FES-supported interval training following sensorimotor-complete spinal cord injury: a case series.

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Abstract

We report on a case-series of four male patients, aimed at investigating the effect of interval training by means of Functional Electrical Stimulation (FES) on ambulation ability in spinal cord injury (SCI). Four male motor complete (ASIA-A) participants were enrolled in this study. They were trained to walk supported by FES using progressive interval exercise training on a motorized treadmill. We used distance walked to muscle fatigue during continuous treadmill ambulation as the primary outcome measure.

Despite varied responses, all subjects increased their ambulation capacity. We conclude that FES-supported interval training offers a useful and effective strategy for strength-endurance improvement in the large muscle groups of the lower limb in motor complete SCI. We believe that this training protocol offers a viable alternative to that of continuous walking training in people with SCI using FES to aid ambulation.

1 Introduction

In spinal cord injury (SCI), FES is used to increase muscle cross-sectional area [1], to improve peripheral circulation and bone density, and assist functional activities [2]. Standing and walking have been identified as rehabilitation priorities [3], but independent ambulation is extraordinarily difficult in those with complete thoracic cord lesions.

Effective strengthening programs using FES protocols – but not investigating functional outcomes – have been reported [4, 5]. Functional muscle strength depends upon exercise intensity rather than duration [6]. Interval training seems appropriate to stimulate endurance whilst demanding (functional) strength and has been found beneficial in able-bodied subjects [7] and in the upper limbs of people with SCI [8].

We investigated interval exercise training in ASIA-A SCI subjects with a complete, thoracic cord lesion undertaking endurance-based ambulation training.

2 Methods

Four adult males with complete thoracic SCI, who all signed Informed Consent approved by the Institutional Human Ethics Committees participated in this study (see Table 1 for details). Screening – by an experienced rehabilitation medicine specialist – involved a clinical evaluation, responsiveness-testing to FES, risk assessment for autonomic dysreflexia and a DEXA scan of bone density to ensure safe weight-bearing during ambulation.

<table>
<thead>
<tr>
<th>Lesion</th>
<th>ASIA</th>
<th>Post injury</th>
<th>Spasticity</th>
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<tr>
<td>A</td>
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<td>11</td>
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<td>B</td>
<td>T4</td>
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<td>D</td>
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Table 1 Overview of patient characteristics.

Participants prepared for ambulation training during a minimum 8 weeks of FES-induced semi-recumbent cycling [9]. The entry-criteria to the ambulation phase was the ability to stand for a period of at least 3 minutes [2]. Following balance training in parallel bars, subjects were transferred to the treadmill once able to ambulate for 3 minutes with a walking frame.

The treadmill program consisted of 18 interval training sessions, each involving walking for a specific target duration, followed by a similar duration of seated recovery, repeated until muscle fatigue precluded further walking. Subjects trained 3 times per week to provide optimum stimulus without residual
fatigue [5] and used a wheeled walking frame and an overhead safety harness (offering no body weight support) to prevent a fall. Ambulation was achieved by means of skin surface electrodes placed over the quadriceps femoris, the gluteus maximus and the common peroneal nerve. Biphasic pulses (charge-balanced) at an initial current intensity of 140mA at 25Hz and a pulse-width of 150µs were used throughout the study. We increased stimulation amplitude of the quadriceps muscle by 10% whenever full knee extension could not be maintained for a maximum of 13 times over baseline. During recovery, we reset stimulation amplitude to a level appropriate to recommence ambulation.

Cadence and speed were chosen to suit participants’ comfort and control and this was assessed by questioning patients after each walk. Duration and number of walks per session were progressed over the 18 training sessions. We timed and recorded stimulation patterns and monitored heart rate (HR). We computed distance ambulated from treadmill speed and test duration. Primary outcome-variable, was distance walked (to onset of fatigue) before and after training.

3 Results

All participants increased ambulation capacity with training (Figure 1), but while the first three subjects tripled or quadrupled their walking distance, Subject D’s distance increase was more modest.

Subject C increased his continuous walking distance by just over 300%, but started from the lowest entry level. There was a break in training of 4 weeks, resulting in a substantial loss of the training effect (Figure 2). However he recovered form within a few sessions and, ultimately, gained the same order of improvement as Subjects A and B. However, exercise HR was more closely related to distance walked ($R^2 = 0.59; p<0.001$) and walking speed ($R^2 = 0.48; p=0.002$) rather than being in steady state across all training sessions.

In contrast, Subject D showed an initial, rapid response to training not evident in the other subjects and his training duration doubled in the first 6 sessions, however after that point in time no further gains were made (Figure 3). There was no suggestion of cardiovascular compromise and subjective responses indicated that perception of effort was “slight” to “moderate”.

The limiting factor was rapid muscle fatigue. Despite varying the training, by altering cadence, speed, initial target intervals, etc., no substantial gains were obtained after the initial 6 sessions. Subject D consequently only improved his post-training continuous walking distance by 44% from his initial distance (Figure 1).
4 Discussion

In this case series, we employed interval training to improve muscle endurance in SCI subjects. Our training (18 sessions) increased walking distance and speed in a group of men with complete SCI with varying degrees of success. Albeit not being the first report of FES-supported ambulation training in SCI subjects, it does demonstrate an alternative training paradigm to those previously deployed. Klose et al. trained participants for a total of 32 sessions, with continuous walking trials of variable duration, interspersed with 15 to 20 minute recovery periods [2] and found an average increase of over 100 meters in walking distance. Although our increases were less than the 100m reported by Klose et al, we still achieved significant gains in walking distance and speed, but with fewer sessions and a shorter training duration within each session.

Our subjects increased duration (muscular endurance) and speed (greater facility), resulting in a longer walking distance. The ability to walk faster is, however, limited by mechanical factors (eg maximum step length), factors related to the duty cycle of the stimulator (eg cadence) and precautionary monitoring of heart rate and may not always reflect the functional capacity of the muscles.

Subjects A, B and C had similar responses to training and demonstrated progressive gains in performance with few set-backs, even in the light of interrupted training (Subject C). Through sustained walking, the pattern of increased current intensity is analogous to progressive fatigue in the muscles. Training also prolonged the duration (and distance) walked between early stimulation increments in Subjects A, B and C. Subject D demonstrated a different set of responses, showing a rapid and positive initial training effect followed by a period of relative stability without progress. Performance did, in fact, even appear to regress during the final training sessions. We can find no definitive explanation for this subject’s responses, beyond speculating that, as a result of the long period between his SCI and the training (13 years) there had been substantial changes in his muscle composition which, within this training program, were not reversible. It would be valuable to investigate whether early use of FES training might restrict or prevent muscle fiber composition changes. Alternatively, it may simply be that this subject’s muscles were not amenable to strength training, a phenomenon not unknown in able-bodied subjects [10].

5 Conclusion

This study has provided evidence that interval training in FES-assisted ambulation is generally an effective strategy. The number of training sessions was established a priori, therefore we cannot determine, from this series, whether further training would have continued to evoke improvement. The evidence from the training diaries is that, in 3 of the 4 subjects, continued progress might be anticipated with an extended program. We believe that this training protocol offers a viable alternative to traditional training paradigms which employ continuous walking training in people with SCI using FES to assist ambulation.

6 References