

Award Number: W81XWH-11-1-0707

**TITLE:**

Cleveland Clinic Rehabilitation Research Program

**PRINCIPAL INVESTIGATOR:**

Vernon Lin, MD PhD

**CONTRACTING ORGANIZATION:** Cleveland Clinic

Cleveland, Ohio

**REPORT DATE:** December 2015

**TYPE OF REPORT:** Final report

**PREPARED FOR:** U.S Army Medical Research and Materiel Command

Fort Detrick, Maryland 21702-5012

**DISTRIBUTION STATEMENT:**

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# REPORT DOCUMENTATION PAGE

*Form Approved*  
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<b>1. REPORT DATE (DD-MM-YYYY)</b> December 2015		<b>2. REPORT TYPE</b> Final		<b>3. DATES COVERED (From - To)</b> 15 Sep, 2011 to 14 Sep, 2015	
<b>4. TITLE AND SUBTITLE</b>  <b>Cleveland Clinic Rehabilitation Research Program</b>				<b>5a. CONTRACT NUMBER</b>	
				<b>5b. GRANT NUMBER</b> W81XWH-11-1-0707	
				<b>5c. PROGRAM ELEMENT NUMBER</b>	
<b>6. AUTHOR(S)</b>  Vernon Lin, MD PhD  email: linv@ccf.org				<b>5d. PROJECT NUMBER</b>	
				<b>5e. TASK NUMBER</b>	
				<b>5f. WORK UNIT NUMBER</b>	
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b>  Cleveland Clinic Foundation 9500 Euclid Ave Cleveland, Ohio 44195				<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>	
<b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b>  U.S. Army Medical Research and Materiel Command Fort Detrick, Maryland 21702-5012				<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b>	
				<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b>	
<b>12. DISTRIBUTION / AVAILABILITY STATEMENT</b>  Approved for public release; distribution unlimited.					
<b>13. SUPPLEMENTARY NOTES</b>					
<b>14. ABSTRACT</b> <p><b>Study 1:</b> The penicillin-induced seizure animal model has been generated by acute focal intracortical injection of penicillin in the motor cortex of rats. The effects of functional magnetic stimulation (FMS) on penicillin-induced seizure have been investigated using behavioral recording and electroencephalographic (EEG) recording.</p> <p><b>Study 2:</b> The motor cortex (M1) and the corticospinal tracts (CST) will be directly modulated using brain stimulation to benefit rehabilitative outcomes of upper limb training in incomplete SCI (iSCI). Eight patients and three healthy control subjects have been enrolled. SCI patients receiving brain stimulation show greater benefit in upper limb function than those receiving rehabilitation alone.</p> <p><b>Study 3:</b> The efficacy of using FMS for respiratory muscle conditioning is evaluated in patients with multiple sclerosis (MS). Four patient with MS have been enrolled. A 6-week FMS conditioning of the expiratory muscles improved voluntary expiratory functions, indicating that FMS may be a potential noninvasive therapeutic technology for training respiratory muscles in patients with MS.</p> <p><b>Study 4:</b> This pilot study will evaluate the usefulness of FMS as a noninvasive method to stimulate the GI motility in individuals with non-neurological constipation. The PI worked with HRPO to modify the protocol (remove the sham treatment).</p>					
<b>15. SUBJECT TERMS</b> Nothing listed					
<b>16. SECURITY CLASSIFICATION OF:</b>			<b>17. LIMITATION OF ABSTRACT</b>	<b>18. NUMBER OF PAGES</b>	<b>19a. NAME OF RESPONSIBLE PERSON</b> USAMRMC
<b>a. REPORT</b> U	<b>b. ABSTRACT</b> U	<b>c. THIS PAGE</b> U			<b>19b. TELEPHONE NUMBER (include area code)</b>

**Standard Form 298 (Rev. 8-98)**  
Prescribed by ANSI Std. Z39.18

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## **Introduction**

Over the years the Functional Magnetic Stimulation (FMS) Laboratory has focused on studying the effectiveness of applying FMS for improving functions in patients with spinal cord injury and spinal cord disorders (SCI/D). Using animals and humans we have successfully demonstrated that FMS is effective for improving cough, bladder function, gastric emptying and colonic transits in SCI/D. This proposal consists of four pilot projects with major aims to determine the mechanisms behind some novel applications of FMS, such as for epilepsy control (study 1), and for improving upper limb function in SCI/D (study 2); and to explore additional clinical benefits of FMS, such as for improving constipation in general population (study 4), and for improving cough in patients with multiple sclerosis (study 3). The following paragraphs provide brief synopsis of these four pilot projects.

### **Study 1: Magnetic stimulation and epilepsy**

In this study, transcranial magnetic stimulation (TMS) will be tested for its efficacy in controlling seizure in a rat seizure model. In addition, a cell culture system will be used to test the mechanisms of the effects of magnetic stimulation on axonal outgrowth and the hypothesis that these responses are mediated by brain-derived neurotrophic factor (BDNF).

### **Study 2: Directing Neuroplasticity to Improve Rehabilitative Outcomes of the Upper Limb in Incomplete Quadriplegia**

In this study, the motor cortex (M1) and the corticospinal tracts (CST) will be directly modulated using brain stimulation to benefit rehabilitative outcomes of upper limb training in incomplete SCI (iSCI). Functional and structural mechanisms of such plasticity, we expect, will be demonstrable using Transcranial Magnetic Stimulation (TMS) and Diffusion Tensor Imaging (DTI) in patients.

### **Study 3: Expiratory Muscle Conditioning Using Functional Magnetic Stimulation for Patients with Multiple Sclerosis**

In this study, we will investigate the efficacy of using FMS technique for respiratory muscle conditioning in patients with multiple sclerosis; and will compare the results of the expired functions (volume, pressure, and flow) generated by using the FMS technique with data obtained from using the resistive expiratory muscle training (REMT) methodology.

### **Study 4: A prospective trial to study whether functional magnetic stimulation enhances gastrointestinal motility in patients with chronic constipation**

This pilot study will evaluate the usefulness of FMS as a noninvasive method to stimulate the GI motility in individuals with non-neurological constipation by adopting a 5-week conditioning protocol. This program may demonstrate that FMS can be an effective treatment modality for patients with constipation and thus promote health, independence, and quality of life.

## **Final Report**

*For the period of September 15, 2014 through September 30, 2015*

### **I. BASIC INFORMATION**

**SUBJECT:** Magnetic stimulation and epilepsy

**AWARD #:** W81XWH-11-1-0707

**CCF IACUC#:** 2010-0415 (expires March 6, 2014)

**SPONSOR:** Department of Defense (DoD) Telemedicine and Advanced  
Technology Research Center

**PRINCIPAL INVESTIGATOR:** Ching-Yi Lin PhD

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**REPORT DATE :** September 17, 2015

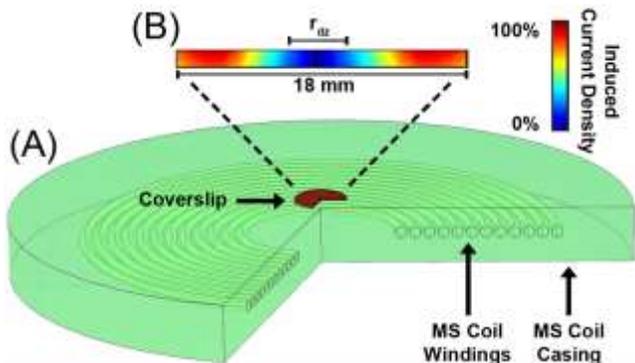
## II. STUDY PROGRESS

### A. Introduction: Study Progress in Relation to Investigational Plan

During previous 22 months of project, we have reached several milestones according to the time frame that has been proposed in the grant. For the Specific Aim 3, the penicillin-induced seizure animal model has been generated by acute focal intracortical injection of penicillin in the motor cortex of rats. The effects of transcranial magnetic stimulation (TMS) on penicillin-induced seizure have been investigated using behavioral recording and electroencephalographic (EEG) recording. The results obtained have been published to *Brain Research* (2014).

