differently. In prepubertal children, significant strength gains can be made independent of changes in muscle size, and hypertrophy appears to be limited.[21] Therefore, it is unknown whether children with SCI will experience muscle hypertrophy if strength gains are made after FESC, passive cycling (PC), or electrically stimulated (ES) exercise. Thus, the purpose of this study was to examine and compare changes in muscle volume and strength after a program of FESC, PC, or ES for children with SCI. These 3 interventions were chosen because they are often recommended to parents to preserve muscle or provide exercise, or both, without strong evidence for their effects. It was hypothesized that children in the FESC group would have the greatest change as a result of actively cycling against resistance.

METHODS

Participants and Training Protocol

A randomized controlled study was conducted with 30 children with C4 through T11 SCI, aged 5 to 13 years. Parents and children signed institutional review board–approved informed consent and assent forms, respectively. Inclusion criteria were 12 months postinjury; cervical or thoracic SCI with American Spinal Injury Association Impairment Scale (AIS) A, B, or C; ages 5 to 13 years; and an upper motor neuron injury to the targeted muscles (tested with electrical stimulation). Children whose SCI was classified as AIS C were included only if the classification was due to the presence of anal contraction or minimal muscle movement proximally.[22] Exclusion criteria included chronic steroid treatment, seizure history, cardiac disease, ventilator dependency, severe spasticity, lower limb fractures of unknown origin, uncontrolled autonomic dysreflexia, heterotopic ossification, and hip dislocation. Children were excluded if they participated in electrical stimulation, cycling, or treadmill training within the past 3 months. Children were screened for contraindications for magnetic resonance imaging (MRI).

After enrolling, children were assigned to 1 of the 3 groups (FESC, PC, and ES) using a computer-generated block randomization schedule with blocks of 3. Children exercised at home with parental assistance for 1 hour, 3 times per week. This frequency was chosen because it is commonly used in FESC studies.[12-16] Children could continue previous therapeutic activities but were not permitted to participate in other lower extremity repetitive motion tasks or electrically stimulated exercise.

The FESC group cycled at 50 revolutions per minute (rpm) using the RT300-P[a] while seated in their wheelchairs. Bilateral cyclical stimulation was delivered to the quadriceps, hamstring, and gluteal muscles with the largest surface electrodes[b] appropriate for the child. Resistance was progressively increased throughout the exercise, while maintaining 50rpm. Stimulation frequency was fixed at 33Hz, and pulse duration between 150 and 300μs. Amplitude increased automatically up to 140mA to generate sufficient force to maintain cadence. This maximum was decreased for smaller children based on individual muscle response.

The PC group used the RT100[a] motorized cycle, which passively moved the limbs at 50rpm for 1 hour with children seated in their wheelchairs. The ES group used a 2-channel surface stimulation unit[c] to create contractions of bilateral hamstrings, quadriceps, and gluteal muscles for 20 minutes per muscle group with a duty cycle of 5 seconds on, 15 seconds off, with stimulation parameters of 33Hz and 300μs, and a maximum amplitude of 100mA. Amplitude was set for each muscle to achieve optimal response based on muscle size and response to stimulation. To achieve the optimal response, the muscle was palpated while the amplitude was increased. When the muscle was perceived to be fully contracted, the amplitude was set at that level. Children exercised while supine, working against zero resistance. Resistance was not added, to replicate a common home exercise protocol.

Children could miss up to 12 sessions over the 6 months. If sessions were missed, parents were instructed to add 1 session per week. Parents logged each session, and phone calls were made to parents every 2 weeks to discuss progress.

Data Collection

Data were collected before and after the 6-month intervention, and all testing was performed with the left lower extremity. To measure muscle volume, axial images (repetition time, 6.2ms; echo time, 1.7ms; field of view range, 15–24cm, 0.7-cm thick with no separation between slices) were collected beginning at the most proximal aspect of the left femoral head and extending to the left knee joint with a GE 1.5T MRI scanner.[d] Quadriceps and hamstrings muscle volume was determined on a personal computer using custom software developed with Interactive Data Language.[e] The software separates muscle from other tissues, such as bone, adipose, and skin, as previously described.[6] Briefly, the individual muscles in each raw image were traced over the muscle boundary and labeled appropriately. The images were then filtered with a median filter, and image segmentation was performed with a fuzzy clustering algorithm.[23] The CSA was determined for each quadriceps muscle (rectus femoris, vastus lateralis, vastus medialis, vastus intermedius) and each hamstring muscle (biceps femoris long head, biceps femoris short head, semimembranosus, semitendinosis) in each image by summing all voxels assigned to muscle and multiplying the number of voxels by the area per voxel. The volume of each muscle was determined by multiplying the CSAs by 0.7 to account for the thickness of the image (0.7cm). The total volume for the quadriceps and hamstring muscles was then calculated by summing the volumes for the individual muscles. The MRI collection and analysis processes were blinded to group assignment. The interrater reliability of the analysis procedure was determined using images from 4 participants in this study. The coefficient of variation of volume estimates was 3.4% for the quadriceps muscle group, 3.5% for the hamstring muscle group, and 5% or less for the individual muscles.

To assess stimulated isometric strength, subjects were seated with hips flexed approximately 80° on an isokinetic dynamometer.[f] The knee was fixed at 60° of flexion to test the quadriceps and at 30° of flexion for the hamstrings. The dynamometer's axis was aligned with the knee joint's axis, and the distal attachment was made approximately 3cm above the lateral