Spinal Cord (2014) 52, 621–624

www.nature.com/sc

ORIGINAL ARTICLE

A six-week motor-driven functional electronic stimulation rowing program improves muscle strength and body composition in people with spinal cord injury: a pilot study

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Study design: Preclinical and postclinical intervention and outcomes measure design.
Objective: To investigate the efficacy of six weeks of motor-driven functional electronic stimulation (FES) rowing exercise intervention on cardiopulmonary fitness, upper body strength and body composition in people with spinal cord injury (SCI).
Setting: The National Rehabilitation Center in Korea.
Methods: A total of 12 people with SCI (ten males, two females) participated in 42.5-minute training sessions on motor-driven FES rowing machine, 5 days a week for 6 weeks. Peak oxygen consumption, body mass index, percent body fat, waist circumference, shoulder abduction and adduction, shoulder flexion and extension and elbow flexion and extension were measured at baseline and after the intervention.
Results: The six weeks of training with a motor-driven FES rowing machine significantly decreased percent body fat (Pre: 23.9 ± 8.5 vs Post: 20.4 ± 7.9, $P=0.028$) and increased lean body mass (Pre: 50.4 ± 9.4 vs Post: 53.3 ± 10.0, $P=0.001$), muscular strength of the shoulder flexors (Pre: 147.5 ± 68.5 vs Post: 180.9 ± 71.8, $P=0.002$), extensors (Pre: 132.7 ± 51.8 vs Post: 160.6 ± 67.9, $P=0.010$), abductors (Pre: 126.1 ± 52.6 vs Post: 163.7 ± 77.8, $P=0.002$) and adductors (Pre: 172.3 ± 69.0 vs Post: 215.2 ± 95.7, $P=0.003$), as well as elbow flexors (Pre: 212.7 ± 66.6 vs Post: 256.6 ± 76.1, $P=0.004$) and extensors (Pre: 190.6 ± 65.0 vs Post: 221.9 ± 63.9, $P=0.002$).
Conclusions: Exercise using a motor-driven FES rowing machine may be used as a new exercise modality to improve body composition and upper body muscle strength in people with SCI.
Sponsorship: This research was supported by a grant (code# 08-B-03, #10-B-01) from the National Rehabilitation Research Institute.
Spinal Cord (2014) **52,** 621–624; doi:10.1038/sc.2014.76; published online 3 June 2014

INTRODUCTION

People with spinal cord injury (SCI) suffer from an increased risk of chronic diseases including type 2 diabetes and cardiovascular disease (CVD).[1,2] The mechanisms for the increased risk of type 2 diabetes and CVD are associated with dysfunction of the sympathetic nervous system, low level of physical activity and neuromuscular changes in paralyzed muscle.[3,4] Therefore, increase in physical activity, as well as exercising the paralyzed muscle via functional electrical stimulation (FES), has been suggested to prevent type 2 diabetes and CVD and to further improve the health of people with SCI.[5]

FES rowing machine has been developed and the acute and chronic physiological responses to exercising with the FES rowing machine were compared with exercising with the FES cycling, arm ergometer and arm ergometer with FES cycling.[6–8] Exercising with FES rowing machine increased oxygen consumption to a significantly greater extent than exercising with FES cycling alone and to a similar level as exercising with arm ergometer and arm ergometer with FES cycling.[6,8,9] Exercise with the FES rowing machine requires significant muscle strength and endurance in the lower extremities, as rowing motion would involve the extension of the knee against their body weight repetitively. However, most people with SCI lack strength and endurance of their lower extremities, which make it difficult for them to continue FES rowing exercise for a long duration. As a result, paralyzed muscle fatigue may be the limiting factor for the duration of exercising with FES rowing when the muscle strength and endurance with FES was not fully achieved before entering the FES-rowing program.

The use of a motorized seat to help people with SCI while rowing in conjunction with FES could be a solution for paralyzed muscle fatigue.[6,9] Recently, we developed a motor-driven FES rowing machine that uses both FES and motorized power to move the seat of the rowing machine back and forth to make a rowing movement.[10] The acute cardiopulmonary response of people with SCI while using a motor-driven FES rowing machine has been recently tested and

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Received 22 April 2013; revised 3 April 2014; accepted 22 April 2014; published online 3 June 2014

reported.[10] However, the feasibility and efficacy of training with the motor-driven FES rowing machine have not been tested. Furthermore, the training effects of exercise with a motor-driven FES rowing machine have not been evaluated.

The purpose of this pilot study was to investigate the efficacy of a six-week motor-driven FES rowing program on cardiopulmonary fitness, upper body strength and body composition in people with SCI.

