FES-rowing for persons with Spinal Cord Injury

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Abstract

FES-rowing has been explored in various pilot studies. The results suggest that FES-rowing is a safe and well-tolerated type of cardiovascular exercise. It gives reliable high VO_2 values (≥1.5 l/min) and could play a role in the prevention of cardiovascular diseases, Type 2 Diabetes and obesity. As well FESrowing forms an alternative for the repetitive stress on the shoulders experienced during wheelchair propulsion

1 Introduction

Physical activity for persons with Spinal Cord Injury (SCI) has traditionally been restricted to upper body exercises or Functional Electrical Stimulation (FES) provoked lower extremity exercises. Both activities have limitations and possible contra-indications. The most frequently engaged physical activity for people with SCI, including wheelchair racing and other wheelchair sports, only involve upper extremities. Serious concerns consist on the contribution of adding stress to the shoulder, elbow and wrist joint by these activities. Several studies have shown that long-term wheelchair use can lead to serious overuse syndrome and pain in the upper extremities [1].

FES assisted lower extremity exercises reduces the stress on the upper body during exercise. Activating the paralysed muscles has numerous benefits, one can think of improved circulation in the lower body, improved wound healing, increased muscle bulk, improved glucose tolerance and insulin sensitivity and increased bone mineral density [2]. If the FES is integrated in a cardiovascular work out, improvements in the cardiovascular and respiratory system could also be expected. Traditionally this has mainly been done by using a FES-bicycle, either stationary or on-road cycling.

Unfortunately the intensity of these FES-cycling exercises is rather low, rarely exceeding 1-1.5 litres of oxygen per minute. This results in a limited impact of these exercise regimes on the cardiovascular system. Large studies in able-bodied subjects have shown that exercising above a certain threshold is more effective is reducing risk factors for cardiovascular and metabolic diseases. Tanasescu et al. concluded in a large cross sectional study (n=44,452) that not only the total time spent on exercise per week is associated with a reduction in risk factors for Coronary Heart Diseases (CHD), but also the intensity of exercise (independent of time spent on exercise) [3].

The intensity of FES induced lower body exercise can be elevated by simultaneously performing an upper body exercise, such as FES-cycling and arm cranking. Indeed these hybrid exercises provoke a significantly higher VO_2max (1.5-2.0 l/min). Unfortunately, due to the unnatural movement of performing two cyclical movements and the lack of widely available systems that are practical, hybrid exercise has never found great implementation in the exercise regimes of persons with SCI. In addition many of the FES-cycle systems can only be used for FES use and therefore the potential group of users is relatively small and consequently the costs are high.

Insufficient levels of physical activity in SCI are a major contributor to elevated risk factors for obesity, cardiovascular diseases (CVD) and Type 2 Diabetes Mellitus (DM).

Bauman et al. found that individuals with SCI have a five to six times higher risk for Type 2 DM than able-bodied persons [4]. Cholesterol levels are higher in persons with SCI (even in active SCI individuals) and this leads to a three to four times higher risk for CHD than the able-bodied population [5]. Obesity is more frequent in SCI and persons with SCI lead more often a sedentary life style than able-bodied persons.

There is a need for an effective exercise program for persons with SCI. This exercise should not only decrease the above-mentioned risk factors but also take into consideration the problem of overuse syndrome in the upper extremities in this population. The authors suggest that FES-rowing could combine the benefits of a high intensity exercise with a well-tolerated type of exercise that does not increase the stress on the upper body as seen in wheelchair propulsion. We are now in a position to present the results of a series of pilot studies that support these claims.

2 FES-rowing

A standard Concept II rowing ergometer has been equipped with a special seat and restraint system that gives sufficient postural support for a paraplegic rower. The legs are kept in one plane with leg stabilisers attached to the calf and base of the rowing machine. Electrodes are placed on the hamstrings and quadriceps to provoke knee flexion and extension. The stimulation is triggered by a switch on the handle bar controlled by the rower him/herself, although an automatic system also has been tested.

Currently a standard Odstock 4-channel stimulator is being used. This stimulator can give electrical stimulation in the range: amplitude: 0-115 mA, frequency: 12-50 Hz, pulse width: 100-450 microsec. Un-ramped simple on-off stimulation pulses have been used.

2.1 Muscle recruitment and safety

To test the safety and acceptance of FES-rowing, Laskin et al. tested eight SCI subjects (ASIA A-D) on three different conditions, arm rowing, FES leg exercise only (bilateral flexion and extension on rowing seat), and FES-rowing. FES-rowing produced higher peak VO_2 values, and was perceived as less strenuous than arm rowing (Borg scale). The authors concluded that FES-rowing represents a potentially valuable hybrid training device that is well accepted by the participants [6].

In order to examine the potential protective effects of rowing exercise on shoulder muscle recruitment, Olenik et al. monitored EMG activity in seven spinal cord injured subjects (ASIA A) and seven able-bodied subjects during three different exercises; rowing, backward wheeling and a standardized scapular retraction exercise. Both rowing and retractor exercise recruited higher levels of scapular retractor involvement than backward wheeling. The authors suggested that rowing is an appropriate and effective means of re-mediating scapular retractor weakness and restoring the balance in the shoulder muscles may play a role in the prevention and treatment of shoulder injuries in athletes [7].

