Motor Cortex Stimulation for Neuropathic Pain: A Randomized Cross-over Trial

Julia A.E. Radic, Ian Beauprie, Paula Chiasson, Zelma H.T. Kiss, Robert M. Brownstone

ABSTRACT: Background: Chronic motor cortex stimulation (MCS) has been used to treat medically refractory neuropathic pain over the past 20 years. We investigated this procedure using a prospective multicentre randomized blinded crossover trial. Methods: Twelve subjects with three different neuropathic pain syndromes had placement of MCS systems after which they were randomized to receive low (“subtherapeutic”) or high (“therapeutic”) stimulation for 12 weeks, followed by a crossover to the other treatment group for 12 weeks. The primary outcome measure was the pain visual analogue scale (VAS). Secondary outcome measures included McGill Pain Questionnaire (MPQ), Beck Depression Inventory-II, medication log, work status, global impression of change, and SF-36 quality of life scale. Results: The trial was halted early due to lack of efficacy. One subject withdrew early due to protocol violation and five subjects withdrew early due to transient adverse events. Six subjects with upper extremity pain completed the study. There was no significant change in VAS with low or high stimulation and no significant improvement in any of the outcome measures from low to high stimulation. SF-36 role physical and mental health scores were worse with high compared to low stimulation (p = 0.024, p = 0.005). Conclusions: We failed to show that MCS is an effective treatment for refractory upper extremity neuropathic pain and suggest that previous studies may have been skewed by placebo effects, or ours by nocebo. We suggest that a healthy degree of skepticism is warranted when considering this invasive therapy for upper extremity pain syndromes.


Keywords: Motor cortex stimulation, neuropathic pain
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Although there are various neurosurgical treatments for pain, few are effective for neuropathic pain syndromes affecting the face or upper extremity. The available treatments have proven generally unsatisfactory for central deafferentation pain including brachial plexus avulsion, phantom limb, or trigeminal neuropathic pain. Deep brain stimulation of the sensory thalamus or midbrain periaqueductal or periventricular gray matter, peripheral nerve stimulation1-3, and spinal cord stimulation4 have all been used, but long term success rates are poor.7,9.

A possible role for the motor cortex in pain emanated from the work of Penfield and Jasper4, who found a lack of pain reduction from primary sensory cortical resection, but relief following subsequent primary motor cortex resection11. Given that motor
cortex resection is fraught with problems, little work proceeded in this area until the development of implantable brain stimulation technology. In the first report of the use of motor cortex stimulation (MCS) to treat central pain syndromes, seven patients with thalamic pain syndrome were treated with MCS and all reported ‘excellent’ or ‘good’ early results and no adverse effects, with an 80% improvement in pain relief maintained for two years. Thus the possibility that MCS could be useful for the treatment of neuropathic pain syndromes was born.

Several studies (mostly retrospective or open label prospective) have been published since, supporting MCS as an effective surgical intervention for central and neuropathic syndromes for which no other intervention has proven effective. A review of the literature showed that a good response to MCS (pain relief of >40-50%) was achieved for greater than one year in 9/18 patients with trigeminal neuropathic pain, and 12/23 patients with brachial plexus avulsion or phantom limb pain. However, studies examining MCS for pain control are limited by large variability in patient selection criteria, surgical protocols, stimulation parameters used, and a lack of blinding and controls.

MCS is ideally suited for sham stimulation because patients are unable to perceive the stimulation. There are four previously published randomized crossover trials studying either continuous or cycling MCS. There were significant analgesic effects when MCS was switched on compared to the off-stimulation condition in three of these studies, supporting MCS as a viable treatment. However, these studies included patients with diverse pain etiologies who first underwent a trial period of stimulation. This raises the possibility that there was either a carry-over effect of stimulation, or patients had learned to perceive – consciously or sub-consciously – when the stimulation was on, thus leading to a placebo effect. In the fourth trial, no differences in pain control were found during the crossover period, despite a reported mean rate of pain relief on pain visual analogue scale (VAS) scores of 48% and good or satisfactory results in 60% of the patients. This again suggests that there was either a carry-over effect from an initial open label period, or a prominent placebo effect.

In order to mitigate the limitations of retrospective or open label series, we aimed to examine the effectiveness of cycling MCS in treating three groups of patients with refractory neuropathic pain using a prospective, randomized, blinded, crossover design. In order to eliminate possible carry-over effects, an open trial period was not used. We were unable to find benefit of MCS.