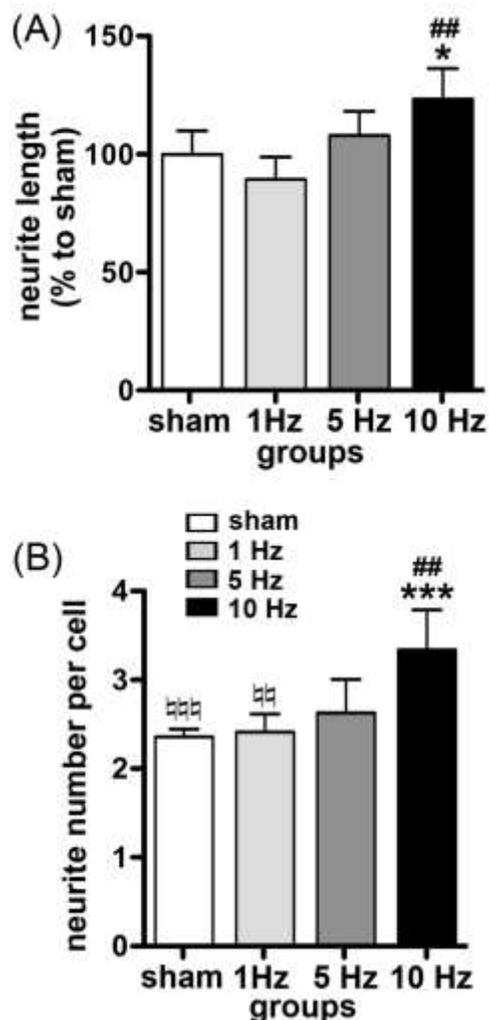
For the Specific Aim 1, the effects of MS on the level of BDNF; (ii) the roles of BDNF on the MS regulation of neurite outgrowth have been studied. The results have been submitted to *Journal of Neural Engineering*.

To test the hypotheses that MS-regulated neuronal activity can be translated to specific changes in neuronal arborization and thus regulate synaptic activity and function, we examine the effects of MS on neurite growth by Neuroscreen-1 (NS-1) cells over the pulse frequencies 1, 5 and 10 Hz. Plated NS-1 cells were exposed to MS twice per day for 3 days and then evaluated for length and number of neurites. We have demonstrated that MS at both 30% and 40% machine output (MO) dramatically affect neurite growth on growing axons but not on dendrites. MS effects were frequency-dependent, most evident in the bolstering of axonal outgrowth only seen at 10 Hz MS group. Using gridded coverslips in our MS protocol enabled us to distinguish two electromagnetic responses, where the center region of the coverslip received minimal MS-induced current density (zone 1) and the remaining area experienced maximal MS-induced current density (zone 2). We have demonstrated that MS-increased axonal growth was most evident in zone 1, but not in zone 2. Furthermore, we found that MS increased brain-derived neurotrophic factor (BDNF) expression and secretion in a frequency-dependent manner. Taken together, our results show that MS exerts distinct effects when different frequencies and intensities are applied on the neuritic compartments (axon versus dendrite) of NS-1 cells. These findings support the concept that MS increases BDNF expression and signaling, which sculpts axonal arborization and connectivity by which neuronal activity is regulated. Understanding the mechanism behind MS action is crucial in order to efficiently incorporate its use into potential therapeutic strategies.

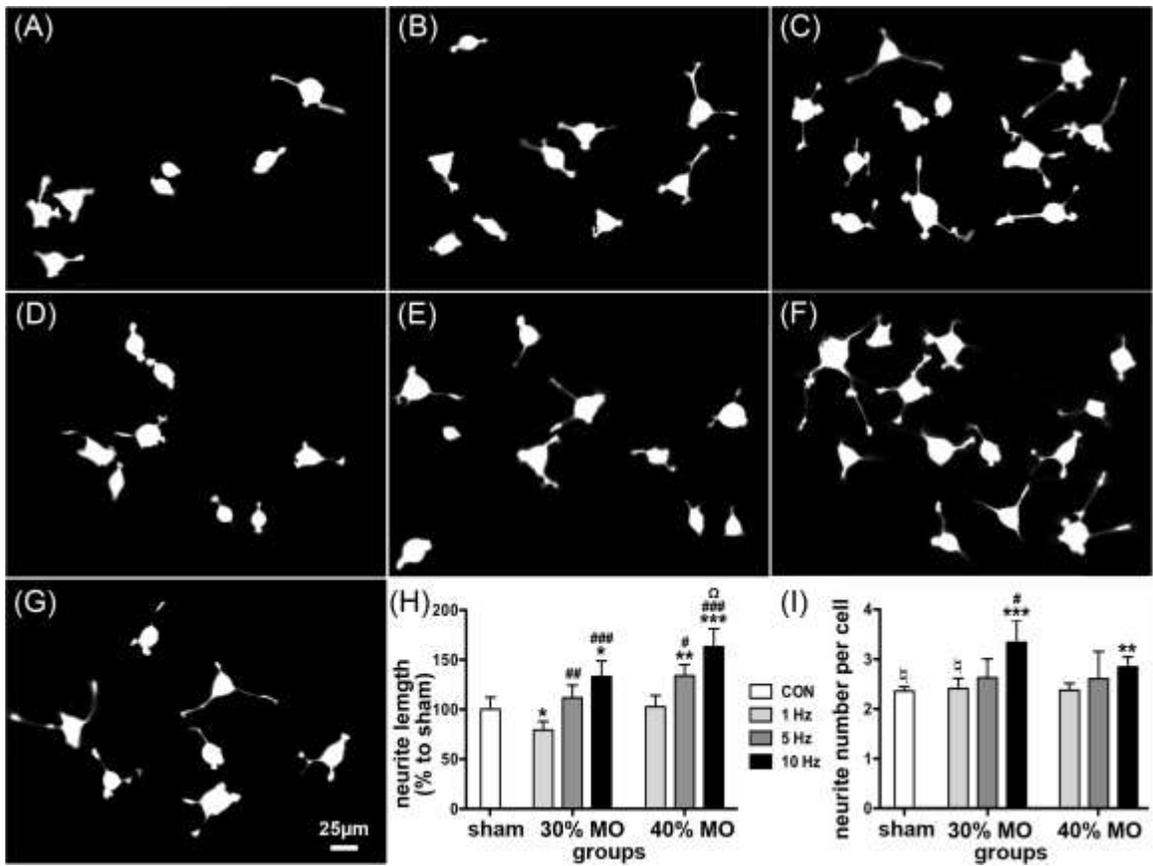


**Figure 1.** Model of experimental setup and MS-induced current density of cultured NS-1 cells. (A) A 3-D model of the experimental setup was constructed using the COMSOL Multiphysics<sup>®</sup> CAD software, including the geometries and relative positions of both MS coil and coverslip during stimulations. Defined by the electric current per unit area of a cross section, electric current density was estimated in the COMSOL<sup>®</sup> simulation in conjunction with fundamental electromagnetic

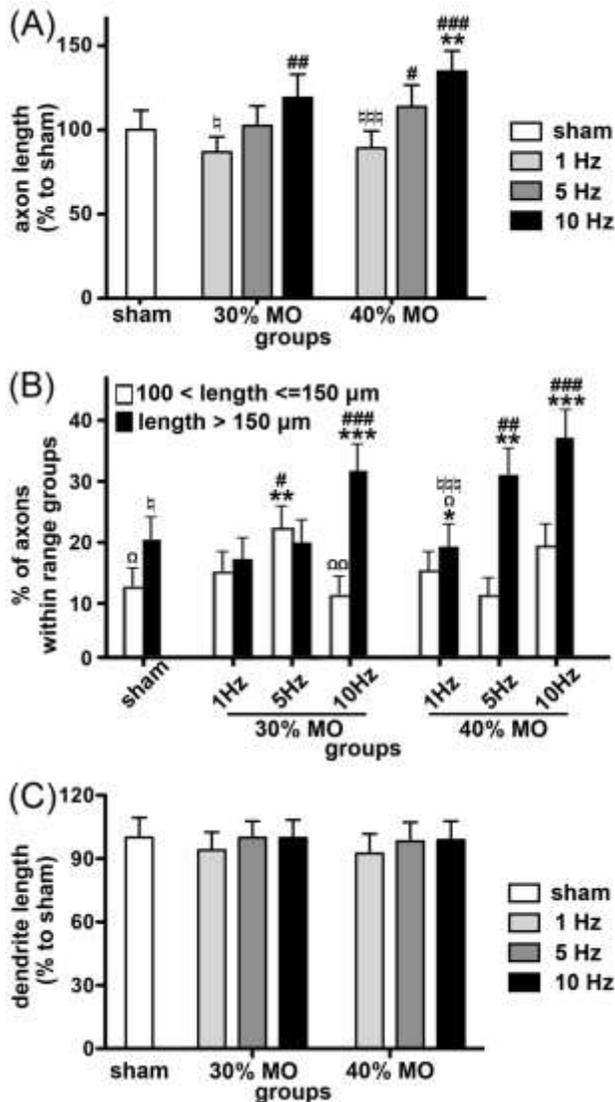
induction laws, Maxwell-Faraday Equations. (B) Due to the nature of circular MS coils, negligible current is induced from the center of the MS coil, described as the dead zone radius ( $r_{dz}$ ). The color bar represents the induced current density spread in the coverslip in  $A/mm^2$ , where the maximum ( $\sim 35$  mA) and minimum (within the dead zone radius) are colored red and blue, respectively.



