Intramuscular Electrical Stimulation to Improve Gait in Children with Cerebral Palsy

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Introduction

It is well established that children with cerebral palsy (CP) demonstrate deficits in gait as compared to age-matched able-bodied peers. Electrical stimulation (ES) has been investigated as a means of addressing abnormal gait mechanics, typically by stimulation of the ankle plantarflexors, ankle dorsiflexors and/or peroneal nerve. The primary focus of these studies has been on the carry over effects of prolonged ES applied during gait on ankle kinematics¹. However, only one study could be found that quantified the immediate short-term effects of ES on ankle kinematics². Bertoti³ reported no change in gait velocity but an improvement in step length in one child with CP post treatment with ES. The effects of ES on gait kinetics have not been reported to date.

Studies of ES in children with CP have primarily involved stimulation applied via surface skin electrodes. Alternatively, intramuscular stimulation, applied using fine wire electrodes through the skin, may have potential advantages over surface stimulation such as obtaining more repeatable stimulated motor responses and increased skin tolerance with prolonged use³.

The purpose of this pilot study was to determine the immediate effect of percutaneous intramuscular ES applied to the gastrocnemius (GA) and tibialis anterior (TA) during the gait cycle on temporal spatial characteristics and sagittal plane ankle kinetics and kinematics in children with CP. We hypothesized that that stimulation to the TA while walking would increase peak ankle dorsiflexion during the swing phase (peak DF), increase dorsiflexion at initial contact (DF at IC), and decrease the amount of power absorbed by the ankle during 0-30% of the gait cycle (Abs work) as compared to walking without stimulation. Also, we hypothesized that stimulation to GA while walking would increase the ankle generation work during 30%-toe off of the gait cycle (Gen work), resulting in an increased stride length and walking velocity as compared to walking without stimulation.

Method

A convenience sample was chosen consisting of eight children with a mean age of 9 years (sd=1). Two subjects had spastic hemiplegia and six subjects had spastic diplegia. Intramuscular electrodes were implanted percutaneously into the TA and GA muscles of each subject’s affected legs⁴. The control of stimulation while walking was accomplished using force-sensing resistors (FSR) placed within an insole worn in the shoe. To determine FSR placement, an F-scan pressure-mapping insole (Tekscan Inc., Boston, MA) was inserted into each shoe prior to electrode implantation to record plantar pressures for three to five steps. Areas of greatest plantar pressure at three gait events (initial contact, mid-stance, and terminal stance) were determined and used for placement of the FSR in the insoles of the shoes worn during the study. Following fabrication of insoles with the FSR embedded within them, the child walked with the insoles to determine the combination of FSR signals and the threshold pressure levels to be used to detect each gait event.

An electrical stimulator was programmed to provide electrical stimulation at appropriate times using the force-sensing foot switches to detect gait phase transitions. A charge balanced asymmetrical stimulation waveform was used at pulse durations ranging up to 200 microseconds, frequencies ranging from of 20-50 Hz, at an amplitude of 20mA. Stimulation patterns were created using custom software and downloaded into a research
grade external stimulator. Stimulation of the TA was provided during the swing phase of gait while GA
stimulation occurred during push-off.

Children practiced using the electrical stimulation under three randomly ordered conditions (GA on, TA on, and
both GA/TA on). Practice consisted of two 45-minute walking sessions per day for approximately one week
under each condition. Immediately after the week of practice, a three-dimensional gait analysis was conducted
for the practiced stimulation condition and without stimulation using a six-camera Vicon motion-capture system
(Vicon Motion Systems, Lake Forrest CA) at the subject’s self-selected walking speed.

To examine the longer-term effects of ES of both the GA/TA, a pilot study was also completed consisting of a
subset of three children (two with spastic diplegia, one with spastic hemiplegia) with a mean age of 10 years
(sd=2) who practiced walking with the ES in the both GA/TA condition for an additional four weeks at home for
two 25 minute sessions per day. Gait lab testing with and without stimulation was performed prior to home
practice and at the end of the four-week at home practice period. The without stimulation gait testing was
included to explore the carryover effects of stimulation.

