Journal of Clinical & Experimental
Cardiology

Banerjee J Clinic Experiment Cardiol 2011, 2:5
DOI: 10.4172/2155-9880.1000134

Research Article

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Can Electrical Muscle Stimulation of the Legs Produce Cardiovascular Exercise?

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Abstract

Physical exercise is beneficial in promoting health and preventing disease. In some disease states such as heart failure and COPD, exercise improves quality of life and exercise tolerance. Using an electrical stimulus to cause muscle contraction may mimic some of the effects of exercise. This article examines whether electrical muscle stimulation of large groups of muscles is able to produce cardiovascular effects.

Keywords: Cardiovascular exercise; Electrical muscle stimulation; Exercise training

Introduction

Physical exercise is beneficial in promoting health and preventing disease. In some disease states such as heart failure [1] and COPD, [2] exercise improves quality of life and exercise tolerance. Using an electrical stimulus to cause muscle contraction may mimic some of the effects of exercise. This article examines whether electrical muscle stimulation of large groups of muscles is able to produce cardiovascular effects.

Background and Physiological effects of EMS

Over the years electrical muscle stimulation (also known as functional electrical stimulation or neuromuscular stimulation) has become well established as a means of improving muscle bulk and strength [3] and has a clinical application in neuro-rehabilitation (e.g. paraplegics due to spinal cord injury) [4,5] by restoring, maintaining or improving muscle function. It is also used to treat pain [6]. To deliver EMS, a number of protocols have been developed, satisfying different therapeutic objectives. Low-amplitude currents are used to stimulate sensory nerves [7]. At these current levels, EMS is perceived by the subject through somatic sensory receptors mainly located in the skin and subcutaneous tissues, there is no motor stimulation. When the amplitude of the current is increased above sensory levels, there is also stimulation of the efferent terminal axon branches, leading to contractile protein interaction and a motor response is elicited in the form of muscle contraction. At these high current levels pain may be perceived although fat cells, located between the skin and the sarcolemma, inevitably limit current diffusion to the targeted muscle [7].

In general, square wave, evenly alternating pulses of short duration (0.5 to 0.1msec) achieve the best motor nerve stimulation and tissue penetration without affecting the pain nerves [8]. Low frequency stimulation has been employed in most studies to cause repeated muscle contraction rather than using protocols that cause tetanic muscle contractions which tend to be rather unpleasant to the patient [7].

Delivery of EMS

Battery operated units are used to generate the electrical impulses which are delivered to the skin via one or more electrodes that are often strapped to the skin over the corresponding muscles to be stimulated. An electroconductive gel is usually applied between the electrodes and skin to minimize impedance. The leg muscles (thigh and calf muscles) have been favoured as targets for stimulation because of their large bulk [8]. EMS has the same effect on skeletal muscle as voluntary contraction in temporarily increasing muscle metabolism with the consequences of increase in oxygen uptake and production of carbon dioxide, lactic acid and other metabolites as well as raised local temperature and greater local blood flow [7]. It increases intramuscular blood flow as well as flow in the adjacent veins, lymphatics and arteries [9]. The effects of EMS on veins and lymphatics have led to its previous use to control limb oedema. Electrical stimulation of the quadriceps has been shown to also increase femoral artery flow [10].

Studies of EMS

Mild increases in peak oxygen consumption (VO2) of around 0.1-0.8L/min were seen in the studies of EMS induced exercise in spinal cord injury patients but these increases were thought to be unlikely to have a therapeutic value [11,12]. However, recent evidence suggests that EMS of the leg muscles can evoke cardiovascular responses such as those seen with conventional exercise in healthy volunteers [13,14] and heart failure patients [15]. These effects of EMS are reproducible [13] and it can also produce training benefits in normal volunteers in home-based programs [14]. In heart failure patients EMS induced training can improve peak oxygen consumption, 6 minute walking distance and quadriceps muscle strength, thus improving overall functional capacity [15].

Mechanisms of increased exercise tolerance with EMS

It is not clear exactly how EMS may be able to produce cardiovascular effects similar to conventional exercise. Muscles may be viewed as energy conversion elements, which convert stored energy to mechanical work, thus causing energy utilisation [16]. The aerobic energy conversion process requires oxygen to be delivered to the

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Received April 13, 2011; **Accepted** May 17, 2011; **Published** May 17, 2011

Citation: Banerjee P (2011) Can Electrical Muscle Stimulation of the Legs Produce Cardiovascular Exercise? J Clinic Experiment Cardiol 2:134. doi:10.4172/2155-9880.1000134

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muscle fibres. Electrical stimulation of large groups of muscles with consequent repetitive muscle contraction is likely to be stimulating muscle metabolism enough to produce a systemic metabolic and cardiovascular response that is significant although less robust than the response seen with conventional exercise. Also, the increase in leg muscle strength that invariably results from EMS is very likely to enhance the ability to exercise.

