BRIEF REPORT

Changes in Skeletal Muscle Size and Glucose Tolerance With Electrically Stimulated Resistance Training in Subjects With Chronic Spinal Cord Injury

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ABSTRACT. Mahoney ET, Bickel CS, Elder C, Black C, Slade JM, Apple Jr D, Dudley GA. Changes in skeletal muscle size and glucose tolerance with electrically stimulated resistance training in subjects with chronic spinal cord injury. Arch Phys Med Rehabil 2005;86:1502-4.

Objective: To determine the effect of residence-based, resistance exercise training (RET) on affected skeletal muscle size and glucose tolerance after long-standing, complete spinal cord injury (SCI).

Design: Before-after trial.

Setting: University laboratory trial.

Participants: Five men with chronic, complete SCI (C5-T9).

Intervention: Magnetic resonance images of the thighs and an oral glucose tolerance test were performed before and after RET. Subjects performed RET with both thighs, 2d/wk for 4 sets of 10 unilateral, dynamic knee extensions for 12 weeks. Neuromuscular electric stimulation induced RET by activating the knee extensors.

Main Outcome Measures: Quadriceps femoris muscle cross-sectional area (CSA), plasma glucose, and insulin concentrations were measured before and after RET.

Results: Skeletal muscle CSA increased by 35% in the right quadriceps femoris (from 32.6cm^2 to 44.0cm^2) and by 39% in the left quadriceps femoris (from 34.6cm^2 to 47.9cm^2) as a result of training ($P<.05$). There were no significant changes in blood glucose or insulin after training. However, a trend for a reduction in plasma glucose levels was observed ($P=.074$).

Conclusions: Affected skeletal muscle can achieve substantial hypertrophy years after SCI with resistance exercise. Furthermore, our results suggest that this type of training may enhance glucose disposal.

Key Words: Electric stimulation; Glucose tolerance test; Hypertrophy; Rehabilitation; Spinal cord injuries.

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COMPLETE SPINAL CORD INJURY (SCI) leads to skeletal muscle atrophy below the level of spinal lesion. The quadriceps femoris muscle, for example, is about 40% smaller than in able-bodied control subjects 48 weeks after SCI.[1] The combination of reduced skeletal muscle mass and the absence of voluntary contractile activity of the paralyzed limbs may play a role in the secondary health complications associated with SCI.

Duckworth et al[2] have reported that 50% of patients with chronic SCI have diabetes mellitus despite having normal fasting glucose levels. Additionally, Bauman and Spungen[3] showed that 50% and 62% of subjects with paraplegia and quadriplegia, respectively, have abnormal oral glucose tolerance tests (OGTTs) compared with 18% of able-bodied controls. The authors attributed these results to the physical inactivity associated with SCI.

We have previously reported hypertrophy of the quadriceps femoris using neuromuscular electric stimulation (NMES)–induced dynamic, loaded knee extension in acutely (<1y) injured SCI patients. Subjects were given an NMES unit and ankle weights and did resistance exercise training (RET) with their thighs in their homes. This simple means of using NMES-induced RET reversed 48 weeks of atrophy.[4]

The purpose of this study was to determine if 12 weeks of NMES-induced RET in subjects with long-term SCI would increase skeletal muscle size and enhance glucose tolerance.

METHODS

Five men with chronic (time since injury, 13.4±6.5y) complete SCI (American Spinal Injury Association grade A, levels C5-T10) participated in this study. Average age and body mass were 35.6±4.9 years and 76.6±21.5kg, respectively. All methods were approved by the Institutional Review Board of the University of Georgia. Briefly, subjects were administered an OGTT and had magnetic resonance imaging (MRI) of both thighs before and after RET.

Magnetic Resonance Imaging

Average quadriceps femoris cross-sectional area (CSA) was determined before and after RET using MRI as was done previously.[1,4] Images of both thighs were collected with a 1.5-T magnet[a] (repetition time, 500; echo time, 14; field of view, 20cm; matrix, 256×256). Transaxial images, 1cm thick and 0.5cm apart, were taken from the hip joint to the knee joint using the whole body coil. The person analyzing images was blinded as to whether images were pre- or posttraining.

Oral Glucose Tolerance Testing

Subjects reported to the laboratory in the morning after fasting overnight. After having a baseline blood sample drawn, each subject drank 75g of glucose solution. They rested for the next 2 hours, having blood drawn at 60, 90, and 120 minutes after glucose consumption. Samples were sent to a laboratory for analysis of plasma glucose and insulin.

Table 1: Quadriceps Femoris Muscle CSA Before and After RET

Quadriceps Femoris	Before	After
Right (cm^2)	32.6±1.9	44.0±2.1*
Left (cm^2)	34.6±2.3	47.9±2.5*

NOTE. Values are mean ± SD.
*$P<.05$ (after vs before RET).