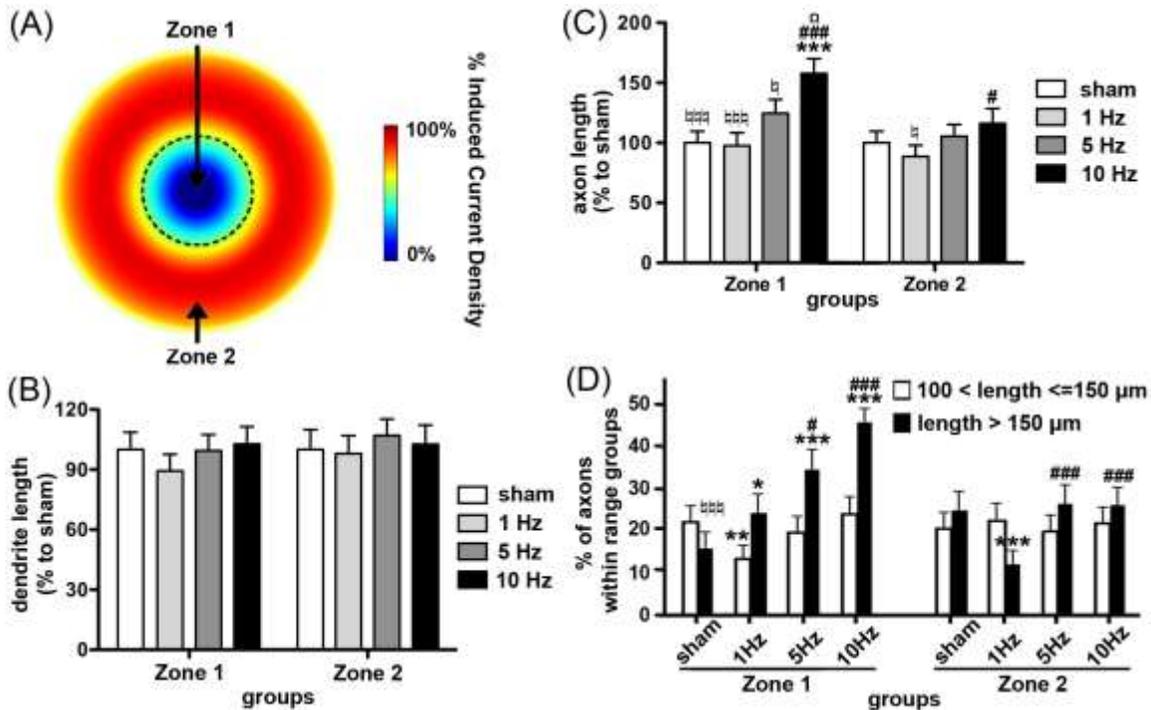
**Figure 2.** Neurite length and number were regulated by MS. NS-1 cells were cultured onto a collagen-coated coverslip. MS (1, 5 or 10 Hz) at 30% MO was applied starting from the second day, twice per day, for the next 3 days. The NS-1 cells were then fixed and stained for HCS CellMask Red. (A) NS-1 cells extended longer neurites, as compared to the sham group, after 3 days of treatment with 10 Hz MS, but not 1 Hz or 5 Hz MS. (B) The average number of neurites per NS-1 cell was significantly increased by 10 Hz MS. Bars show mean  $\pm$  SEM values. \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.005$  vs. sham MS group; #  $p < 0.05$ , ##  $p < 0.01$ , ###  $p < 0.005$  vs. 1 Hz MS group;  $\Omega\Omega$   $p < 0.01$ ,  $\Omega\Omega\Omega$   $p < 0.005$  vs. 5 Hz MS group;  $\natural$   $p < 0.05$ ,  $\natural\natural$   $p < 0.01$ ,  $\natural\natural\natural$   $p < 0.005$  vs. 10 Hz MS group; Two-way ANOVA with Bonferroni *post-hoc* tests.



**Figure 3.** Neurite growth was regulated by both MS frequency and intensity. Representative images show that neurite lengths and counts per NS-1 cell were regulated by MS, as compared to the sham MS group (G). NS-1 cells treated with 1 Hz MS (A, D) expressed shorter neurites, whereas 5 Hz MS (B, E) had negligible effects. 10 Hz MS (C, F) however, consistently expressed longer neurites and higher counts per cell. The graphs illustrate average neurite lengths (H) and neurite counts (I) for NS-1 cells treated with sham MS (sham) and all MS treatment groups (1, 5, or 10 Hz) at 30% MO or 40% MO. Bars showed mean  $\pm$  SEM values. \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.005$  vs. sham MS group; #  $p < 0.05$ , ##  $p < 0.01$  vs. 1 Hz MS group; †  $p < 0.05$  vs. 10 Hz MS group; Two-way ANOVA with Bonferroni *post-hoc* tests.



**Figure 4.** Degree of MS influence over axon and dendrite lengths. Neurite outgrowth measurements were broken down into axons and dendrites for further analysis. Graphs show either axon (A) or dendrite (C) lengths measured for NS-1 cells fixed with sham MS treatment (sham) or MS (1, 5 or 10 Hz) at 30% or 40% MO. (B) further illustrates any trends in the percentage of axons with specified greater length ranges for all test groups. Bars show mean  $\pm$  SEM values. \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.005$  vs. sham MS group; #  $p < 0.05$ , ##  $p < 0.01$ , ###  $p < 0.005$  vs. 1 Hz MS group; Ω  $p < 0.05$ , ΩΩ  $p < 0.01$  vs. 5 Hz MS group; †  $p < 0.05$ , †††  $p < 0.005$  vs. 10 Hz MS group; Two-way ANOVA with Bonferroni *post-hoc* tests.



**Figure 5.** MS intensity differentially increased axonal growth via double-zone analysis. The following results were derived from three representative experiments measuring neurite length and number in zones 1 and 2 of gridded coverslips after MS (30% MO) to either 1, 5, or 10 Hz at 3-d. (A) Schematic of the gridded coverslip divided into zone 1 and zone 2, where NS-1 cells received minimal (zone 1) and maximal (zone 2) MS-induced current densities, respectively. The gridded coverslips were categorized under zones 1 and 2 to distinguish regions either in or out  $r_{dz}$  and their respective electric field distribution in our experimental model. If we consider 100% induced current density as maximal MS efficiency, zone 1 NS-1 cells were subjected to <10% efficiency, whereas zone 2 was primarily subject to ~90% efficiency. Zone differential data are illustrated via dendrite (B) and axon (C) lengths and percentage of axons within specified greater lengths range groups (D). Bars show mean  $\pm$  SEM values. \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.005$  vs. sham MS group; #  $p < 0.05$ , ###  $p < 0.005$  vs. 1 Hz MS group;  $\Omega$   $p < 0.05$ ,  $\Omega\Omega$   $p < 0.01$  vs. 5 Hz MS group;  $\natural$   $p < 0.05$ ,  $\natural\natural\natural$   $p < 0.005$  vs. 10 Hz MS group; Two-way ANOVA with Bonferroni *post-hoc* tests.

## B. Investigators/Investigational Sites

The study is being conducted at only one site – Cleveland Clinic Foundation. There are no plans to add another site.

Investigational Site	Investigators
Cleveland Clinic Foundation 9500 Euclid Avenue, Cleveland, OH 44195	Ching-Yi Lin PhD

### **C. Number of Subjects / Animals**

N/A

### **D. Summary of Anticipated and Unanticipated Adverse Effects**

N/A

### **E. Investigational Devices**

N/A

### **F. Deviations from Investigational Plan**

No deviations from the investigational plan.

## **III. RISK ANALYSIS**

### **A. New Adverse Information and New Risk Analysis**

No new risks have been identified that would require a new risk analysis.

### **B. Publications and Presentations**

#### **Publications directly resulting from this award in 2013-2014**

\***Lin C-Y.**, K. Li, L. Franic, J. Gonzalez-Martinez, V.W. Lin, I. Najm, Y.-S. Lee. (2014). Frequency-dependent effects of contralateral repetitive transcranial magnetic stimulation on penicillin-induced seizures in rats. *Brain Research* **1581**: 103-116. PMID: 24937795. \* corresponding author.

\***Lin C-Y.**, W. J. Huang, K. Li, R. Swanson, B. Cheung, V. W. Lin, Y.-S. Lee. (2014). Differential Intensity-dependent Effects of Magnetic Stimulation on Axons and Dendrites in Neuroscreen-1 Cells. *Journal of Neural Engineering* (submitted). \* corresponding author.