MATERIALS AND METHODS

Study design and participants

Twelve people with SCI (ten males, two females) who met our inclusion criteria were recruited for the study. The inclusion criteria included the following: (1) duration of SCI over 6 months, (2) unrestricted passive range of motion and (3) the ability to contract quadriceps and hamstring muscles with FES. The exclusion criteria included the following: (1) CVD, (2) type 2 diabetes, (3) lower extremity fracture, (4) dislocated hip and (5) pressure ulcers. This study was approved by the Institutional Review Board at The National Rehabilitation Center of Korea. The characteristics of the participants are shown in Table 1.

Motor-driven FES rowing

A detailed explanation of the motor-driven FES rowing machine has been described previously (Figure 1).[10] Briefly, the motor-driven FES rowing machine consisted of a chair with inclination control, motor system, control button, control program, leg supporter, safety belt and seat. The four-channel FES stimulator (MEGA XP, Cybermedic Corp., Iksan, Korea) was mounted on the motor-driven FES rowing machine. Electrical stimulation (monophasic rectangular phase, 30 Hz, 10–140 mA) was applied through surface electrodes to the hamstring and quadriceps muscles. There is a closed-loop and feedback control FES stimulation system with an optical encoder that senses the position of the seat and manipulates the electrical stimulation to flex or extend knee joints. When the participant with SCI experiences leg fatigue during FES rowing exercise, he or she can turn the motor on to achieve motorized movement of the seat while electrical stimulation is still delivered to the hamstring and quadriceps muscles. During exercising with the motor-driven FES rowing machine, spasticity and contractures seems not to limit the necessary functional range of motion for hip, knee and ankle joint movement.

Exercise program

Participants trained with the motor-driven FES rowing machine for 42.5 min per day, 5 days a week for 6 weeks. The daily exercise program consisted of a 5-minute warm-up, 32.5 min of motor-driven FES rowing training and a 5-min cool down. The 32.5 min of motor-driven FES rowing comprised six sessions of 5-min exercise bouts with 30 s rest between bouts. The subjects with SCI adjusted the position of their seat according to their leg length before rowing at a self-selected stroke rate. During training, participants maintained their heart rate over 70 percent of maximum heart rate[11] using a Polar Beat apparatus (Polar Beat, Electro Oy, Kempele, Finland).

Measurements

To measure cardiopulmonary fitness, VO_2 peaks were measured using a portable K4b2 gas analyzer (COSMED Srl., Rome, Italy) while the participants exercised with an arm ergometer. To measure the upper body strength, a hand-held dynamometer (J-tech Medical Industries Inc., Salt Lake City, UT, USA) was used. Detailed methods on how to measure the upper body strength using a hand-held dynamometer have been described previously.[12] In brief, shoulder flexor and extensor strength were measured with the shoulder and elbow flexed at 90° and the arm in a neutral rotation in a supine position with the dynamometer placed proximally to the humeral epicondyle. To measure the strength of the shoulder abductors and adductors, the examiner placed the dynamometer proximal to the elbow, with the elbow fully extended and the shoulder abducted 45° while supine. The strength of elbow flexors and extensors was measured with the shoulder adducted to the trunk in a supine position, and the elbow flexed to 90°. Body composition was measured by Inbody S20 (Biospace Inc., Seoul, Korea). InBody S20 is a bedside body composition analyzer for the patients who cannot stand for a body composition measurement. The validity of Inbody S20 has been established against dual-energy X-ray absorptiometry previously, with a correlation coefficient over 0.9.[13–15] To prevent and monitor the pressure sore, the skin condition of the participants was checked for pressure sores and friction mark after each exercise program.

Statistical analysis

Statistical analysis was performed using SPSS version 18.0 for Windows (SPSS Inc., Chicago, IL, USA). Descriptive statistics were used to evaluate baseline characteristics. Pre- and post-training differences were analyzed with Wilcoxon signed-rank tests. A *P*-value <0.05 was considered statistically significant.

RESULTS

Participant characteristics at baseline

Twelve people with SCI volunteered for this study and all successfully completed the 6-week training intervention. The characteristics of the participants are presented in Table 1. The mean age of participants was 36 ± 12 years, with a mean body mass index of 23.2 ± 3.6 $kg\,m^{-2}$.