METHODS

The study was approved by the Capital Health Research Ethics Board in Halifax, and by the University of Calgary Conjoint Health Ethics Research Ethics Board in Calgary, and was registered at clinicaltrials.gov (NCT00462566).

All subjects who were referred for neurosurgical intervention to treat neuropathic pain at the Queen Elizabeth II Health Sciences Centre and at the Foothills Hospital from April, 2005 to September, 2010, were screened for admission into this study. Patients who continued their therapy have been followed since.

Inclusion criteria included: (1) a diagnosis in one of the following three categories: a) unilateral upper extremity neuropathic pain secondary to phantom limb pain, stump pain or brachial plexus avulsion, b) neuropathic deafferentation facial pain, or c) upper extremity complex regional pain syndrome (CRPS); (2) pain refractory to conservative treatment (e.g. medications, regional blocks) as reviewed by a chronic pain physician and/or a multidisciplinary pain centre; (3) the patient was medically fit for neurosurgery; and (4) the patient was willing to provide informed consent.

Exclusion criteria included: (1) the patient was not medically fit for surgery; (2) the patient had not exhausted conservative methods of pain control prior to considering motor cortex stimulation; (3) the patient was not able to provide informed consent; and (4) the patient was unable to undergo magnetic resonance imaging (MRI).

Surgical Procedure

Surgical approaches were slightly different at each site. In Halifax, a magnetic resonance image was obtained using one mrem cuts, and a three-dimensional reconstruction of the brain was obtained using an image guidance system (Stealth Station – TREON 2001, Surgical Navigation Technologies, Medtronic). In Calgary the same MR imaging was obtained after placement of a stereotactic frame (Leksell, Elektta). The location of the hand representation in the contralateral motor cortex was determined and the target mapped onto the scalp.

A burr hole was made, and a four-contact electrode (Resume II lead, Medtronic) was placed in the epidural space, aligned parallel (in Halifax) or perpendicular (in Calgary) to the central sulcus. This electrode type is the same as those used in previous studies. Intraoperative electrical stimulation was used to ensure that we were over the intended region. In patients who did not have a functional limb, such as those with brachial plexus avulsion, motor threshold was determined in a similar way but the threshold was determined to be the voltage at which the patient repeatedly and consistently reported the sensations of twitch (at low frequencies) or tetany (at high frequencies) in the appropriate somatotopic location or real motor twitching in the intact proximal limb, face, or shoulder girdle. At the Calgary site, somatosensory evoked potentials were also obtained in the subjects with brachial plexus avulsion to confirm motor hand territory using phase reversal. Once satisfied with placement, the electrode was secured using a burr hole cover (in Halifax) or sutured to the calvarium and cemented in place (in Calgary), the patient was placed under general anaesthesia, and an extension (Medtronic 7426A) and infra-clavicular pulse generator (Medtronic Itrel 3) were inserted.

Randomisation and programming

All subjects except one were randomized within two weeks of surgery to one of two groups (“high” and “low”) and remained blinded to their group assignment. One (Subject 4) was randomized two months post-operatively when she felt that her pain returned to baseline. We selected a high/low stimulation protocol in order to reduce potential placebo effects from subconscious perception of stimulation. The use of a control arm of low stimulation was similar to the original trials with vagus nerve stimulation for epilepsy and the low setting was much lower than any previously published MCS cases. Stimulation was applied in the cycling mode in all cases: for high stimulation the device was ‘on’ for ten minutes and ‘off’ for two hours; for low stimulation, ‘on’ was set for one minute and ‘off’ for six hours. The primary investigator (the neurosurgeon) remained unblinded and randomized.
Motor cortex stimulation did not change primary outcome

The primary outcome measure was the VAS. Pain reduction on the VAS was scored as follows: 80 to 100% excellent reduction; 60 to 79% good pain reduction; 40 to 59% fair pain reduction and less than 40% poor pain reduction. The secondary outcome measures were the McGill Pain Questionnaire (MPQ), Short Form 36 quality of life scale (SF-36), Beck Depression Inventory-II, patient global impression of change (PGIC), medications log, and return to work. The measures were completed pre-operatively (during the screening visit), at 12 weeks (cross-over time point) and at 24 weeks post-operatively (study completion) for a total of three test points (Table 1).