#### **Publications in the general area of PI's research in 2013-2014**

Li, K., Y.-S. Lee, L. Franic, J. Gonzalez-Martinez, V. W. Lin, I. Najm, **C.-Y. Lin**. The anti-convulsive effects of Transcranial Magnetic Stimulation (TMS) on penicillin-induced seizures. 2012, LRI retreat, Ohio (Corporate College East), USA.

Li, K., Y.-S. Lee, L. Franic, J. Gonzalez-Martinez, V. W. Lin, I. Najm, **C.-Y. Lin**. The anti-convulsive effects of Transcranial Magnetic Stimulation (TMS) on penicillin-induced seizures. 2012, Cleveland Clinic Research Day, Ohio, USA.

- \***Lin, C.-Y.**, Y.-S. Lee, V. W. Lin, and J. Silver. (2012). Fibronectin inhibits chronic pain development after spinal cord injury. *Journal of Neurotrauma* **29**: 589-599. PMID: PMC3278810 \* corresponding author.
- Jiang, H.-H., O. N. Kokiko-Cochran, K. Li, **C.-Y., Lin**, V. W. Lin, M. Damaser, Y.-S. Lee. (2013). Bladder dysfunction changes from underactive to overactive after experimental traumatic brain injury. *Experimental Neurology*. **240**: 57-63. PMID: PMC3552010
- Lee, Y.-S., K. Li, L. Franic, J. Gonzalez-Martinez, V. W. Lin, I. Najm, \* **C.-Y. Lin**. 2013. Frequency-Dependent Effects of Transcranial Magnetic Stimulation on Penicillin-Induced Seizures in Rats. *Society for Neuroscience (submitted)*.
- Lee Y.-S., **C.-Y. Lin**, H.-H. Jiang, M. Depaul, M. Damaser, V. W. Lin, and J. Silver. (2013). Nerve regeneration restores supraspinal control of bladder function after complete spinal cord injury. *Journal of Neuroscience*. **33(26)**: 10591-10606. PMID: PMC3693049
- Lee Y.-S., A. Danandeh, J. Baratta, **C.-Y. Lin**, J. Yu, and R.T. Robertson. (2013). Neurotrophic factors rescue basal forebrain cholinergic neurons and improve performance on a spatial learning test. *Experimental Neurology*. **249**: 178-186. PMID: PMC3939719
- Park K.W., **C.-Y. Lin**, and Y.-S. Lee. (2014). Expression of Suppressor of Cytokine Signaling-3 (SOCS3) and its role in neuronal death after complete spinal cord injury. *Experimental Neurology* **261**: 65-75. NIHMS607759

#### IV. OTHER CHANGES

N/A

#### V. FUTURE PLANS

In order to move our research findings forward to clinical application, we have started to investigate the changes in brain oscillation after seizure induction/progression and/or magnetic stimulation.

## Final Report

*For the period of October 1, 2014 through September 8, 2015*

### I. BASIC INFORMATION

**AWARD NUMBER:** W81XWH-11-10707

**IRB NUMBER:** 11-823 (expiration date: 9/8/2015)

**STUDY NAME:** Directing Neuroplasticity to Improve Rehabilitative Outcomes of the Upper Limb in Incomplete Quadriplegia

**SPONSOR:** Department of Defense (DoD) Telemedicine and Advance Technology Research Center

**PI:** Ela Plow PhD PT  
9500 Euclid Ave  
CLEVELAND, OHIO 44106

**CONTACT PERSON:** Ela Plow PhD PT  
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E-MAIL: [plowe2@ccf.org](mailto:plowe2@ccf.org)

**REPORT DATE :** September 14, 2015

## I. FINAL STUDY REPORT

### A. Summary

The long-term objective of our study is to maximize the rehabilitative potential in spinal cord injury (SCI). We are addressing this goal by harnessing the maximal potential available for neuroplasticity in patients with SCI. Spinal cord injury (SCI) is important since it is a prominent cause of long-term disability in the United States, particularly in young adults and veterans. With approximately 12,000 new cases every year, prevalence has exceeded 253,000. Given the systemic morbidity, *costs of managing SCI disability disproportionately exceed prevalence*, resulting in a burden of \$1.5 to 4.7 million per patient. Further, considering that individuals have an estimated life expectancy of up to 40 more years after injury, and <12% return to work, each patient is estimated to accumulate indirect costs (losses in wages, benefits, and productivity) of an additional \$70.1k per year. This burden is particularly exaggerated in patients with injury to the cervical spinal cord that results in tetraplegia. Tetraplegia the most common form of SCI (~40.6%). It imposes significant burden because weakness of the upper limbs is more functionally limiting and associated with more serious co-morbidities.

While many interventions have been developed to mitigate weakness of the upper limbs, rehabilitation is the most common and cost-effective. Unfortunately, current interventions require a considerable amount of time to demonstrate measurable improvements. Such protracted programs are impractical given recent cuts in reimbursement coverage and the disproportionately high number of veterans who have survived but with greater disability from modern wars.

*Limited success of rehabilitation is speculated to be associated with maladaptive changes in the brain;* for instance, maps in the motor cortex (M1) devoted to less-affected muscles of weak limbs expand at the expense of maps devoted to the more affected muscles, limiting effects of training of the more affected segments. Recovery can be served by adaptive changes of maps in the M1 that potentially improve descending motor output to affected limbs.

Our *objective* has been to directly modulate plasticity in M1 using brain stimulation. Our *central hypothesis* is that noninvasive brain stimulation, called transcranial direct current stimulation (tDCS), when directed to maps of affected upper limb in M1 will generate functional advantage for rehabilitation. Thus, patients are assigned randomly to either the tDCS plus rehabilitation group or the sham plus rehabilitation group. We premise that rehabilitative outcomes of paralyzed upper limbs will improve in patients in both groups, but they will improve more significantly for patients in the tDCS plus rehabilitation group. The underlying mechanism would involve reorganization of maps; maps of affected muscles would expand at the expense of those of less affected, as demonstrated with noninvasive Transcranial Magnetic Stimulation (TMS) and an MRI method called Diffusion Tensor Imaging (DTI).

Towards our objective, we enrolled 8 patients and 3 healthy control subjects. All patients have completed study interventions and follow-up. Overall this study has shown tremendous progress since we met >80% of the anticipated number of patients. Results from all patients who completed the study after enrollment are listed here.

## B. Investigators/Investigational Sites

The study was being conducted at only one site – Cleveland Clinic Foundation. There are no plans to add another site.

Investigational Site	Investigators
Cleveland Clinic Foundation 9500 Euclid Avenue, Cleveland, OH 44195	Ela Plow PhD PT Frederick Frost MD Ken Sakaie PhD

## C. Number of Subjects

Eight SCI patients and three control subjects were enrolled.

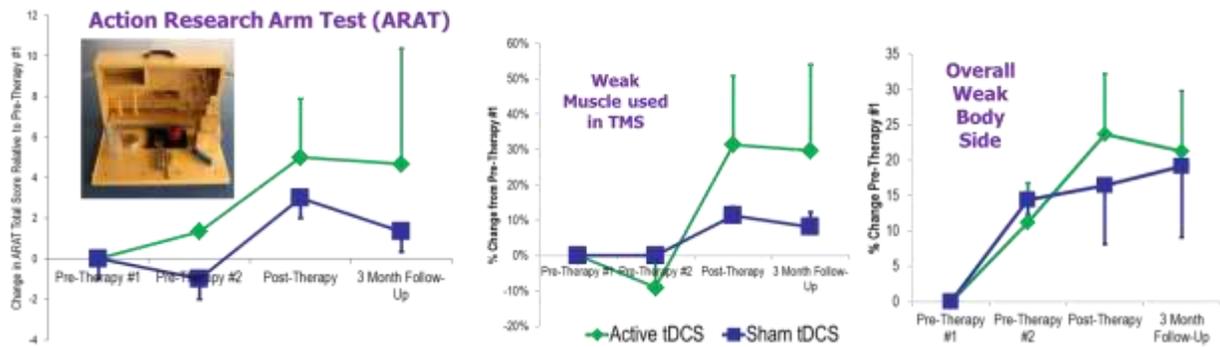
Ethnic/Racial Category	Sex/Gender		
	Females	Males	Total
Hispanic or Latino	0	0	0
American Indian/ Alaska Native	0	0	0
Asian	0	0	0
Native Hawaiian or Other Pacific Islander	0	0	0
African-American	0	1	1
White	0	10	10
<b>Ethnic/Racial Category Total</b>	0	11	11

