Investigation of Long Pulse Electrical Stimulation of Denervated Muscle in Humans to evaluate Therapeutic and Functional benefits

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Abstract

Four subjects (30 – 37 years of age) who sustained a spinal cord injury around the L1 level between six and seventeen years ago took part in this study investigating the effect of stimulating denervated quadriceps muscle with up to 200ms long pulses via self adhesive surface electrodes. A 3-month baseline, 12-month intervention, 3-month follow-up protocol was adopted.

No change in limb girth or muscle depth (other than expected measurement variability) was observed throughout the study other than a slight trend of increased limb girth and muscle depth measurements during the long pulse stimulation phase of the study for one subject. Two subjects demonstrated a reduction during the trial in the minimum pulse width required to activate a quadriceps muscle contraction from 10ms to 500µs and 300µs respectively.

All of the subjects in the trial commented that Long Pulse Electrical Simulation had an effect on their sensation of pain. Given the high priority that people with Spinal Cord Injury place on research into the possible reduction of pain this is an area that may be worth further exploration.

1 Introduction

In conditions where the nerve to the muscle (lower motor neurone) is no longer completely functional the muscle is said to be denervated, voluntary control of contraction and therefore the muscle function is lost or impaired. This may be caused by direct injury of the nerve, compression or infection, and can occur at the spinal nerve roots, plexi or more peripherally. Typically, muscle wasting occurs, especially of the contractile elements, together with changes in the muscle fibre membrane, which if prolonged can hinder successful re-innervation. Muscle capillary density and blood flow are also reduced, such that if re-innervation does not occur, for instance in cases of complete limb denervation, the limb may be more susceptible to poor skin condition, infection, prolonged wound healing or sores in addition to poor cosmetic appearance and diminished personal esteem of the patient.

Indirect electrical stimulation of innervated muscle via its nerve in patients with spinal cord injuries has been shown to restore the reduction of muscle bulk and limb blood flow to near normal values over a period of 3 months [1]. Contraction of denervated muscle is possible by electrical stimulation of the muscle fibres themselves, known as 'direct stimulation', but requires greater intensities and pulse widths than indirect stimulation.

Use of balanced, alternate polarity, biphasic pulses with no net charge transfer to the tissue can allow pulse widths of approximately 20-30ms and frequencies sufficient to achieve tetanic contraction of the muscle. Depending on the period of denervation, it may be necessary to commence with twitch contractions from pulse widths of up to 150ms, with a progressive reduction and transition to tetanic contractions as the contractile mechanism of the muscle fibres is restored, which may take 3-4 months [2]. Treatment with this Long Pulse Biphasic (LPB) stimulation for up to 30 minutes each day for 8 months or longer in recent studies
have demonstrated sustained improvements in muscle contraction force and bulk, and limb blood flow in lower and upper limbs [1][2][3][4][5]. All were long term, greater than one year post injury and most were complete lesion cases. However, some state that improvements were dependent upon achieving tetanic contractions [2].

Five subjects with complete and partial limb denervation arising from T12 level spinal cord, peroneal nerve, and brachial plexus injuries took part in study investigating the effect of a six month period of charge balanced, long pulse, biphasic stimulation of peripheral limb muscle [6]. No significant changes in resting tissue properties occurred. It was observed that in the case where treatment was most consistent, some positive changes were detectable in all measurements, suggesting that greater benefit may accrue from a more prolonged treatment period. This present study was proposed in order to investigate the effect of a similar intervention applied over a longer 12 month stimulation regime.

2 Methods

The objective of the study was to investigate the effect of a 12 month programme of electrical stimulation of denervated quadriceps muscle in humans using Long Pulse Biphasic pulses and surface electrodes. The trial followed a 3 month baseline, 12 month intervention (with stimulation), 3 month follow-up protocol

Outcome measures of limb girth, muscle depth and limb blood flow were made as well as the minimum pulse widths required to produce muscle innervation. Limb girth was measured with a tape measure 15cm above the patella. Ultrasound measurements of Quadriceps muscle depth were recorded at the same position. Limb blood flow was measured by Impedance Plethysmography.

3.1 Recruitment

The Head of Department of the Spinal Unit, Salisbury District Hospital, identified 22 people with lesions around L1 and living within reasonable travelling distance of Salisbury District Hospital from the departmental database. These people were invited to attend an initial assessment session and four suitable volunteers were recruited (Table 1). None of the volunteers withdrew from the study despite the 18 month time commitment.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Sex</th>
<th>Age (yrs)</th>
<th>Time since injury (yrs)</th>
<th>Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>M</td>
<td>35</td>
<td>17</td>
<td>Incomp.</td>
</tr>
<tr>
<td>B</td>
<td>M</td>
<td>37</td>
<td>15</td>
<td>Comp.</td>
</tr>
<tr>
<td>C</td>
<td>F</td>
<td>30</td>
<td>15</td>
<td>Comp.</td>
</tr>
<tr>
<td>D</td>
<td>M</td>
<td>34</td>
<td>6</td>
<td>Comp.</td>
</tr>
</tbody>
</table>

Table 1: Summary of study volunteers

3.2 Results

No change in limb girth or muscle depth (other than expected measurement variability) was observed throughout the study for subjects A, B and C (Figure 1). Subject D exhibited a slight trend of increased limb girth and muscle depth measurements during the long pulse stimulation phase of the study.

Subjects C and D demonstrated a reduction during the trial in the minimum pulse width required to activate a quadriceps muscle contraction from 10ms to 500µs and 300µs respectively (Figure 2). There was also a clear reduction in the current intensity required to produce muscle contraction at each pulse width. Subject A showed little change in these characteristics. Subject B did not achieve a muscle contraction at any pulse width for the duration of the trial.

Measurements of blood flow were inconclusive in demonstrating any changes in this outcome measure. All subjects on the trial commented that using the stimulation had an impact on their sensation of pain. Subject A felt that there was no overall change in the amount of root pain he experienced during the day, during the intervention phase of the study, but that stimulation appeared to trigger any episodes he did experience. Subject B believed he had less pain during days that he used the stimulator. The sensation of stimulation became more tolerable as the trial progressed for subject C, and subject D commented that he had less pain during and following the treatment phase.

Subjects A and D also commented that they had more awareness and felt more positively about their treated leg. Subject D also noticed that his leg looked more toned, felt less cold and that he had improvements in his sleeping patterns.
4 Discussion and Conclusions

The changes observed following long pulse stimulation in this group of patients appeared to be more therapeutic than functional. Clear improvements in the strength-duration characteristics of denervated muscle following long pulse stimulation were observed although there were no obvious functional benefits from this. While a trend towards improvement in muscle depth was noticed in subject D, and the subject commented on this himself, this trend was not observed in other subjects.

All of the subjects in the trial commented that Long Pulse Electrical Simulation had an effect on their sensation of pain. Given the high priority that people with Spinal Cord Injury place on research into the possible reduction of pain this is an area that may be worth further exploration.

References


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