Sample size and analysis

Our goal was to enroll six subjects in each arm, given the assumption that the expected difference in VAS from 12 weeks to 24 weeks was a reduction of 50% for the low/high group and an increase of 100% for the high/low group with a standard deviation of 10%. This expected clinical response was estimated based on prior literature and because it was felt that it was necessary to have a good clinical response to justify the procedure and its risks, given its invasive nature.

Participation in the study was halted if patients were dissatisfied or wished for any reason to withdraw, if the neurosurgeon felt it was indicated, or if a serious adverse event occurred (defined as any event occurring after treatment assignment that was considered to cause temporary or permanent harm to the subject, as determined by the neurosurgeon looking after the subject). In the case of a serious adverse event, subjects would be withdrawn and would receive appropriate medical intervention.

Continuous measures (i.e. means of scores on McGill Pain Inventory, SF-36, and Beck Depression Inventory) were analyzed with paired t-tests comparing scores in each of the treatment conditions with the pre-intervention scores and comparing the scores between the treatment conditions. Categorical variables were analyzed with Chi Square and Fisher’s Exact Test. Analyses were done using SPSS v.14. Results are presented with standard deviations, and were considered significant when p < 0.05. Data are expressed as mean ± standard deviation unless otherwise stated.

RESULTS

A total of 12 patients met inclusion criteria during the study period and had insertion of a MCS for refractory neuropathic pain (Table 2). The mean duration of neuropathic pain before MCS insertion was 78 months (range 20–183 months). Of these, eight patients were treated in Halifax, four in Calgary. Six patients withdrew from the study (three in Halifax, three in Calgary), all prior to the three-month crossover point. One patient was withdrawn because their stimulator turned off unexpectedly (breach of study protocol), one patient for panic attacks later shown to be unrelated to stimulation (adverse event), one patient for post operative infection (adverse event), two patients for focal motor seizures (adverse events), and one patient for anxiety related to a focal motor seizure experienced during threshold testing (adverse event). Thus, six patients completed the study and were included in the analysis. (When data from a seventh subject (Subject 11) was included in analysis – the only one of the six who withdrew after some data were collected – the results were unchanged.) The study was stopped before the target of 12 subjects because of a clear lack of patient satisfaction that suggested that the therapy was not effective.

Motor cortex stimulation did not improve secondary outcomes

McGill Pain Questionnaire

The MPQ total, sensory, affective, evaluative, miscellaneous scales, and present pain intensity were compared between pre-
operative and low stimulation settings, pre-operative and high stimulation settings, and low and high stimulation settings (Fig. 2). There was a statistically significant worsening of the six subjects’ MPQ miscellaneous pain scores when moving from baseline to low stimulation (increase of 3.3 ± 2.9 points, \( p = 0.039 \)). There was also a statistically significant worsening of the six subjects’ MPQ total pain scores when moving from pre-operative to high stimulation state (increase of 4.5 ± 4.1 points, \( p = 0.045 \)). There were no other statistically significant differences.