## D. Investigational Devices

N/A

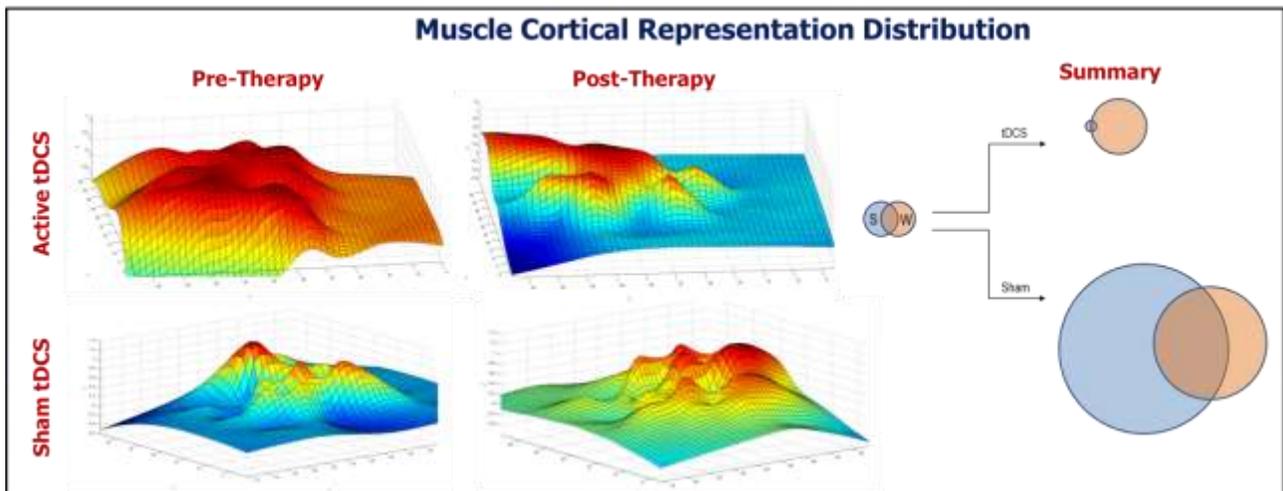
## E. Study Results

Patients in both groups showed functional improvements in the short time frame of 2 weeks, but patients receiving tDCS plus rehabilitation experienced more remarkable recovery. Muscle strength and function on grasp, grip and gross upper limb movements improved as shown in **Figure 1**. Patients in tDCS plus rehabilitation group showed a greater improvement in abilities of grasp and grip, as measured with the action research arm test (ARAT) (**Figure 1, Left**). In addition, the weak muscle that was targeted with tDCS had a greater improvement in average muscle strength (**Figure 1, Middle**). These improvements in muscle strength were also noted across the entire weak side of the body (**Figure 1, Right**). One important finding we noted was that in both intervention groups gains in functional improvement were maintained over time. Specifically, as shown in **Figure 1**, at the 3 month follow-up, patients maintained their level of functional recovery longitudinally. Therefore, in line with aim 1 of the study, we have found that patients with SCI receiving brain stimulation during rehabilitation show greater benefit in upper limb function than those receiving rehabilitation alone; these improvements are greater for more-affected muscles emphasized in training.



**Figure 1. Patients receiving tDCS and rehabilitation showed greater improvements in grip, grasp, pinch and muscle strength in comparison to patients receiving sham tDCS and rehabilitation.** In addition, regardless of group assignment, all patients demonstrated recovery both initially and longitudinally at 3 months following the end of intervention.

The improvement in tDCS group was paralleled by adaptive plasticity of maps of the more affected muscles. Our evaluation with transcranial magnetic stimulation (TMS) mapping showed maps in the brain devoted to more affected muscle and less affected muscle reorganize from pre- (**Figure 2**) to post-treatment (**Figure 2**). For the tDCS group, maps devoted to more affected weak muscle, which was trained extensively, enlarged (by 60%) and maps of the less affected (strong) muscle were reduced (by 70%). In contrast, both muscle maps grew proportionally in the sham tDCS group.

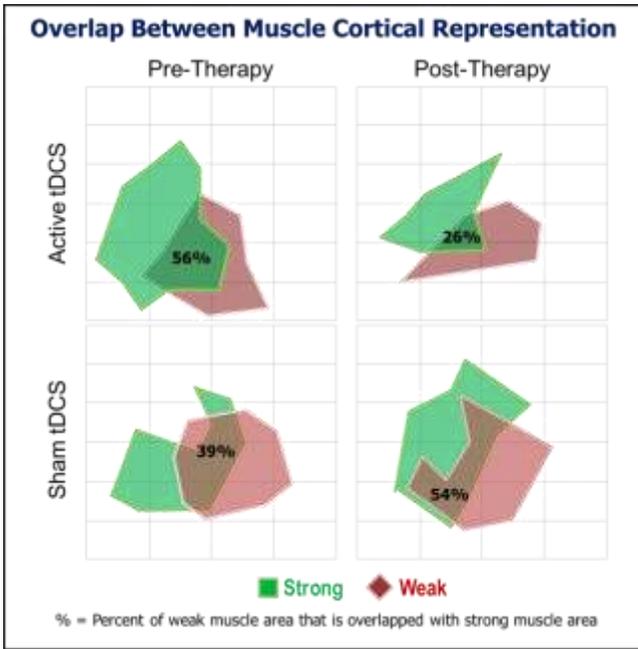


**Figure 2. Patients receiving tDCS and rehabilitation showed focal increases in more affected weak muscle cortical maps.** Increases in the area of weak muscle map area were approximately 60% in the tDCS group. In addition, for the tDCS group, we noted a 10 mm medial shift in less affected stronger muscles suggesting a loss of maladaptive plasticity.

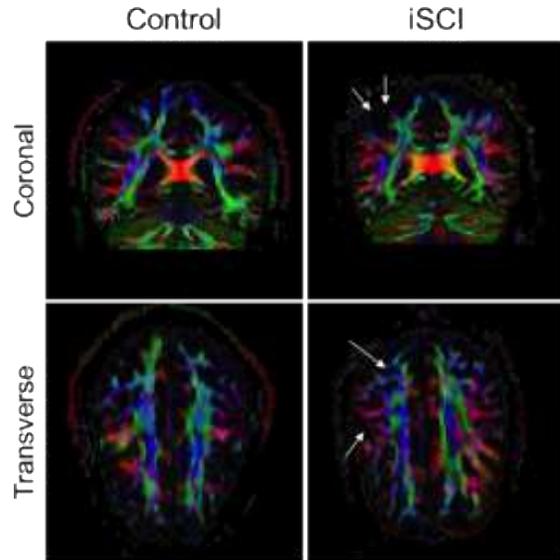
Beyond shifts in muscle maps, we also noted changes in the amount of overlap between the more affected weak muscle and less affected strong muscle following intervention in the groups. For the tDCS group, cortical representations of weaker muscles displayed less overall with strong muscles further suggesting a possible change in neuroplasticity favorable to recovery in these patients (**Figure 3**). Thus, in line with aim 2, it appears that functional improvements in the more affected

muscles may be explained by reorganization of their maps in the brain, which tend to enlarge and occupy M1 territory devoted to the less-affected muscle (**Figure 2 and Figure 3**).

Mechanistically, we found that the amount of degeneration in the brain influenced the cortical plasticity that facilitated recovery in patients with iSCI. DTI imaging (**Figure 4**) showed that changes in tracts emerging from motor cortex could predict the baseline impairment, degree of recovery and amount of cortical plasticity in our patients with SCI.

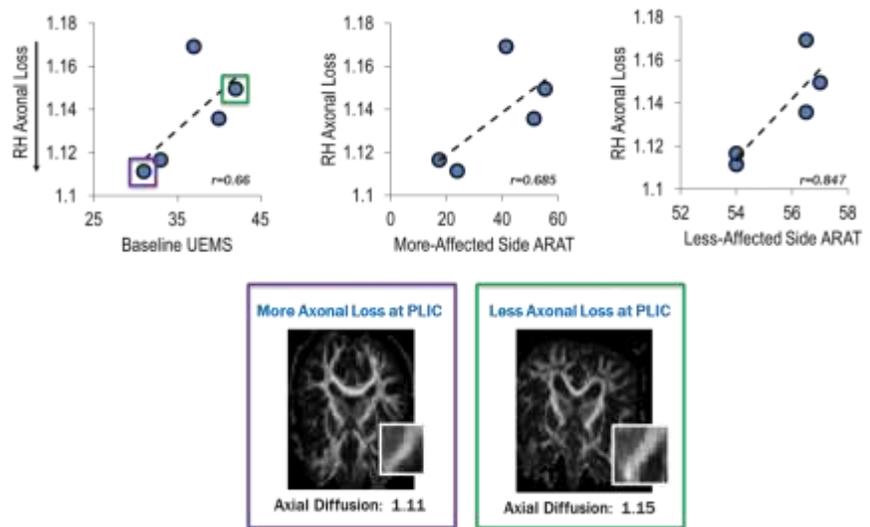


**Figure 3. Overlap between more affected and less affected muscles reduces following tDCS and rehabilitation in iSCI patients.**