2.2 Cardiovascular training

To examine the potential of FES-rowing for cardiovascular training, Wheeler et al. trained six spinal cord injured subjects (ASIA A, except one, ASIA C) for 36 sessions during a progressive FES-rowing program. After three months of training, rowing distance increased by 25% ($P<0.02$), VO_2max by 11.2% ($P<0.001$), and peak oxygen pulse by 11.4% ($P<0.01$). The authors concluded that pre- and post-training peak aerobic power values for FES-rowing training were comparable to previously reported values for hybrid exercise [8].

Verellen et al. (under review) studied these VO_2 peak values further and compared VO_2 values during FES-rowing, FES-cycling, arm cranking and traditional hybrid exercise (consisting of FES-cycling in combination with arm cranking). The authors concluded that FES-rowing gives reliable and significantly higher peak functional VO_2 values than FES-cycling and arm cranking. Oxygen consumption during FES-rowing was slightly higher than during traditional hybrid exercise. This implies the potential superiority of FES-rowing over other types of cardiovascular exercises. In turn this may have major implications for the central benefits that may occur after aerobic exercise training.

2.3 Health benefits

Two training studies by Hettinga et al. (in process) and Jeon et al. (in process) looked at the effects of FES-rowing on these central systems, in particular lipid profile, body composition, leptin levels and insulin sensitivity. In both studies motor complete paraplegics were trained for 12 weeks for three of four sessions per week. Total weekly energy expenditure was 600-800 kcal. Training intensity was set at 80%VO_2max. A similar improvement in cardiovascular fitness as reported by Wheeler et al. was found in these two studies.

Hettinga et al. found in six subjects a significant decrease in body weight (-2.2%, p=0.046) increase in sub-max power output (+66.7%, p=0.028) and considerable decrease in fat mass (-5.4%, p=0.080) and fat percentage (-4.3%, p=0.074), free fatty acids (-29.8% p=0.074) and triglycerides. The extend of improvement in total cholesterol, FFA, TG, TC/HDL ratio, LDL/HDL ratio and total body weight was significantly correlated (Spearman's R=-0.76 - -0.9 1) with the average weekly energy expenditure achieved during the training (P<0.05). This implies that this high intensity training is potentially more beneficial than existing (lower intensity) exercises.

Jeon et al. found that in five subjects plasma leptin levels significantly decreased by 27.7% after exercise training (P=0.046). Exercise training also decreased fasting plasma glucose by 10.3% (P=0.028) and improved insulin sensitivity measured by HOMA by 29.4% (P=0.046). Fat mass decreased by 5.4% after the training but did not reach statistical significance (P=0.08). Reduction in plasma leptin levels after training could be explained by reduction in plasma glucose, FM and improved insulin sensitivity.

Both studies suggested that FES-rowing could play a role in the prevention and treatment of CVD, type 2 DM and obesity in SCI.

3 Conclusion

The results of these pilot studies suggest that FES-rowing is a safe and well-accepted alternative for existing types of exercise for persons with SCI. FES-rowing training could play a role in decreasing risk factors for cardiovascular diseases, Type 2 DM and obesity. These diseases represent a major threat for the quality and quantity of life after SCI and a high intensity exercise seems the most effective intervention; FES-rowing could provide that high intensity.

Future studies will focus on further improving the equipment and increasing the intensity. As well the above-mentioned effects will have to be reproduced using larger sample sizes.

Integrating FES-rowing in the able-bodied rowing world is also being explored. Including FES-rowing during Indoor Rowing Championships and perhaps on water rowing are realistic possibilities.

References

[1] Burnham RS, May L, Nelson E, et al. Shoulder pain in wheelchair athletes. The role of muscle imbalance. *Am J Sports Med*, 21: 238-42, 1993.

[2] Andrews BJ, Wheeler GD. Functional and therapeutic benefits of electrical stimulation after spinal injury. *Curr Opin Neurol*, 8: 461-6, 1995.

[3] Tananescu M, Leitzmann MF, Rimm EB, et al. Exercise type and intensity in relation to coronary heart disease in men. *JAMA*, 288: 1994-2000, 2002.

[4] Bauman WA, Adkins RH, Spungen AM, et al. The effect of residual neurologic deficit on oral glucose tolerance in persons with chronic spinal cord injury. *Spinal Cord*, 37: 765-7 1, 1999.

[5] Brenes G, Dearwater S, Shapera R, et al. High-density lipoprotein cholesterol concentrations in physically active and sedentary spinal cord injured patients. *Arch Phys Med Rehabil*, 67: 445-50, 1986.

[6] Laskin JJ, Ashley EA, Olenik LM, et al. Electrical stimulation assisted rowing exercise in spinal cord injured people. A pilot study. *Paraplegia*, 31: 534-41, 1993.

[7] Olenik LM, Laskin JJ, Burnham R, et al. Efficacy of rowing backward wheeling and isolated scapular retractor exercise as remedial strength activities for wheelchair users: application of electromyography. *Paraplegia*, 33: 148-52, 1995.

[8] Wheeler GD, Andrews BJ, Lederer R, et al. Functional electrical stimulation assisted rowing: increasing cardiovascular fitness through functional electrical stimulation rowing training in persons with spinal cord injury. *Arch Phys Med Rehabil*, 83: 1093-9, 2002.

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