Table 2: Subject Details.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Sex</th>
<th>Center</th>
<th>Finished or Withdrawn</th>
<th>High or Low Stimulation First</th>
<th>Motor Threshold</th>
<th>Final Setting</th>
<th>Pain Duration Prior to MCS Implantation (months)</th>
<th>Neuropathic Pain Etiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>54</td>
<td>M</td>
<td>Hal</td>
<td>Finished</td>
<td>L</td>
<td>3</td>
<td>Amp 2.1</td>
<td>122</td>
<td>Left brachial plexus avulsion</td>
</tr>
<tr>
<td>2</td>
<td>26</td>
<td>F</td>
<td>Hal</td>
<td>Finished</td>
<td>L</td>
<td>3.5</td>
<td>Amp 2.5</td>
<td>47</td>
<td>Right brachial plexus avulsion</td>
</tr>
<tr>
<td>3</td>
<td>43</td>
<td>M</td>
<td>Hal</td>
<td>Finished</td>
<td>H</td>
<td>3.9</td>
<td>Amp 2.7</td>
<td>69</td>
<td>Left 2nd finger phantom limb</td>
</tr>
<tr>
<td>4</td>
<td>47</td>
<td>F</td>
<td>Hal</td>
<td>Finished</td>
<td>H</td>
<td>9</td>
<td>Amp 6.0</td>
<td>108</td>
<td>Right upper extremity CRPS type 2</td>
</tr>
<tr>
<td>5</td>
<td>28</td>
<td>M</td>
<td>Hal</td>
<td>Finished</td>
<td>H</td>
<td>7</td>
<td>Amp 5.0</td>
<td>20</td>
<td>Right brachial plexus avulsion</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>M</td>
<td>Cal</td>
<td>Finished</td>
<td>L</td>
<td>8.5</td>
<td>Amp 4.5</td>
<td>85</td>
<td>Left brachial plexus avulsion</td>
</tr>
<tr>
<td>7</td>
<td>30</td>
<td>M</td>
<td>Hal</td>
<td>Withdrawn – Stimulator turned off unexpectedly</td>
<td>L</td>
<td>4</td>
<td>Amp 2.8</td>
<td>48</td>
<td>Right second finger phantom limb</td>
</tr>
<tr>
<td>8</td>
<td>41</td>
<td>M</td>
<td>Hal</td>
<td>Withdrawn – Panic attacks</td>
<td>H</td>
<td>4</td>
<td>Amp 2.8</td>
<td>84</td>
<td>Left upper extremity CRPS</td>
</tr>
<tr>
<td>9*</td>
<td>40</td>
<td>F</td>
<td>Cal</td>
<td>Withdrawn – Infection</td>
<td>H</td>
<td>6.1</td>
<td>Amp 3.5</td>
<td>54</td>
<td>Left CRPS hand</td>
</tr>
<tr>
<td>10</td>
<td>29</td>
<td>M</td>
<td>Cal</td>
<td>Withdrawn – Focal motor seizure</td>
<td>H</td>
<td>6.5</td>
<td>Amp 3.5 (dropped from 4 and PW 360)</td>
<td>183</td>
<td>Left brachial plexus avulsion (and complete T5 spinal cord injury)</td>
</tr>
<tr>
<td>11</td>
<td>48</td>
<td>M</td>
<td>Cal</td>
<td>Withdrawn – Focal motor Seizure</td>
<td>L</td>
<td>9</td>
<td>Amp 6.8</td>
<td>63</td>
<td>Left deafferentiation facial pain (post-herpetic neuralgia)</td>
</tr>
<tr>
<td>12</td>
<td>23</td>
<td>M</td>
<td>Hal</td>
<td>Withdrawn – anxiety following an early seizure during threshold testing</td>
<td>L</td>
<td>3.3</td>
<td>Amp 2.5</td>
<td>57</td>
<td>Right brachial plexus avulsion</td>
</tr>
</tbody>
</table>

M = male; F = female; Hal = Halifax patient; Cal = Calgary patient; MCS = motor cortex stimulation; H = high stimulation first; L = low stimulation first; Amp = stimulation amplitude (V); PW = pulse width (μs); Freq = frequency (Hz); CRPS = upper extremity complex regional pain syndrome.

*Note that subject 9 mistakenly received 70 Hz stimulation, however as infection appeared within one month of implantation the entire system was explanted without significant change in patient reported pain.
Short Form-36 Quality of Life Questionnaire

Short form-36 subsection scores were compared between pre-operative and low stimulation, pre-operative and high stimulation, and low and high stimulation states (Fig. 3). Complete data were only available for five of six patients who completed the trial. SF-36 subsections included bodily pain, general health, vitality, social functioning, emotional well-being, role limitations-emotional, physical functioning, role limitations-physical, as well as physical component and mental component summaries. The SF-36 role physical scores in the high stimulation condition were significantly lower (decrease of $5.9 \pm 3.7$ points, $p = 0.024$) than in the low intensity condition, indicating a worsening of role physical scores when patients moved from low to high stimulation (Fig. 3B). The SF-36 bodily pain scores in the low stimulation condition were significantly higher than in the pre-operative condition (increase of $4.5 \pm 3.2$ points, $p = 0.034$), indicating an improvement in bodily pain scores when patients moved from baseline to low stimulation. The SF-36 mental health scores in the high stimulation condition were significantly lower than in the low intensity condition (decrease of $3.9 \pm sd 1.5$ points, $p = 0.005$), indicating a worsening of mental health scores when patients moved from low to high stimulation. There were no other statistically significant differences.

Beck Depression Inventory II

Beck Depression Inventory II scores from all six subjects were compared between baseline and low stimulation, baseline and high stimulation, and low and high stimulation using Chi square analysis. There were no differences in any of the conditions (Fig. 4).