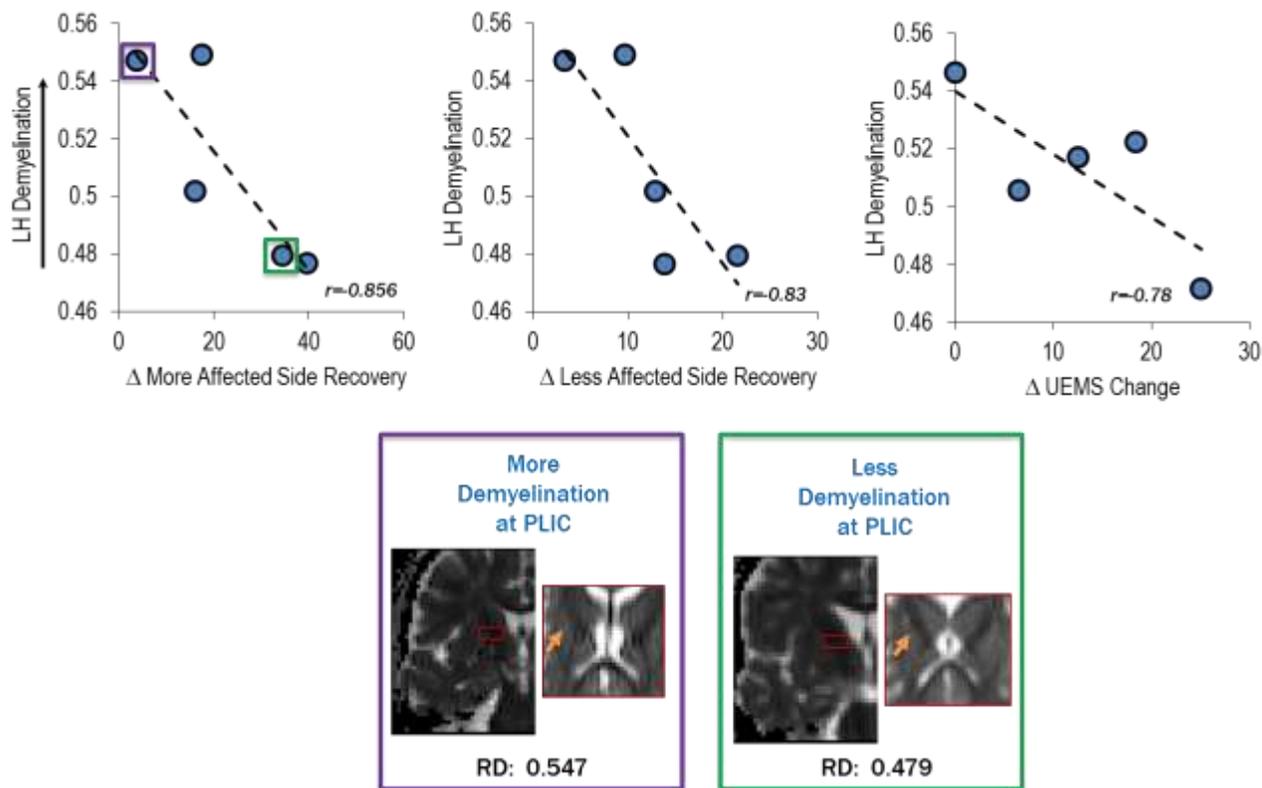
**Figure 4. DTI Imaging of the pathways in the brain of iSCI patients and controls. iSCI patients show increased levels of degeneration throughout the brain.**

In particular, we found that the level of axonal loss within the brain was positively related with baseline impairment (**Figure 5**). More simply, patients with more functional deficits were those who had more axonal loss in the brain.



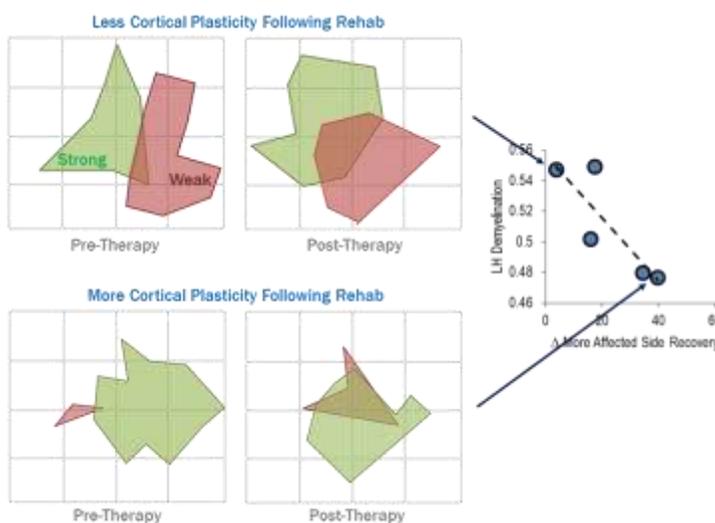
**Figure 5. iSCI patients with more functional impairments had increased axonal loss in the motor pathways in the brain.**

Further, the amount of demyelination in the brain related to the level of recovery in patients following the two week intervention (**Figure 6**). This suggested that regardless of group assignment, the baseline level of demyelination may have influenced our observed results in functional improvements.



**Figure 6.** iSCI patients with more functional gains from therapy had increased demyelination in the motor pathways in the brain.

Collectively we noted that patients with more cortical degeneration were also those that showed reduced cortical plasticity following treatment (**Figure 7**). Taken collectively with the results show in Figure 1, this suggests that the high variation we noted in functional improvements, particularly in the tDCS group, may have been influenced by the amount of degeneration in the patients prior to enrollment.



**Figure 7.** Patients with more degeneration of motor pathways in the brain were also those with reduced neuroplasticity and functional recovery.

In conclusion, we have found that tDCS paired with rehabilitation can reverse maladaptive plasticity in the brain and result in marked improvements in functional recovery in comparison to the sham group. However, baseline degeneration to pathways in the brain may limit the ability of therapeutic adjuncts, like tDCS, to function to the full extent. Therefore, future work should consider the amount of degeneration in the brain prior to use of therapeutic adjuncts.

#### **F. Summary of Anticipated and Unanticipated Adverse Effects**

N/A

#### **G. Deviations from Investigational Plan**

No deviations from the investigational plan.

### **III. RISK ANALYSIS**

#### **A. New Adverse Information and New Risk Analysis**

No new risks were identified that would require a new risk analysis. The study was registered as a pilot clinical trial. Use of tDCS, TMS and structural and functional MR imaging poses some risk, but strict adherence to inclusion-exclusion criteria, and protection against risks in conjunction with Clinical and Translational Science Association's Clinical Research Unit assistance has helped attenuate any safety threats.

#### **B. Publications and Presentations between October 1, 2014 to September 8, 2015**

##### **Presentations directly resulting from this award in time period**

1. Potter-Baker KA, Janini DP, Frost FS and **Plow EB** (2015) "Using the Brain to Prognosticate Baseline Function and Rehabilitation-related Recovery Potential in Quadriplegia". The Academy of Spinal Cord Injury Professionals (ASCIP), New Orleans, Louisiana. (podium)
2. Potter-Baker KA, Janini DP, Frost FS and **Plow EB** (2015) "Retraining the Brain to Restore Cortical Representation of Paralyzed Muscles in Quadriplegia". The Academy of Spinal Cord Injury Professionals (ASCIP), New Orleans, Louisiana. (poster)
3. Potter-Baker KA, Janini DP, Varnerin NM, Cunningham DA, Sankarasubramanian V, Sakaie KE, Frost FS and **Plow EB** (2015) "Enhancing cortical representational plasticity with non-invasive direct current stimulation to accelerate upper limb recovery in quadriplegia". The Society for Neuroscience, Chicago, Illinois. (podium)
4. Potter-Baker KA, Janini DP, Varnerin NM, Cunningham DA, Sankarasubramanian V, Sakaie KE, Frost FS and **Plow EB** (2015) "Enhancing cortical representational plasticity with non-invasive direct current stimulation to accelerate upper limb recovery in quadriplegia". American Society for Neurorehabilitation, Chicago, Illinois. (podium)

## Publications directly resulting from this award in time period

1. **Plow, E.B.**, Frost, F. S., Potter-Baker K, Chabra, P. (2014) “Testing brain stimulation’s potential to direct neuroplasticity and improve rehabilitation outcomes in spinal cord injury patients”. *Frontiers in Rehabilitation*

## Publications in the general area of PI’s research in brain stimulation, MRI and Rehabilitation in time period (in reverse chronological order)

