QUADRICEPS ACTIVATION VIA TRANSCUTANEOUS MAGNETIC STIMULATION OF THE FEMORAL NERVE

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**Introduction**

Muscle stimulation has traditionally been accomplished via electrical means, applied either to the surface of the skin, or subcutaneously via needles. To evoke a contraction of sizable magnitude, large voltages and currents are required (on the order of 100-500 volts at 100 milliamps), which can be quite painful. However, new technology potentially allows for stimulation of motor nerves via magnetic means (1), activating the associated muscles with little discomfort at levels approaching those of maximal voluntary contraction (MVC). The (relatively) painless nature of this stimulation opens up almost unlimited possibilities for research and rehabilitation.

Magnetic stimulation works via the principle of magnetic induction (Faraday’s Law). Briefly, a time-varying magnetic field around a wire will induce an electric current in the wire, in a direction given by the right-hand rule. Similarly, a current through a wire will induce a magnetic field around the wire. Magnetic stimulation works analogously, with the stimulator providing a large magnetic field, which will induce a nerve (the “wire”) to depolarize, thus activating the muscle which it innervates. Previously, this system has been used mainly for transcranial stimulation (2,3,4,5). Of studies that looked at peripheral magnetic stimulation, one found that magnetic stimulation significantly retarded weight loss in denervated gastrocnemius muscles in rats (6). Another compared the use of electric stimulation with a combination of electric/magnetic stimulation in patients recovering from anterior cruciate ligament (ACL) reconstruction surgery (7). Reports showed the combined electric/magnetic stimulation to be half as painful as electrical stimulation, while there was no difference in thigh girth between the two techniques, with control subjects having a significant loss in thigh girth. Polkey et al. (8) found it possible to attain supramaximal twitches in the quadriceps via magnetic stimulation of the femoral nerve. All these studies were limited by the then-available technology.

The purpose of this study was to stimulate the femoral nerve innervating the quadriceps muscle group, in order to determine the optimal stimulus intensity and frequency to maximize both contraction intensity and patient comfort.

**Methods**

10 healthy subjects (6 male, 4 female, age range 21-44 yrs.) participated in this study. Subjects sat in the chair of an isokinetic dynamometer (Biodex, Shirley, NY) with their ankles fixed to the arm of the dynamometer. The dynamometer arm was fixed at 90° and subjects' trunks reclined at 45°, in order to facilitate location of the femoral nerve. Three five-second MVCs were recorded for each subject, with a 30-second rest in between each. Torque values for these MVCs were averaged to obtain a measure for MVC.

Magnetic stimulation was then administered using a MagStim Rapid (MagStim Corp., Whitland, Wales) with four booster units and a branding iron type stimulating coil, controlled from a laptop. This unit can generate a magnetic field of up to 2 Tesla. It has settings to control intensity, frequency, and duration of stimuli. Subjects were tested with three-second pulse trains at the following frequencies and intensities (expressed as percent of maximum output of the unit), dictated by the maximum output allowed by the controller software:

- 20 Hz: 60%, 80%, 100%; 30 Hz: 60%, 80%; 40 Hz: 60%

Prior to the administration of the stimulus trains, optimal placement of the stimulating electrode over the femoral nerve was determined by administering single pulses at the femoral crease and finding the location that elicited the greatest response. Additionally, in order to determine whether subcutaneous fat played a role in the magnitude of the elicited contraction, body fat measurements were taken using calipers. The thigh fold measured by the calipers was recorded in addition to percent body fat.

**Results**

Torque elicited by magnetic stimulation at different intensities and frequencies is shown in Table 1 below. Results are expressed as a percentage of MVC and are mean ± std. error.

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>60% Intensity</th>
<th>80% Intensity</th>
<th>100% Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Hz</td>
<td>37.2 ± 7.3</td>
<td>58.4 ± 4.7</td>
<td>68.2 ± 3.9</td>
</tr>
<tr>
<td>30 Hz</td>
<td>48.0 ± 6.6</td>
<td>65.4 ± 5.5</td>
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<tr>
<td>40 Hz</td>
<td>55.2 ± 9.3</td>
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**Discussion**

Magnetic stimulation of the femoral nerve was able to elicit contractions of significant magnitude in the quadriceps, approaching therapeutic levels. With more booster units for the MagStim, higher frequencies and intensities could be used and should produce even higher torque levels. Based on the correlation between body fat/thigh girth and torque level, it seems that higher power output from the stimulator may be needed to elicit training-level torques in patients with greater adipose tissue.

Eliciting therapeutically-useful contractions via electric stimulation is quite painful. Most subjects in this study reported pain at the highest intensity only (100% at 20 Hz) with magnetic stimulation. We feel that this would be greatly alleviated by software which allowed the intensity of the stimulus to be gradually increased rather than coming on at full force. While this is a limitation for treating patients, meaningful contractions can be attained at lower intensities, without pain.

It has been shown that quadriceps inhibition following ACL reconstruction significantly impairs the ability to train with voluntary contractions (9). Based on our data, magnetic stimulation should prove to be an useful tool for overcoming this problem in rehabilitation without subjecting the patient to unnecessary discomfort.

**References**


**The Cooper Union School of Engineering, New York, NY.**

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**Figure 1:** Elicted torque as a function of body fat percentage and thigh fold.