Standard 7-Point Patient Global Impression Of Change (PGIC)

The Standard 7-Point PGIC scores were compared between low and high stimulation (Fig. 5). The PGIC is scored from 1-7, with 1 signifying no change, and 7 signifying a great deal better. A clinically significant improvement corresponds to a score of 5-7. The mean PGIC score after 12 weeks of high stimulation was $4.3 \pm 0.8$ compared to $4.0 \pm 0.9$ after 12 weeks of low stimulation. This difference was not significant ($p = 0.465$).

Medication Logs

The medication logs from baseline, low stimulation, and high stimulation settings were collected at each clinic visit. Three subjects, Subject 2, Subject 3, and Subject 4, had no change in dose or types of pain medications they were taking over the study period. Subject 5 had an overall increase in pain medications when moving from pre-operative to high stimulation states and a further increase when moving from high stimulation to low stimulation. Subject 1 had an overall decrease in pain medications when moving from...
pre-operative to low stimulation states and then an increase in pain medications when moving from low to high stimulation. Subject 6 had an overall decrease in pain medications when moving from pre-operative to low stimulation and a further decrease when moving from low to high stimulation. On average, therefore, there was no significant decrease in pain medication usage during the high stimulation period compared with the pre-operative or low-stimulation period.

**Work Status Questionnaire**

The pre-operative, 12 week post-randomization and 24 week post-randomization work status of all six subjects were analyzed.
Four subjects were not working pre-operatively, one was working full time, and one was working flexible hours in a family business. Only one subject, Subject 6, changed employment status over the study period: from unemployed preoperatively, to partially employed on low stimulation, to fully employed on high stimulation, but failed to have significant pain relief over the long term and ultimately requested explantation of their device.

Figure 6: Absolute changes in each subject’s VAS scores (A) at rest, (B) with activities, (C) least pain experienced, (D) most pain experienced] between baseline, low levels of stimulation, high levels of stimulation and final follow-up. Higher scores correspond to worse pain. There was no statistically significant change in pain scores over the study period or over the open-label follow-up period.

Table 3: Results of long term follow up.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Number of Months of Follow-up</th>
<th>Using Stimulator at Time of Last Follow-up [Yes/No]</th>
<th>Subjective Long Term Outcome</th>
<th>Working at Baseline [Yes/No]</th>
<th>Working at End of Study Period [No/Full Time/Part Time]</th>
<th>Working at Last Follow Up [No/Full Time/Part Time]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>51</td>
<td>No</td>
<td>Felt pain had worsened overall by 4 years post-implantation, so turned off stimulator; has been off since with ongoing poor pain control</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>71</td>
<td>Yes</td>
<td>Reasonable multimodal pain control. IPG replaced 70 months post-operatively.</td>
<td>Full Time</td>
<td>Full Time</td>
<td>Full Time</td>
</tr>
<tr>
<td>3</td>
<td>33</td>
<td>No</td>
<td>No benefit from MCS and tension on extension so stimulator explanted</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>84</td>
<td>Yes</td>
<td>No benefit from MCS. Despite this, IPG replaced 83 months post-operatively.</td>
<td>Part Time</td>
<td>Part Time</td>
<td>Part Time</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
<td>Yes</td>
<td>No benefit from MCS during study period; slightly better pain control during open label period</td>
<td>No</td>
<td>No</td>
<td>Part Time</td>
</tr>
<tr>
<td>6</td>
<td>53</td>
<td>No</td>
<td>No benefit from MCS so stimulator explanted</td>
<td>No</td>
<td>Full Time</td>
<td>Full Time</td>
</tr>
</tbody>
</table>

MCS = motor cortex stimulation; IPG = implantable pulse generator.
Lack of Improvement at Follow-up

For the six subjects who completed the study, the mean length of follow-up after MCS implantation was 54 months (30 to 84 months). Pain visual analogue scores did not significantly change over this open-label follow-up period (Fig. 6). Two of the six subjects felt that MCS offered subjective pain relief. One (Subject 5) began part time work. Interestingly, despite no changes in VAS scores, two people (Subjects 2 and 4) requested replacement of their implantable pulse generators after noting an increase in pain after battery depletion (at 70 and 83 months respectively), suggesting either a subconscious awareness of stimulation or some modulation of their pain or suffering. The remaining subjects felt that MCS added no benefit to their pain management. One (Subject 1) felt that their pain had worsened and permanently turned off their MCS, and one of the six subjects requested explantation of their device (Table 3).

Overall, these results indicate a lack of benefit of cycling MCS in this study population.

