The effect of different types of chronic electrical stimulation training on muscle contractile and histological properties: A pilot study.

Duffell, LD, Rowlerson, AM, Donaldson, N de N & Newham, DJ.

Dr Lynsey Duffell, Division of Applied Biomedical Research, King’s College London, UK.

Abstract

Electrical stimulation (ES) can be used by spinal cord injured (SCI) people to exercise paralysed muscles, and reverse some of the muscular changes that occur. The effects of chronic ES training on muscle are variable, and the optimal training protocol to improve performance is unknown. We recruited SCI people to compare the effects of different training regimens on muscle contractile and histological properties and on power output during ES cycling. Strength training improved muscle strength but not cycling performance. The proportion of slow fibres in the muscle was positively related to cycling performance. It appears that in well trained SCI people ES, cycle performance is limited by factors other than muscle strength, and might be associated with the aerobic capacity of muscle. The muscle biopsies showed evidence of muscle pathology, including regeneration, perhaps from chronic ES.

1 Introduction

A spinal cord injury results in considerable adaptations to the paralysed muscles. They become small, weak and highly fatigable. Due to the removal of the chronic, low intensity and frequency activity that is normally imposed upon type I muscle fibres, they rapidly convert towards predominantly or uniformly fast Type IIx fibres. However these changes seem to be somewhat variable and unpredictable; some studies have reported individuals with chronic SCI who experience little or no fibre type transformation [1,2].

Electrical stimulation (ES) for functional and sporting activities is used by some SCI people for health and recreation. It can reduce or reverse the muscular changes [3,4], however the effects of different regimens of chronic ES exercise on the structure, composition and histological and contractile properties of paralysed muscle remains ambiguous. Furthermore, performance is limited, and the power output (PO) achieved is low. The type of training required for optimal ES elicited performance is unknown.

A number of studies have reported a Type IIx to IIa conversion with ES training; however a fast to slow fibre type transformation is less reported [5] even after one year of training [6]. The extent of fibre-type transformation is probably dependent upon the frequency, intensity and duration of ES as well as the type of training carried out. The relationship between contractile and histological properties in trained SCI muscle is also uncertain. In agreement with previous literature [2,3], we have shown that long term ES training results in increased size, strength and fatigue resistance of paralysed muscle [7]. However, the muscles also appeared to become faster [7], fatigue rapidly during ES cycling [8] and produced very low maximal PO [9].

We investigated the effects of different types of ES training (strength, endurance, strength + endurance) on the quadriceps muscle and how these related to the PO generated during ES cycling. We measured the contractile and histological properties of the quadriceps in 5 SCI people, who were carrying out different types of ES training: cycling (endurance), rowing (strength-endurance) and weight training (strength).

2 Methodology

2.1 Subjects

Four SCI people aged 49.8 (SEM 3.5) years with lesions below T4 for 12.3 (3.8) years were recruited to carry out a 12 week training programme. Height and weight were 168.5 (2.6) cm and 64.5 (9.3) kg, respectively. Three were well trained ES cyclists and one was untrained. One well trained ES rower aged 52 years with a lesion level of T10 for 10 years (height 171.0 cm and weight 72.0 kg) was also recruited for one-off measurements. These were chosen to compare the effects of endurance + strength training (cyclists) and strength training alone (rowers).

2.2 Training

The three ES cyclists had been regularly training at least twice a week for >3 months. They were requested to complete ES weight training 3 times per week for 12 weeks, in addition to their regular cycle training. Weight training involved progressive resisted knee extension exercises with weights attached to the ankles from 0.5-10 kg depending on individual ability and progression. The untrained subject began a programme of ES rowing, and was requested to train at least 3 times per week.

2.3 Measurements

Measurements were taken before and after training in the 4 subjects that carried out a training programme, and once in the well trained ES rower.
Muscle samples were taken from the right vastus lateralis muscle using the percutaneous needle biopsy technique [10] with suction attachment. Samples were snap-frozen in dry-ice cooled isopentane and then sectioned transversely in a cryostat. Serial ten micrometer sections were picked up on poly-lysinated slides, and stained for: (i) general morphology (haematoxylin & eosin) and connective tissue content (Weigert-van-Gieson), (ii) oxidative (succinate dehydrogenase, cytochrome oxidase), and glycolytic (alpha-glycerophosphate) marker enzymes, (iii) myosin isoform content (by immunostaining with antibodies to type I, IIA, IIX and neonatal myosins).

For quadriceps contractile properties, subjects were seated on a dynamometer in isometric mode, with the knee at 90º flexion, and the ankle strapped to the dynamometer lever arm. To assess maximal strength, the stimulation intensity was increased incrementally until the torque reached a plateau or declined. The stimulation intensity was then reduced to that which generated 20-30% of the maximal strength and fatigue resistance was measured over 3 min of stimulation at 40 Hz for 250 ms.s⁻¹ [11].

A motor assisted tricycle was used to measure maximal PO during ES cycling. PO was increased by 1-2 Watts.min⁻¹, by gradually increasing the stimulation intensity at 50 rpm, until the PO reached a plateau or declined, which took between 5 and 15 minutes.

