Effects of isometric FES and dynamic FES on cardiovascular parameters on an active tilt-table stepper

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Abstract

Functional Electrical Stimulation (FES) has the potential to address orthostatic hypotension, which is a common problem in acute Spinal Cord Injury, by activating the skeletal muscle pump in the lower extremities. A randomized cross-over study was performed in which two interventions were compared: isometric FES and dynamic FES combined with constrained stepping movements. 16 young, able-bodied subjects participated. Each subject performed three trials on separate days in random order. Subjects were tilted to 75 degrees from horizontal for a maximum of 30 minutes. The protocol for the three trials were: A) subjects were immobilized and received no FES; B) subjects were immobilized and cyclical FES was applied; C) subjects' legs were moved in a stepping pattern and FES was applied. Of the 16 subjects, 5 experienced syncope or pre-syncope during the control trial (A). Those 5 plus one more experienced syncope or pre-syncope during the static FES trials (B), however it occurred on average 6.5 minutes later than in the static trials. No one experienced syncope or pre-syncope during the FES-stepping trials (C). Isometric FES appeared to cause short-term increases in blood pressure and heart rate, but these were not maintained over the long term. Dynamic FES produced much better results. We conclude that FES has potential to counteract orthostatic stress, however it should be combined with movement of the legs.

1. INTRODUCTION

Subjects suffering from neurological diseases such as spinal cord injury (SCI) and stroke often have impaired circulatory regulation, which can lead to orthostatic hypotension (OH) and syncope. OH prevents approximately 64% of acute SCI patients from participating in rehabilitation activities involving mobilization [1]. It is critical that SCI patients participate in mobilization activities as soon as possible in order to take advantage of synaptic growth, to prevent the loss of muscle mass due to inactivity, and to maximize clinical outcomes [2].

We propose a new therapy for the treatment of OH in early SCI rehabilitation that involves activating the physiological muscle pump in the legs using Functional Electrical Stimulation (FES). While it has been shown that FES can increase blood pressure and improve circulation in the lower extremities [3][4][5] it is not known if these effects can be maintained for extended periods of time. Also, in previous studies, the muscles have been stimulated while the legs are immobilized resulting in isometric contractions. We sought to evaluate the benefit of applying FES in synchronous with movements to produce concentric contractions. We developed an intervention that is a combination of FES and active tilt-table therapy that can be used as a means to increase blood pressure and circulation in acute SCI patients.

2. METHODS

2.1. Subjects

16 young, healthy adults participated in the study (Mean ± S.D.; Age: 26 ± 4.1, Height 1.72 ± 0.07 m, Weight: 65.4 ± 9.1 kg). Each subject performed three trials on separate days. All trials were conducted between 7:30 AM and 11:00 AM in a dim, quiet room with an ambient temperature of 19-21 degrees Celcius. Subjects were instructed to eat and drink nothing for 12 hours prior to each trial.

2.2. Experimental apparatus

A tilt-table stepper that induces passive leg movements and physiological loads to the feet

(afferent input) was developed by University Hospital Balgrist, Zurich in collaboration with University Hospital Heidelberg, Germany [6]. It consists of an ordinary tilt-table (Gymna, Belgium) combined with an integrated leg drive that produces stepping movements in the lower extremities. FES was synchronized with the actuators and delivered to the legs via surface electrodes and a 4-channel stimulator (Compex Motion, Compex Medical SA, Switzerland). The following muscle groups were targeted: Left and right quadriceps, left and right triceps surae. Symmetrical, bipolar stimulation impulses were delivered at a frequency of 30 Hz, pulse width of 250 us, and amplitude of two times the motor threshold (18 to 40 mA). For each muscle, the motor threshold was determined by gradually increasing the stimulation amplitude until a palpable contraction appeared. Muscles were stimulated in a repetitive sequence similar to normal gait at a period of 2 s (i.e. left quad and right triceps roughly simultaneous, alternating with right quad and left triceps). Stimulation was delivered in 2-minute work cycles with 1-minute rest periods.

2.3. Experimental protocol

Subjects were laid on the tilt-table stepper and secured by a torso harness. The legs were attached to the robotic actuators by thigh cuffs and the feet were secured to the foot plates. All trials began with a 10 min rest in the supine position. This was followed by a tilt to 75 degrees relative to horizontal. Subjects remained tilted for 30 minutes or until syncope or pre-syncope occurred. Syncope was defined as a transient loss of consciousness. Pre-syncope was defined as the sudden appearance of one or more of the following symptoms: dizziness, cloudy vision, cold sweat, repetitive yawning, headache, nausea, pallor or weakness of legs. Both conditions were associated with a rapid decrease in systolic blood pressure < 60% of baseline value.

Three trials were performed in random order. The protocol for each trial was as follows:

A) Subjects were immobilized and received no FES (control trial).

B) Subjects were immobilized and cyclical FES was applied (static FES trial).