DISCUSSION

In this randomized, blinded, cross-over study, MCS did not improve neuropathic pain of the upper extremity, as measured by any of our outcome measures. In fact, there was a statistically significant worsening of the MPQ miscellaneous pain scores when moving from baseline to low stimulation and MPQ total scores when comparing pre-operative to high stimulation states. Also, SF-36 mental health scores in the high stimulation condition were significantly worse than in the low stimulation condition (p = 0.015). Despite the fact that one subject had an overall reduction in pain medications from pre-op/low stimulation to high stimulation and returned to work during the high stimulation period, this subject failed to have significant pain relief over the long term and had their system explanted.

This failure to demonstrate efficacy from MCS therapy was generally surprising, given most previously published findings in the literature. Despite one recently published retrospective review of 14 consecutive patients receiving MCS for neuropathic pain that failed to show an acceptable benefit28 a literature review revealed that a good response to MCS was achieved for greater than one year in 50% of patients: 9/18 patients with trigeminal neuropathic pain, and 12/23 patients with brachial plexus avulsion or phantom limb pain18. Our own unblinded experience prior to this randomized trial demonstrated similar benefits (unpublished data). In fact, we and others (A. Parrent, personal communication) have had patients who noted significant pain worsening when their battery depleted and who requested battery replacement. It is interesting to consider, therefore, why our study failed to show efficacy of this therapy.

Blinded studies take into account placebo effects. Surgical procedures in general are very effective in inducing placebo effects29. Four previous double blind, randomized prospective controlled trials found that MCS offered significant pain relief to many patients20-22. Three of these studies were conducted following an initial open label period21-23 and one was only randomized during a blinded externalized trial period20. Therefore a possible reason for the discrepancy between our results and these previous studies are that the open label period may be confounding, patients may experience a subconscious “perception” of stimulation, and/or the selection of “responders” – which may have been those most influenced by placebo29. For these reasons, our randomized trial was in stimulation-naïve patients: we did not begin with an open label time period, so subjects may not have “learned” to discern when the stimulator was on.

Another possibility to consider is whether our trial suffered from a nocebo effect30. As part of a clinical trial, our patients were told from the outset that the purpose of the trial was to determine whether or not this procedure works and that there were, in fact, risks. That is, an optimistic picture was not painted. Consent forms themselves can induce nocebo responses31. For example, one study found that 19% of subjects signing a consent form citing gastrointestinal (GI) symptoms as a potential adverse effect dropped out of the study because of GI symptoms, compared to 3% who received a form that did not cite GI symptoms as a potential adverse effect32. In other words, simply going through the consent process for participating in our study could have led to adverse events or elimination of a placebo response necessary for efficacy.

It is possible that the therapy is effective but we failed to demonstrate this, because of patient selection. Only six subjects completed the protocol to be included in analysis; therefore, it is possible that by chance, patients who were not predisposed to respond to MCS may have been selected. In addition, the subjects included in our final analysis had upper extremity pain, so we cannot make meaningful conclusions on the effect of MCS in the treatment of neuropathic facial pain, or other neuropathic pain syndromes. Although there were some technical differences between the two study sites, stimulation sites and parameters were the same so it is doubtful that these differences would have affected the results. Finally, our stimulation parameters may not have been optimal. While many groups used cycling stimulation for MCS20-22, two previous trials used continuous stimulation21,23.

It is possible that we committed a Type II error by not rejecting the null hypothesis that MCS did not confer benefit to people with specific neuropathic pain syndromes but we would suggest that this is unlikely to be the case. That is, there was no trend to suggest that we should reject the null hypothesis. Furthermore, to determine whether we committed a Type II error, additional people would need to be implanted. Given that there is not even a trend to suggest improvement, the ethics of doing so could be legitimately questioned. Finally, the consequence of a Type I error would be serious, whereas the consequence of a Type II error is not – this would simply put the onus on the community to find a convincing treatment.

In conclusion, we failed to find a meaningful therapeutic effect of MCS therapy in patients with refractory neuropathic upper extremity pain.

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DISCLOSURES

Julia Radic, Ian Beauprie, and Paula Chiasson do not have anything to disclose. Zelma Kiss has the following disclosures: AHFMR, Researcher, Salary grant; AIHS, Researcher, Salary grant. Robert Brownstone has the following disclosures: CIPHER, Researcher, Research support; CFI, Researcher, Research support; CRC, Researcher, Research support; NSRIT, Researcher, Research support.

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