1. Cunningham DA, Varnerin N, Machado A, Bonnett C, Janini D, Roelle S, Potter-Baker P, Sankarasubramanian V, Wang X, Yue G, **Plow EB**. Stimulation targeting higher motor areas in stroke rehabilitation: A proof-of-concept, randomized, double-blinded placebo-controlled study of effectiveness and underlying mechanisms. *Restorative Neurology and Neuroscience (in Press)*
2. A Game of Hide and Seek: Is it possible to recruit more patients for NIBS studies in stroke? Potter-Baker KA, Bonnett C, Chabra P, Roelle S, Varnerin N, Cunningham DA, Sankarasubramanian V, Pundik S, Conforto AB, Machado A, **Plow EB**. *Journal of Neurological Sciences (in Press)*
3. Gopalakrishnan R, Burgess RC, **Plow EB**, Floden D, Machado AG. A Magnetoencephalography study of multi-modal processing of pain anticipation in primary sensory cortices. *Neuroscience* (in press) Jul 22. pii: S0306-4522(15)00663-6. doi: 10.1016/j.neuroscience.2015.07.049.
4. Cunningham DA, Potter-Baker K, Knutson JS, Sankarasubramanian V, Machado AG, **Plow EB**. Tailoring brain stimulation to the nature of rehabilitative therapies in stroke- a conceptual framework based on their unique mechanisms of recovery. *Physical Medicine & Rehabilitation Clinics of North America 2015* (in Press)
5. Sankarasubramanian V, Roelle SM, Bonnett CE, Janini D, Varnerin NM, Cunningham DA, Sharma JS, Potter-Baker KA, Wang X, Yue GH, **Plow EB**. Reproducibility of transcranial magnetic stimulation metrics in the study of proximal upper limb muscles. *J Electromyogr Kinesiol*. 2015 Jun 14. pii: S1050-6411(15)00114-5. doi: 10.1016/j.jelekin.2015.05.006.
6. Page SJ, Cunningham, DA, **Plow, EB**, Blazak B. Neurorehabilitation and Non-Invasive Brain Stimulation: Two Great Tastes That Taste Great Together? *Archives of Physical Medicine and Rehabilitation (accepted)*
7. Cunningham DA, Machado A, Janini D, Varnerin N, Bonnett C, Yue GH, Jones SE, Lowe MJ, Beall E, Sakaie K, **Plow EB** (2014). Assessment of inter-hemispheric imbalance using imaging and noninvasive brain stimulation in patients with chronic stroke. *Archives of Physical Medicine and Rehabilitation*. Sep 3. doi: 10.1016/j.apmr.2014.07.419
8. Cooperrider J, Furmaga H, **Plow EB**, Park H-J, Chen Z, Kidd G, Baker K, Gale J, Machado A (2014). Chronic deep cerebellar stimulation promotes long-term potentiation, microstructural plasticity and reorganization of perilesional cortical representation in a rodent model. *Journal of Neuroscience*. 2;34 (27):9040-50. PMCID: PMC4078081.
9. **Plow EB**, Cunningham DA, Varnerin N, Machado A (2014). Rethinking stimulation of brain in stroke rehabilitation: Why higher-motor areas might be better alternatives for patients with greater impairments. *Neuroscientist*. Jun 20. pii: 1073858414537381.

10. Machado AG, Gopalakrishnan R, **Plow EB**, Burgess RC, Mosher JC (2014). A Magneto-encephalography Study of Visual Processing of Pain Anticipation. *Journal of Neurophysiology*. Jul 15;112(2):276-86. PMID: PMC4064417
11. **Plow EB**, Cattaneo Z, Carlson TA, Alvarez GA, Pascual-Leone A, Battelli LB (2014). The compensatory dynamic of inter-hemispheric interactions in visuospatial attention revealed using rTMS and fMRI. *Frontiers in Human Neuroscience* Apr 17;8:226. doi: 10.3389/fnhum.2014.00226. PMID: PMC4029023
12. **Plow EB**, Varnerin N, Cunningham DA, Janini D, Bonnett C, Wyant A, Hou J, Siemionow V, Wang X, Machado AG, Yue GH (2014). Age-related Weakness of Proximal Muscle studied with Motor Cortical Mapping: A TMS Study. *PlosOne*. Feb 21;9(2):e89371. doi: 10.1371/journal.pone.0089371. PMID: PMC3931763
13. **Plow EB** and Fehlings MG (2014). [invited] Hypoxic locomotor rehabilitation for incomplete spinal cord injury: Not an oxymoron. *Neurology* 82(2): 98-99.

#### **IV. OTHER CHANGES**

N/A

#### **V. FUTURE PLANS**

Based on the tremendous progress we made with the present award and our promising results, we are currently in the process of applying for continued funding to test generalizability in a larger, more diverse sample, identify factors predicting best response and determine the timing and retention of our potentially promising intervention. In addition, since the pilot study has now reached a close, we are also in the process of writing up several publications based on the results of the study.

**Final progress Report**  
*For the period of September 15, 2014 through September 29, 2015*

**I. BASIC INFORMATION**

**SUBJECT:** Expiratory Muscle Conditioning Using Functional Magnetic Stimulation (FMS) for Patients with Multiple Sclerosis

**AWARD #:** W81XWH-11-1-0707

**CCF IRB#:** 11-780 (expiration date: 9/29/2015)

**SPONSOR:** Department of Defense (DoD) Telemedicine and Advanced Technology Research Center

**PRINCIPAL INVESTIGATOR:** Vernon Lin MD PhD

**CONTACT PERSON:** Vernon Lin MD PhD  
PHONE: 1-216 445-7350  
FAX: (216) 636 0221  
E-MAIL: [linv@ccf.org](mailto:linv@ccf.org)

**REPORT DATE:** 09/17/2015

## II. STUDY PROGRESS

### A. Summary: Study Progress in Relation to Investigational Plan

The research study was reviewed and fully approved by Cleveland Clinic IRB. The expiration date is 9/29/2015. Xiaoming Zhang, PhD was hired in September 2012 as a co-investigator to manage the day-to-day activities of the project, participate in subject screening, data collection and analysis, manuscript and report preparation and dissemination of study results.

The MagPro R30 magnetic stimulator in July 2012 and the investigators completed training with the system. The team started to screen subjects with multiple sclerosis (MS) in September 2012. Inclusion criteria for this study are subjects with clinically defined MS whose baseline maximal expiratory pressure (MEP) values are between 50% and 70% of predicted. The medical records of approximately 200 MS patients were screened. The study has so far enrolled and completed data collection for 4 subjects.

### B. Investigators/Investigational Sites

The study is being conducted at only one site – Cleveland Clinic Foundation. There are no plans to add another site.

<b>Investigational Site</b>	<b>Investigators</b>
Cleveland Clinic Foundation 9500 Euclid Avenue, Cleveland, OH 44195	Vernon Lin MD PhD Francois Bethoux MD Vinoth Ranganathan MSE MBA Xiaoming Zhang PhD Ela Plow PhD PT

All subject records and documentation will be kept in the FMS Laboratory at Cleveland Clinic Foundation.

### C. Number of Subjects

Approximately 25 charts are screened each month to identify potential subjects. Four subjects have completed the protocol. The study has completed protocol for 3 subjects (two subjects in FMS arm and one subject in the RRMT arm) during the reporting period. One patient is still in the training protocol.

<b>Ethnic/Racial Category</b>	<b>Sex/Gender</b>		
	Females	Males	Total
Hispanic or Latino	0	0	0
American Indian/ Alaska Native	0	0	0
Asian	0	0	0
Native Hawaiian or Other Pacific Islander	0	0	0
African-American	0	0	0
White	2	2	4
<b>Ethnic/Racial Category Total</b>	2	2	4

#### D. Investigational Devices

N/A

#### E. Summary of Results

Three MS subjects with multiple sclerosis were recruited and completed the study protocol as of 10/31/14. Expiratory muscle activation was achieved by placing the center of the MC at T9 vertebral level. Baseline respiratory variables included maximal expiratory pressure (MEP), peak expiratory flow (PEF), and expiratory reserve volume (ERV). In this investigation, a six-week FMS conditioning protocol was performed. The stimulation intensity increased from 40% to 70%, progressively. The stimulation parameters were 20-Hz frequency, and 2-second stimulation duration. Pulmonary function tests were performed every two weeks. After 6 weeks of conditioning, the values for the main outcome measures (mean  $\pm$  standard error) were: MEP  $77 \pm 7.0$  cmH<sub>2</sub>O; PEF,  $6.0 \pm 2.2$  L/sec; and ERV,  $0.72 \pm 0.15$  L. These values corresponded to, 112%, 123%, and 120% of pre-FMS conditioning values, respectively. When FMS was discontinued for two weeks, these values had the following decrements (MEP, 3.5%, PEF, 15%, and ERV, 9.1%).