C) Subjects' legs were moved in a stepping pattern and FES was applied (Dynamic FES trial)

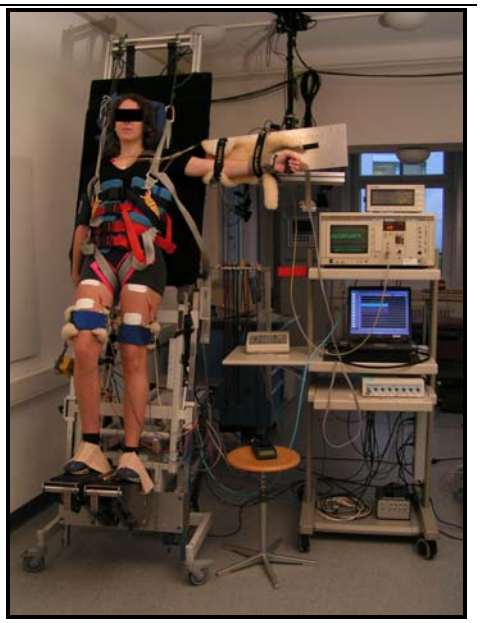

Figure 1 – Experimental setup. Left arm secured in extension with blood pressure monitor attached at wrist. 5x10 cm Surface electrodes are attached to thighs for quadriceps stimulation and calves (not seen) for gastrocnemius stimulation.

In trials B and C, the interventions were initiated 1 minute before tilt-up.

Blood pressure was measured continuously throughout each test using a non-invasive tonometric blood pressure monitor (CBM-7000, Colin Medical Instruments Corp., Japan). The sensor was worn on the left wrist, and it was calibrated automatically every 2.5 minutes using an inflatable cuff worn on the right upper arm. Systolic and diastolic blood pressure was calculated from the pressure signal, as was heart rate. Heart rate was confirmed by a continuous 5-lead electrocardiogram (PPG Hellige, Germany). During Trial A, EMG was recorded on the vastus lateralis and medial gastrocnemius bilaterally using surface electrodes to ensure that muscle activity was minimal in the legs.

2.4. Data analysis

Repeated measures ANOVA was used to test for differences between trials A, B and C in terms of:

1) Maximum HR during tilt

2) Time integral of HR during tilt

3) Maximum systolic BP during tilt

4) Time integral of BP during tilt.

A Wilcoxon rank-sum test, based on time before pre-syncope or syncope occurred (or 30

minutes if it did not occur), was used to determine differences between trials.

3. RESULTS

Six of the 16 subjects experienced syncope or pre-syncope during at least one trial. The duration of the trials for these six subjects is shown in Figure 2. No one experienced pre-syncope or syncope during Trial C.

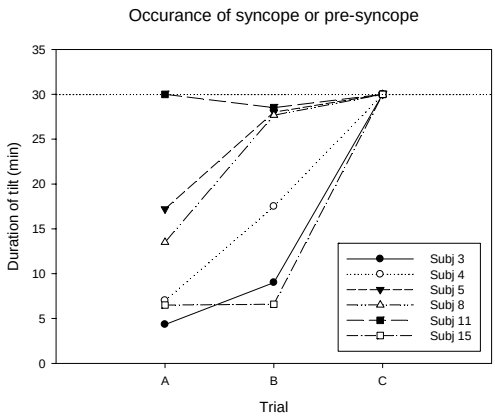

Figure 2 – Data from the six subjects who experienced syncope or pre-syncope. Note that a trial of 30 min indicates that no syncope occurred.

In terms of trial duration and incidence of syncope or pre-syncope, Trial C produced significantly better results (p=0.013). Static FES did not prevent syncope, but it delayed it an average of 6.5 minutes. When syncope occurred, the drop in blood pressure happened rapidly, usually in 2 to 5 heartbeats. Figure 3 illustrates one such episode.

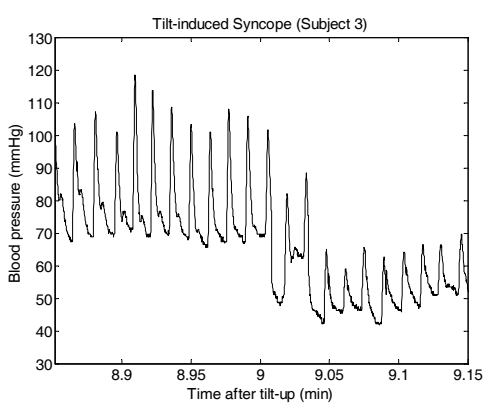

Figure 3 – Sudden blood pressure drop at syncope occurs in only a few heartbeats.

It was found that there were no significant differences between the maximum HR or BP during tilt between the trials. However, Trial C yielded significantly higher integrals of HR and BP (both systolic and diastolic) over the duration of the tilt-up period (p = 0.021).

4. DISCUSSION AND CONCLUSIONS

Lower limb FES has been shown to increase blood pressure and circulation, however previous studies have only looked at the instantaneous response [3][4][5]. Our results show that although isometric FES increased systolic and diastolic blood pressure at onset, it was not able to prevent sudden decreases after several minutes of head-up tilt. When FES was combined with movement, however, blood pressure was maintained for the full 30 minutes. This suggests that the amount of lower limb muscle activity induced by FES of the triceps surae and quadriceps was insufficient to prevent the sudden loss of venous tone that occurs in some able-bodied individuals.

The apparatus used in this study has potential to deliver valuable movement therapy to the many acute SCI patients who cannot be mobilized due to orthostatic hypotension. Using FES at this time could reduce the amount of muscle atrophy that typically occurs during prolonged bed rest, as well as provide valuable proprioceptive feedback to the healing spinal cord during movement. Future studies will look at the effect of this technique on SCI subjects.

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