FES-rowing After SCI for Health, Recreation and Sport

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Abstract

VO_2 consumption up to 2.8 l/min have been achieved for periods in excess of 20 minutes. Such exercise when taken regularly could play an important role in the prevention of CVD, Type 2 Diabetes and obesity.

FES-rowing involves different upper body musculature than wheeling and may offer some therapeutic benefit for the chronic repetitive stress of wheelchair propulsion.

FES rowing offers opportunity for leisure and sport. FES rowers have for the first time competed against able-bodied rowers over the Olympic distance of 2,000 meters at the British Indoor Rowing Championships (BIRC2004 and 2005) and World Indoor Rowing Championships (WIRC-2006) held in Boston. The best performance to date has been achieved by a 51 yr old male (T6 ASIA (A)) of 11 min 11sec and who in training, typically achieves a steady state VO_2 in excess of 35 ml/kg/min.

1. INTRODUCTION

Physical exercise after paraplegia has traditionally involved the preserved upper limb musculature. Wheelchair sports may exacerbate overuse injury to the upper limbs (1). FES can be used to exercise the lower extremity and when combined with the upper body can reduce upper limb force actions for a given intensity of workout. FES activation of paralysed muscles can improve circulation in the lower body, increase muscle bulk, improve glucose tolerance, insulin sensitivity and bone mineral density (2).

FES can be used to stress the cardiovascular and respiratory system. FES-cycling has been investigated by a number of groups, however, the intensity of rarely exceeds 1-1.5 litres of oxygen per minute.

The exercise intensity and volume required to reduce the risk of CVD and diabetes II has yet to be determined in SCI. However, large scale 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 an urgent need for an effective physical exercise for paraplegics that can reduce disease risk factors without exacerbating overuse syndrome in the upper extremities. We present the results of our pilot studies that support FES rowing as a suitable candidate.

2. METHODS

We have adapted a standard Concept II rowing ergometer with a custom seat and restraint system see www.FESrowing.org . The rowing motion occurs in one plane using a telescopic leg stabiliser attached to the calves and base of the rowing machine. The track of the ergometer can be raised by a screw jack mechanism. Sprung loaded stops limit the motion of the seat to avoid hyperextension of the knees at “finish” and bouncing the heels at “catch”.

The simplest FES configuration, self-adhesive surface electrodes Pals+ are placed bilaterally over the hamstrings and quadriceps to provoke knee flexion and extension. On occasions, additional electrodes have been applied over the gastrocnemius and common peroneal nerve (to elicit a flexion response that counters the hip extension due to hamstrings or ankle plantar flexion due to gastrocnemius) and gastrocnemius to improve leg flexion during the recovery phase of rowing. The stimulation is triggered by a switch, positioned on the handle bar, and operated by the rower. An automatic system also has also been tested for quadriplegics. Biphasic, balanced electrical stimuli typically amplitude: 0-125 mA, frequency: 12-50 Hz, pulse width: 100-450 microseconds were used.

3 DISCUSSION OF RESULTS

FES-rowing: acceptance 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 potential hybrid training device well accepted by the participants (6).

The potentially protective effects of rowing exercise on the shoulder was investigated by Olenik et al. EMG activity was examined in 7 SCI 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).

FES-rowing: 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. (in press) studied these VO_2 peak values further and compared VO_2 values during FES-rowing, FES-cycling, arm cranking and traditional hybrid exercise (a combination of FES-cycling and 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.

FES-rowing: health benefits

Two training studies by Hettinga et al. (in process) and Jeon et al. (in press) 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 improvement in total cholesterol, FFA, TG, TC/HDL ratio, LDL/HDL ratio and total body weight was significantly correlated (Spearman's R=-0.76 - -0.91) 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.

Leisure & Sport – BIRC and WIRC

FES rowers have now competed in major national and international rowing events. In Nov 2004 for the first time, RG and SS (complete paraplegia with mid-thoracic lesions), entered the British Indoor Rowing Championship (BIRC) see photo. In recognition there is now a permanent exhibit of the event in the River and Rowing Museum in Henley on Thames http://www.rrm.co.uk/ The winning time over the official 2000meter race was achieved by RG in 12 minutes and 2 seconds (www.FESrowing.org). In the BIRC-2005 three FES-rowers competed and the winning time was again RG in 11 minute and 11 seconds (http://www.concept2.co.uk/pressroom/archives/team-of-six-paraplegic-rowers-compete-at-the-british-indoor-rowing-championship). In 2006 a team of 4 rowers successfully competed in the World Indoor Rowing Championships (WIRC) http://www.concept2.co.uk/wirc/news.php

Mostly, RG's training sessions consisted of 2000 meter followed by a short rest to monitor performance and heart rate, and then an additional 3000 meters. The total 5000 meters averaging 30-35 minutes at approximately VO_2 of 2.5l/min.

3. CONCLUSIONS

We have found FES-rowing to be a safe and well-accepted physical exercise for paraplegics. We have successfully included individuals with complete injuries from C4 to T12 in our FES rowing program. FES-rowing training could play a future role in decreasing risk factors for cardiovascular diseases, Type 2 DM and obesity where a high intensity exercise seems the most effective intervention.

FES rowing allows paraplegics further inclusion into the largely able-bodied world of indoor rowing. Perhaps in the future, on water FES rowing may also become possible.

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: 765-71, 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 Rehabilitation*, 83: 1093-9, 2002.

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