Studies of EMS training on cardiovascular responses

We have reported 3 studies of EMS focused on cardiovascular training effects- a dose response study [13], a study on normal healthy volunteers [14] and a study on patients suffering from heart failure [15]. To my knowledge the first two studies are the only studies reported so far looking directly at cardiovascular training effects in healthy subjects. Other studies have focused on the effects of EMS in individuals with diseases such as spinal cord injury, COPD and heart failure, as described above. In all our studies we used a new system of electrical muscle stimulation that attempted to cause an increase in energy expenditure by mimicking the action of shivering in the body, which is the natural process for generating heat when body temperature falls. Shivering generates heat with no external work [17] through rhythmical muscle contractions, occurring at a rate of approximately 4-8Hz. We attempted to mimic this pattern of muscle activity by using EMS at 4Hz to elicit cardiovascular exercise via rapid, short duration, rhythmical contractions in the large lower extremity muscle groups. The equipment for delivery of this form of EMS was very robust and consisted of a pair of cycle shorts containing built-in silicone rubber electrodes that connected via an electrical cord to a battery operated unit that acted as the generator of the electrical stimuli.

Our own study using EMS at increasing intensities in healthy volunteers (dose response study)[13] showed that physiological responses to the EMS induced exercise were consistent with light to moderate exercise intensity – peak EMS induced exercise intensities ranged from 2.5 to 7.7 metabolic equivalents (METs) [13,14]. There was a corresponding significant rise in physiological parameters such as peak VO2, carbon dioxide production, ventilatory capacity and heart rate with increasing intensity of stimulation [13]. In healthy subjects EMS at peak stimulation intensity produced an average peak HR and peak VO2 of 101 ± 12 beats per minute and 14.9 ± 4.3ml/kg/min, respectively. At peak stimulation intensity VO2 and VCO2 increased by 0.7 ± 0.2 L/min and 0.6 ± 0.2 L/min, respectively compared to resting levels; VE increased by 13.8 ± 10.8 L/min and HR increased by 30.1±11.1 beats per minute above resting values [13].

Mean levels of energy expenditure (351 ± 82 kcal/hr) were similar to levels expected for activities such as walking at 3-3.5mph – calculated on the basis of a mean body weight of 76Kg [13,17]. At this level of energy expenditure, subjects would have to use the device for approximately 2 hours per week to have performed the quantity of exercise recommended for health benefit by the American Heart Association (700+Kcal/week).

In the second study [14] fifteen healthy subjects (10 men, 5 women) with a sedentary lifestyle completed a 6-wk training program during which they completed an average of 29 1-h EMS sessions at home. A crossover study design was employed with subjects undergoing their habitual activity levels during the non-training phase of the study. The training effect was evaluated by means of a treadmill test to determine peak aerobic capacity (peak VO2), a 6-min walking distance test, measurement of body mass index (BMI) and quadriceps muscle strength. After training, subjects demonstrated statistically significant improvements in all variables except BMI. Peak VO2 increased by an average of 0.24 ± 0.16 l/min ($P < 0.05$), walking distance increased by 36.6 ± 19.7 m ($P < 0.005$), and quadriceps strength increased by 87.5 ± 55.9 N ($P < 0.005$); we did not observe a significant effect due to training on BMI ($P > 0.05$) [14]. These results suggested that EMS can be used in sedentary adults to improve physical fitness and may provide a viable alternative to more conventional forms of exercise in this population.

Our third study was on patients with heart failure [15]. In a crossover designed study, 10 patients (age 66 ± 6.5 years, 9 male) were randomized to 8 weeks of training or habitual activity before crossing over to the other limb after a washout period of 2 weeks. Training consisted of electrical muscle stimulation of the major leg muscles for a minimum of 1 hour, 5 days a week. Peak oxygen consumption, 6-minute walking distance test, body mass index, and quadriceps muscle strength were the end points. EMS training produced significant increases in peak VO2 of 10%, six minute walk distance by 7.5% and quadriceps muscle strength by 25% compared to habitual activity. Patients with greater limitation at baseline had more improvement in these variables. There was no effect on BMI [15].

In the above studies EMS did not cause any serious direct cardiovascular or muscular adverse effects. ECG and blood pressure monitoring, especially in heart failure patients, did not reveal provocation of arrhythmias or undue dangerous changes in heart rate or blood pressure. Renal function and serum CK did not show a significant deterioration following prolonged EMS training. These findings are similar to other studies of EMS done on spinal cord injury patients and those with chronic heart failure.

Information about exercise effects from other studies on EMS training

EMS induced training in heart failure patients has been shown to improve endothelial function [18], reduce peripheral immune responses [18], demonstrate muscular adaptations [19] and improve detrimental skeletal muscle changes [20] - effects that are also seen with conventional exercise.

Conclusion

EMS is in its early stages of being assessed as a means of cardiovascular exercise and a lot more research is needed. However, the results of the series of studies discussed above would appear to suggest that EMS may be an effective and novel method of producing cardiovascular exercise. It also appears safe.

If this is established through more extensive research, EMS training has the potential to benefit several groups of people. It has promise in rendering training benefits in home-based programmes to those with chronic diseases like COPD, heart failure and spinal cord injury. In the obese, EMS-EX training could encourage participation in voluntary exercise. In the infirm elderly with poor muscle strength and exercise tolerance, EMS can help in rehabilitation especially by its effects on leg muscle strength. Finally, in the sedentary normal subject with poor motivation to exercise or those with mild joint or orthopedic problems limiting voluntary exercise, EMS training could be used for cardiovascular disease prevention. There will be several limitations to this promise but, for the moment, the prospects of EMS induced exercise training seem bright.

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