Table 1 Participant characteristics

	Sex	*Age (years)*	*Height (cm)*	*Weight (kg)*	*BMI (kg m^{-2})*	*Waist (cm)*	*Duration (years)*	*Lesion level*	*ASIA[a]*
1	Male	45	163	70	26.3	70	10	T8	A
2	Male	26	175	60	19.6	60	24	T3	A
3	Male	49	182	68	20.5	68	18	T4	A
4	Male	24	181	75	22.9	75	16	C6	B
5	Male	26	177	66	21.1	66	5	T3	A
6	Male	41	172	74	25	74	10	T7	C
7	Male	29	178	100	31.6	100	13	L1	C
8	Male	40	183	83	24.8	83	6	T9	A
9	Male	41	170	68	23.5	68	13	T4	A
10	Male	39	178	63	19.9	63	6	C8	A
11	Female	16	164	50	18.6	50	9	L1	C
12	Female	56	163	65	24.5	65	8	T9	C
Average		36 ± 12	173.8 ± 7.5	70.2 ± 12.5	23.2 ± 3.6	83.9 ± 9.9	11.4 ± 5.8		

Abbreviations: BMI, Body mass index; Duration, The time interval between the onset of stroke and exercise training; T, Thorax; L, Lumbar; C, Cervical.
Values are mean ± s.d.
[a]ASIA impairment scale: American spinal cord injury association impairment scale (A, complete injury—no motor or sensory function is preserved in sacral segments S4-5; B, incomplete injury—sensory function but no motor function is preserved below the neurologic level and extends through sacral segments S4-5; C, incomplete injury—motor function is preserved below neurological level and more than half of key muscles below the neurological level have a muscle grade less than 3).

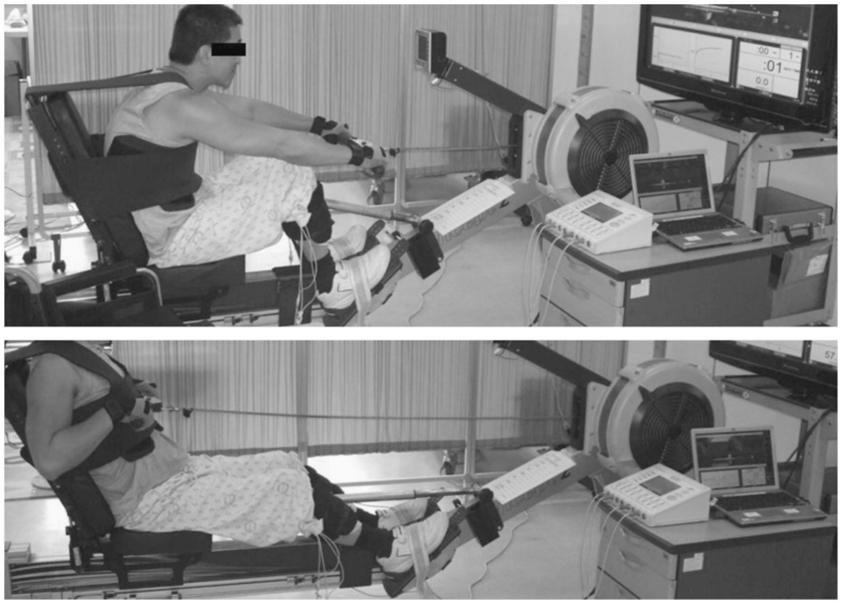

Figure 1 Motor-driven functional electronic stimulation (FES) rowing equipment.

Table 2 Change in body composition, muscle strength and VO_2 peak

	Pre	*Post*	P-*value*
Body mass index ($m\,kg^{-12}$)	23.4 ± 3.7	23.0 ± 3.9	0.058
Body fat (%)	23.9 ± 8.5	20.4 ± 7.9	0.028
Lean body mass (kg)	50.4 ± 9.4	53.3 ± 10.0	0.001
Waist circumference (cm)	84.1 ± 10.3	82.0 ± 9.9	0.059
Shoulder flexion (*N*)	147.5 ± 68.5	180.9 ± 71.8	0.002
Shoulder extension (*N*)	132.7 ± 51.8	160.6 ± 67.9	0.010
Shoulder abduction (*N*)	126.1 ± 52.6	163.7 ± 77.8	0.002
Shoulder adduction (*N*)	172.3 ± 69.0	215.2 ± 95.7	0.003
Elbow flexion (*N*)	212.7 ± 66.6	256.6 ± 76.1	0.004
Elbow extension (*N*)	190.6 ± 65.0	221.9 ± 63.9	0.002
VO_2 peak ($ml\,kg^{-1}\,min^{-1}$)	17.2 ± 3.8	19.4 ± 4.7	0.099

Abbreviations: Pre, before training; Post, 6 weeks after training; VO_2 peak, peak oxygen consumption.
Values are mean ± s.d. *P*-value for categorical variables according to the Wilcoxon signed-rank test.

Effects of exercise on body composition, upper body muscle strength and VO_2 peak

Table 2 shows the changes in body composition, upper body muscle strength and VO_2 peak over the 6-week training intervention. Percent body fat was reduced from 23.9 ± 8.5 to 20.4 ± 7.9% ($P = 0.028$), whereas lean mass was increased from 50.4 ± 9.4 kg to 53.3 ± 10.0 kg ($P = 0.001$) after 6 weeks of training. Upper body muscle strength in shoulder flexion, extension, abduction and adduction, as well as elbow extension, among participants with SCI was significantly increased. There were no significant changes in body mass index ($P = 0.058$), waist circumference ($P = 0.059$) and VO_2 peak after training ($P = 0.099$).