Resistance Exercise Training

Surface NMES of both thighs was done as described previously.[4,5] After familiarization with the use of the electric stimulation unit, subjects were provided with an electric stimulation unit[b] and ankle weights.[c] Training was performed 2d/wk for 12 weeks at the subject's home. An investigator provided instruction by telephone for each session, which consisted of 4 sets of 10 NMES-induced knee extensions. A 5 second/5 second work/rest ratio was used with a 3-minute rest between sets. Knee extensions were performed as subjects sat in a chair with weight attached to the shin. Current from the stimulator was manually increased in 2- to 3-second intervals to evoke full knee extension followed by the lengthening action. Subjects progressively increased loading by about 0.9 to 1.8kg/wk for 12 weeks.

Statistics

Repeated-measures analysis of variance (ANOVA) was used to detect changes in the quadriceps femoris muscle CSA. Two-way ANOVA for repeated measures was used for glucose and insulin data (fasting, 60, 90, 120min) before versus after training. Results are expressed as mean ± standard deviation (SD) and statistical significance was accepted at P less than .05.

RESULTS

Average quadriceps femoris muscle CSA increased significantly in both thighs (≈37%) after NMES-induced RET (table 1). Individual and mean blood glucose values for OGTT are listed in table 2. All subjects had normal fasting glucose levels before and after training. There were no significant changes in blood glucose or insulin with training. However, there was a trend for a reduction in plasma glucose levels ($P=.074$). All subjects progressively increased resistance over the 12 weeks. They used as little as 5.5kg and as much as 12.7kg per leg by week 12. All subjects completed this study without medical complications (eg, autonomic dysreflexia, lower-extremity injury).

DISCUSSION

The major finding of this study was that 12 weeks of NMES-induced RET elicited substantial hypertrophy in subjects with long-term SCI. These results provide further evidence to the responsiveness of skeletal muscle to RET in the SCI population. Large increases in skeletal muscle size are possible, provided the appropriate mode of exercise is used. Before training, subjects in this group had about 50% of CSA compared with ambulatory subjects. Despite the magnitude of hypertrophy at 12 weeks, quadriceps femoris CSA increased to about 70% of the average muscle size of ambulatory individuals.

The exercise protocol we used was selected to simulate standard resistance training for increasing muscle mass. However, this type of exercise is not often used in studies of muscle plasticity in paralyzed muscle. Most studies perform isometric and/or cycling exercises to examine training adaptations within skeletal muscle.[6,7] These activities have shown modest increases in skeletal muscle CSA. In comparison, our method is relatively simple, elicits substantial hypertrophy, and can be completed at home with minimal interruption of daily activities.

This study yielded greater hypertrophy than what is expected with a 12-week training program. Resistance programs for able-bodied people report about a 5% to 10% increase in CSA after 10 to 12 weeks.[8] The RET performed in this study was similar to that in the study by Ploutz et al,[8] in which untrained subjects performed 4 to 6 sets of 10 repetitions of voluntary, unilateral knee extension to failure for 9 weeks and quadriceps femoris CSA was increased by 5%. Ruther et al[9] trained sedentary subjects with either NMES or voluntary activation for 9 weeks and measured quadriceps femoris CSA and muscle performance. The NMES group increased its quadriceps femoris CSA and torque by about 10% and 50%, respectively. The voluntary group had modest hypertrophy of 4% and strength gains of about 25%. What is remarkable is the magnitude of the hypertrophy that we report here. The best explanation for this is that subjects with SCI in this study had atrophied to such an extent that they had much more room for improvement.

Another interesting finding of this study was that 2 subjects (S3, S4) improved their glucose values during OGTT after RET (table 2). Resistance exercise has been recommended for diabetic patients to increase muscle mass and thereby assist in glucose clearance.[10] These results are promising for the SCI population, which is at high risk for developing diabetes because of a small available muscle mass that cannot be voluntary activated. These findings warrant future studies, especially in people with SCI who have diabetes.

Absence of a control group and the small sample size in this study may limit our findings. However, the RET protocol we used substantially increased muscle mass in subjects with long-term SCI.

Table 2: Individual and Mean Blood Glucose Concentrations Before and After RET at Fasting and 60, 90, and 120 Minutes After Oral Glucose Challenge

Subject and RET	Blood Glucose Concentrations (mg/dL)			
	Fasting	60 Min	90 Min	120 Min
S1				
Before	73	121	115	76
After	80	127	95	74
S2				
Before	98	164	125	121
After	DM	DM	DM	DM
S3				
Before	89	205	163	134
After	87	106	79	78
S4				
Before	97	174	152	98
After	89	96	100	80
S5				
Before	92	127	119	123
After	95	113	99	165
Mean ± SD				
Before	87.8±10.4	156.8±39.9	137.3±23.9	107.8±26.0
After	87.8±6.2	110.5±13.0	93.3±9.7	99.3±43.9

Abbreviation: DM, data missing.

CONCLUSIONS

Large increases in skeletal muscle size are possible even years after injury if the appropriate mode and intensity of exercise are utilized. Our results suggest that this type of training may enhance glucose disposal, but more research on larger groups of subjects with SCI is needed.

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Suppliers

a. General Electric, 3135 Easton Tpke, Fairfield, CT 06828.
b. Rich-Mar Corp, 15499 E 590th Rd, Inola, OK 74036.
c. Electro Medical Equipment Inc, 4371 Shallowford Ind Pkwy, Marietta, GA 30066.