3 Results

3.1 Training effects

Weight training, additional to ES cycle training, significantly increased the strength of quadriceps in 3 SCI people by 31.6 (4.4) % (P<0.05) but had no effect on maximal PO during cycling. Fatigue resistance also remained unchanged. There were no significant differences between the biopsies taken before and after additional weight training for any variables, although the area occupied by Type I + IIa fibres tended to increase (P=0.08). The ES rower was stronger and had a larger average fibre cross sectional area than the trained ES cyclists (before additional weight training), but produced a similar maximal PO during cycling.

3.2 Muscle Biopsies

All biopsies showed indications of muscle pathology, for example small group atrophy (angulated fibres) and regeneration (internal nuclei and neonatal-myosin-positive fibres) that are unusual in healthy control muscle. Overall, the SCI fibres appeared more rounded and there was a greater amount of non contractile material between fibres than observed normally. Fibre size was highly variable between subjects, with some appearing larger than control, and others smaller (Fig. 1).

Three subjects had some Type I fibres (18.4 (5.3) % of measured area); and Type Ila fibres were predominant in all subjects, comprising 68.7 (4.8) % of the measured area.

Activities of oxidative enzymes (succinate dehydrogenase; SDH) were low in all biopsies, and staining for both glycolytic and oxidative enzymes appeared to be more uniform than is normally seen in control muscle (Fig. 2).

The average fibre cross sectional area of Type Ila fibres correlated significantly with both the strength of the whole quadriceps muscle and the maximal PO produced during ES cycling (P<0.05). Both strength and PO also correlated with the proportion of Type I and Type I + Ila fibres (Fig. 3). Fatigue resistance did not correlate with the proportion of any specific fibre types; and, despite the quadriceps muscles of well trained SCI people being highly resistant to fatigue [7]; low SDH activity was evident in all biopsies.
4 Discussion

4.1 Training effects

We have found that ES strength training (weight training or rowing) can increase the size and strength of paralysed muscle fibres to a greater extent than endurance training alone; however, maximal PO during ES cycling remained low. It appears that in SCI people who have undergone atrophy, improvements in strength and PO are related at the start of an ES exercise programme [7]. However, after 3-6 months of training, PO attains a plateau [9] and is limited by something other than muscle strength.

The biopsy data showed a significant correlation between maximal PO and the proportion of the muscle that comprised of slow (Type I and IIa) fibres. We have previously shown that maximal PO as measured here correlates with sustainable, steady state PO in these subjects [8]. It therefore seems that, in order to improve both the maximal and sustainable PO during ES cycling, it is important to improve the aerobic capacity of the muscle fibres. ES recruits muscle fibres randomly, and therefore a greater proportion of anaerobic fibres are probably activated during ES elicited exercise than voluntary. These fibres can only generate ATP anaerobically and release metabolites that limit performance. A greater proportion of aerobic muscle fibres would reduce anaerobic metabolism, allowing higher PO’s to be attained.

Fatigue resistance during isometric contractions in trained SCI subjects was similar to that seen in untrained able bodied people and was unaffected by the additional strength training. Nevertheless, the activity of oxidative enzymes was low in all biopsy samples, supporting the suggestion that anaerobic metabolism limits PO during ES cycling. Presumably a greater amount of aerobic (low-intensity) training would increase the metabolic activity of oxidative enzymes, thereby improving the aerobic capability of the muscle.

4.2 Muscle biopsies

The ‘angulated’ fibres evident in most are usually associated with denervation. To our knowledge, none of these subjects were denervated and they would be expected to be in a steady state in terms of the muscular changes that occur after SCI. This should be further investigated. There were also indications of regenerating fibres (small diameter, internal nuclei and neonatal-myosin-positive) in all biopsies. It was apparent that the subjects who carried out the greatest amount of training (frequency and duration) had more signs of muscle pathology, including regeneration.

Few studies have reported evidence of Type I fibres in either trained or untrained SCI muscle. These fibres were evident in biopsies from three of our 5 subjects, including the untrained SCI person. This highlights the variability in the changes that occur following both an SCI and subsequent ES training. In the well trained subjects, the Type I fibres present were perhaps the result of the chronic ES training, but we have no direct evidence of this. In any case, the proportion of Type I fibres was well below that seen in the vastus lateralis muscle of able bodied people (41%) [12], except in one well trained cyclist (35%).

Metabolic activity was more uniform in trained SCI muscle than is seen in normal muscle. Since ES is usually carried out maximally by these subjects, it is expected that the adaptations that occur would be uniform across the muscle fibres.

5 Conclusions

Our data indicate that in well trained SCI people, power output is limited by factors other than muscle strength alone, and is perhaps associated with the aerobic capacity of muscle. Muscle pathology including regeneration was evident in all biopsies, perhaps as a result of chronic ES, and this should be further investigated.

6 References


6 Acknowledgements

We gratefully acknowledge funding from INSPIRE that supported this work. We also wish to thank Lindsey Marjoram for assistance with biopsy analysis.