DISCUSSION

In the current study, we tested whether exercise training with a motor-driven FES rowing machine would change the cardiopulmonary fitness, upper body strength and body composition of people with SCI. We found that 6 weeks of training with a motor-driven FES rowing machine resulted in a significant reduction in percent body fat and an increase in shoulder and arm strength. Although it was not statistically significant, VO_2 peak also tended to be increased after the training program.

It is noticeable that both upper and lower body muscles are used while exercising with a motor-driven FES rowing machine. Physiological responses to exercise with a fixed rowing machine were tested in the previous study,[10] which participants only used their upper body and VO_2 peak of $17.86 \pm 5.17\,ml\,min^{-1}\,kg^{-1}$ was achieved. However, VO_2 peak of $21.78 \pm 6.23\,ml\,min^{-1}\,kg^{-1}$ was achieved in the study when participants exercised with a motor-driven FES rowing machine. Hooker *et al.*,[16] previously demonstrated that hybrid exercise, which uses both upper and lower body muscle, is a more effective exercise modality to improve cardiovascular fitness than arm crank and FES cycle alone. As exercise with a motor-driven FES rowing machine uses both upper and lower body, this mode of exercise may be suitable for the improvement of cardiopulmonary fitness for people with SCI. In the current study, we found a statistically nonsignificant 12.4% increase in VO_2 peak after 6 weeks of exercise training with a motor-driven FES rowing machine ($P = 0.099$). The increment in VO_2 peak after training in the current study was similar to the findings of Jeon *et al.*,[17] which found a 7.9% increase in VO_2 peak after 12 weeks of FES rowing training. Although the degree of improvement in the VO_2 peak in our study was higher than the findings of Jeon *et al.*,[17] the current study did not find statistical significance, probably owing to the small sample size and large individual variations.

As people with SCI are more susceptible to metabolic disorders that are linked to obesity, such as type 2 diabetes and CVDs,[1,2] the reduction in percent body fat is meaningful. Previous studies have reported significant improvement in glucose tolerance, insulin sensitivity and lipid profiles after FES rowing and FES cycling.[5,18,19] Although insulin resistance and glucose tolerance were not measured in this study, a 14.6% reduction in percent body fat and a 5.8% increase in lean mass may suggest possible positive changes in insulin resistance and glucose tolerance. Jeon *et al.*,[17] found that 12 weeks of FES rowing reduced plasma glucose and leptin levels. They also reported that fasting insulin levels decreased after training in five out of six participants with SCI.

People with SCI often suffer from shoulder muscle imbalances, rotator cuff impingement syndrome and subacromial bursitis, and therefore experience problem in propelling wheelchairs and transferring.[20,21] Shoulder problems in people with SCI are critical given that the upper extremities are used for most daily activities. Olenik *et al.*,[22] tested the efficacy of rowing, backward wheeling and isolated scapular retractor exercises in strengthening the scapular retractor muscles and found that rowing and isolated scapular retractor exercises were effective. In our study, we found a significant increase in muscular strength of the shoulder flexors, extensors, abductors and adductors after 6-week exercise training with a motor-driven FES rowing machine, which would improve the scapular stability. Improvement of shoulder strength and scapular stability is important to prevent and treat shoulder problems.

Limitations of this study include the small number of participants and the lack of a control group. Nevertheless, we tested the efficacy of motor-driven FES rowing exercise on cardiopulmonary fitness, body composition and strength of upper body extremities, which are important factors in determining the benefits of using this device to remediate and prevent other diseases and health conditions in people with SCI. One of the limitations of the study is the lack of data on the strength of hamstring and quadriceps muscles and oxygen consumption during steady-state training with a motor-driven FES rowing machine. Further limitation of the study includes the use of an arm ergometer, which only uses upper body, for VO_2 peak measurements, whereas training with a motor-driven FES rowing machine involves both upper and lower body muscles. Another limitation of the study was the use of the bioimpedence analysis (BIA) method to measure body composition in the current study instead of dual energy X-ray absorptiometry (DEXA), which has been validated in people with SCI. Therefore, body composition data need to be interpreted with caution. Future studies with more participants and control groups are needed to confirm the findings of our study.

In conclusion, rowing with a motor-driven FES rowing machine could be used as a new exercise modality for people with SCI to improve cardiopulmonary fitness and body composition and to increase upper extremity muscle strength once efficacy, effectiveness and safety of the this training modality are achieved by further study.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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