Results

Table 1 illustrates the immediate effect of stimulation on ankle kinematics on the more affected limb. With
stimulation of the TA or both GA/TA on when compared to their respective off conditions, children improved in
ankle DF at IC and peak DF in swing by approximately three to five degrees. With stimulation of the TA or both
GA/TA, ankle absorption work during early stance decreased by 19% and 25% respectively which represents
improvement. There were minimal changes of approximately less than 5% in temporal spatial variables (stride
length and velocity) and ankle generation work during late stance when comparing stimulation of the GA or both
GA/TA to their respective off conditions.

<table>
<thead>
<tr>
<th></th>
<th>GA/TA On</th>
<th>GA/TA Off</th>
<th>TA On</th>
<th>TA Off</th>
<th>GA On</th>
<th>GA Off</th>
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<tbody>
<tr>
<td>DF at IC</td>
<td>-0.5</td>
<td>-5.5</td>
<td>+1.6</td>
<td>-2.9</td>
<td>-3.0</td>
<td>-3.4</td>
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<tr>
<td></td>
<td>(6.7)</td>
<td>(6.7)</td>
<td>(5.6)</td>
<td>(5.5)</td>
<td>(9.7)</td>
<td>(9.4)</td>
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<tr>
<td>Peak DF</td>
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<td>-2.1</td>
<td>+3.5</td>
<td>+0.6</td>
<td>-1.6</td>
<td>-1.2</td>
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<td></td>
<td>(6.8)</td>
<td>(6.3)</td>
<td>(5.5)</td>
<td>(7.0)</td>
<td>(9.2)</td>
<td>(10.2)</td>
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<tr>
<td>Abs Work</td>
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<td>-.091</td>
<td>-.121</td>
<td>-.125</td>
<td>-.112</td>
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<tr>
<td></td>
<td>(.04)</td>
<td>(.05)</td>
<td>(.04)</td>
<td>(.05)</td>
<td>(.06)</td>
<td>(.06)</td>
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<tr>
<td>Gen Work</td>
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<td>+.127</td>
<td>+.113</td>
<td>+.116</td>
<td>+.120</td>
<td>+.115</td>
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Table 1: Mean ankle position in degrees and ankle work in (J/kg) for the more affected limb (N=8) across FES conditions. A negative angle indicates a plantarflexed position while a positive angle indicates a dorsiflexed position. A negative work value indicates energy absorption while a positive work value indicates energy generation. The standard deviation is in parenthesis.

Table 2 illustrates the carryover effect of stimulation on the temporal spatial characteristics of gait in our pilot study of 3 children. After 4 weeks of additional practice with stimulation, the subjects walked faster
and took larger steps when they walked without stimulation when compared to their baseline condition. No
changes were seen in ankle kinematic and kinetic variables post 4 weeks of additional practice when compared
to their baseline values.
Table 2: Mean temporal spatial gait characteristics for the more affected limb for children who walked additional 4 weeks at home (N=3). All data presented was obtained without stimulation.

<table>
<thead>
<tr>
<th></th>
<th>Walking Velocity (cm*s⁻¹)</th>
<th>Step Length (m)</th>
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<tbody>
<tr>
<td>Pre-Training</td>
<td>1.11 (.17)</td>
<td>0.53 (.06)</td>
</tr>
<tr>
<td>Post-Training</td>
<td>1.20 (.17)</td>
<td>0.56 (.06)</td>
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<tr>
<td>Change %</td>
<td>8.7</td>
<td>5.8</td>
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</table>

Discussion

This pilot study suggests that percutaneous intramuscular ES applied during walking immediately improved aspects of ankle kinematics in children with CP. Stimulation of the TA and both the GA/TA resulted in a more dorsiflexed ankle position at initial contact and during swing when compared to without stimulation. The improvements in ankle absorption work during early stance with stimulation of both the GA/TA and the TA may have been the result of a more dorsiflexed ankle at initial contact that allowed for a decreased PF moment and reduced energy absorption due to a reduced demand for eccentric activity of the triceps surae.

The improvements in voluntary walking velocity and step length after 4 weeks of additional walking with stimulation suggest a carryover effect from the training program. These changes are noteworthy as the temporal spatial characteristics of gait in children with CP are especially difficult to improve with therapeutic interventions. Additional training with ES with a longer practice period may be necessary to produce longer-term changes in mechanics during gait. Comparison to a control group receiving gait training without ES is also warranted.

References