For the REMT group, the values for the main outcome measures, after 6-weeks of intervention, increased by 121% (MEP), 123% (PEF), and 120% (ERV) of pre-RRMT conditioning values, respectively. When REMT was discontinued for two weeks, these values had the following decrements (MEP, 3.5%, PEF, 9.4%, and ERV, 13%). A 6-week FMS conditioning of the expiratory muscles improved voluntary expiratory functions similar to traditional REMT, indicating that FMS may be a potential noninvasive therapeutic technology for training respiratory muscles in persons with multiple sclerosis.

<b>FMS Group (N = 2)</b>	<b>ERV (L)</b>	<b>PEF (L/sec)</b>	<b>MEP (cmH<sub>2</sub>O)</b>
<b>Baseline</b>	0.6	4.86	69
<b>2 weeks</b>	0.67	4.91	77
<b>4 weeks</b>	0.68	5.66	77.5
<b>6 weeks</b>	0.72	6.01	77
<b>post-test</b>	0.62	5.21	74.75

<b>REMT Group (N = 1)</b>	<b>ERV (L)</b>	<b>PEF (L/sec)</b>	<b>MEP (cmH<sub>2</sub>O)</b>
<b>Baseline</b>	0.23	2.57	66
<b>2 weeks</b>	0.2	2.3	77
<b>4 weeks</b>	0.17	3.05	77
<b>6 weeks</b>	0.31	3.74	80
<b>post</b>	0.27	3.39	78

#### F. Summary of Anticipated and Unanticipated Adverse Effects

N/A

#### G. Deviations from Investigational Plan

No deviations from the investigational plan.

### **III. RISK ANALYSIS**

#### **A. New Adverse Information and New Risk Analysis**

No new risks have been identified that would require a new risk analysis.

#### **B. Publications and Presentations**

Lin, VW and Zhang, XM. “Evaluating Functional Magnetic Stimulation’s Potential to Improve Expiratory Function in Multiple Sclerosis Patients”. *Frontiers in Rehabilitation*

Zhang XM, Huang HL, Ranganathan V, Lin VW, Expiratory muscle conditioning in patients with multiple sclerosis using functional magnetic stimulation, ASIA Meeting, San Antonio, May 2014

Zhang XM, Huang HL, Ranganathan V, Lin VW, Expiratory muscle conditioning in patients with multiple sclerosis using functional magnetic stimulation, AAPMR annual conference, Boston, October 2015

### **IV. OTHER CHANGES**

N/A

### **V. FUTURE PLANS**

Based on the progress we made with the present award and our promising results, we are in the process of writing up several publications based on the results of the study. In addition we are in the process of submitting to various funding sources regarding respiratory and additional clinical applications for using functional magnetic stimulation in patients with various neurodegenerative diseases.

**Final Progress Report**  
*For the period of September 15, 2014 through September 30, 2015*

**I. BASIC INFORMATION**

**AWARD NUMBER:** Proposal log number 10176004, Award Number W81XWH-11-10707

**IRB NUMBER:** 11-182 (expiration date: 04/07/2015)

**STUDY NAME:** A trial to compare the efficacy of Functional Magnetic Stimulation in enhancing GI motility in patients with constipation.

**SPONSOR:** Department of Defense (DoD) Telemedicine and Advance Technology Research Center

**INDICATIONS FOR USE:** Slow transit constipation

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**REPORT DATE :** September 18, 2015

## **II. STUDY PROGRESS**

### **A. Summary: Study Progress in Relation to Investigational Plan**

The study will evaluate the effects of functional magnetic stimulation (FMS) on colonic transit in non neurological constipated patients. Inclusion criteria for this study are subjects with clinically defined non-neurological constipation. Chronic functional constipation will be defined by the Rome II criteria and slow colonic transit will be documented by a Smart Pill which is wireless motility pill study. Eligible subjects will have a colonic transit time that is significantly longer than healthy subjects (>60hrs). The timing of treatment is a 5-week conditioning protocol. Sixteen patients are to be randomized to receive either the treatment or sham with a crossover design. Patients will be evaluated with the Smart Pill after receiving treatment. The site received IRB approval of the amendment (Protocol Version 3) on August 7, 2012 and approval from HRPO on 8/23/2012.

During the current reporting period, the study team was unable to recruit any subjects due to the following factors:

1. Patients do not want to be randomized as they need to set aside 10 weeks for treatment if they receive sham treatment. This is not feasible for working patients.
2. Smart Pill procedure prior to treatment was not budgeted for the study. It was to be billed to the patients insurance as it is considered standard of care. However, most insurance will not pay for it as they still continue to consider using SmartPill as investigational. As a result, most patients under going SmartPill procedure have to pay more than \$2000 as out of pocket expense which most patients cannot afford. Patients who pay this huge out-of pocket expense do not wish to be part of a study where they could be receiving sham treatment.
3. The enrollment rate has been difficult because most of the eligible patients live outside of Cleveland or do not have reliable transportation available to visit our research lab 5 days/week for 6-weeks.

Due to these issues, it has been very difficult to enroll subjects for this pilot study. The PI worked with HRPO to modify the protocol (remove the sham treatment). An amendment to this greater than minimal risk protocol was received by the HRPO on January 8, 2014. The amendment was approved by the Cleveland Clinic Institutional Review Board on December 13, 2013.

The amendment allows the following changes:

1. Reducing sample size from 16 to 8.
2. Removing the sham group.
3. Removing randomization.
4. Removing block design.
5. Cost of Smart Pills to be covered by institution.

The changes proposed in the amendment have been reviewed by the HRPO and found to be acceptable. The protocol amendment was approved (protocol version 4/dated 25 November 2013).

## **B. Investigators/Investigational Sites**

The study is being conducted at only one site – Cleveland Clinic Foundation. There are no plans to add another site. No changes were made to the study team during this reporting period.

All regulatory documentations are kept at the Cleveland Clinic Foundation, 9500 Euclid Ave, Cleveland Oh 44195.

## **C. Number of Subjects**

As of date, no patients have been enrolled or participated in the study. Since last approval, approximately 40 patients have been screened; 12 patients qualified; and 2 patients' insurance refused to cover the Smart Pill procedure. Unfortunately, after the amendment approval, neither of these two patients returned study coordinator's phone calls or emails updating and informing them that there was no out of pocket expense for the SmartPill.

## **D. Investigational Devices**

N/A

## **E. Summary of Results**

There are no results.

## **F. Summary of Anticipated and Unanticipated Adverse Effects**

### **III. RISK ANALYSIS**

#### **A. New Adverse Information and New Risk Analysis**

None

#### **B. Publications and Presentations**

None

### **IV. OTHER CHANGES**

Study was closed with our IRB on 5/21/15.

<b>Investigational Site</b>	<b>Investigators</b>
Cleveland Clinic Foundation, 9500 Euclid Avenue, Cleveland, Oh 44195	Massarat Zutshi,MD Xiaoming Zhang PhD Tracy Hull MD Brooke Gurland MD

## **V. FUTURE PLANS**

We have had numerous patients interested who have contacted us however they are not local and cannot remain in Cleveland for the required 5 weeks.

## **KEY RESEARCH AND ACCOMPLISHMENTS**

### Study 1: Magnetic stimulation and epilepsy

- The penicillin-induced seizure animal model has been generated by acute focal intracortical injection of penicillin in the motor cortex of rats.
- The effects of functional magnetic stimulation (FMS) on penicillin-induced seizure have been investigated using behavioral recording and electroencephalographic (EEG) recording.

### Study 2: Directing Neuroplasticity to Improve Rehabilitative Outcomes of the Upper Limb in Incomplete Quadriplegia

- After treatments, patients with SCI receiving brain stimulation show greater benefit in upper limb function than those receiving rehabilitation alone.
- It appears that these functional improvements in the more affected muscles may be explained by reorganization of their maps in the brain, which tend to enlarge and occupy M1 territory devoted to the less-affected muscle.

### Study 3: Expiratory Muscle Conditioning Using Functional Magnetic Stimulation for Patients with Multiple Sclerosis

- A 6-week FMS conditioning of the expiratory muscles improved voluntary expiratory functions, indicating that FMS may be a potential noninvasive therapeutic technology for training respiratory muscles in patients with Multiple Sclerosis.

### Study 4: A prospective trial to study whether functional magnetic stimulation enhances gastrointestinal motility in patients with chronic constipation

- The PI worked with HRPO to modify the protocol (remove the sham treatment). The amendment was approved by the Cleveland Clinic Institutional Review Board on December 13, 2013.

## REPORTABLE OUTCOMES:

- Lin C-Y.**, K. Li, L. Franic, J. Gonzalez-Martinez, V.W. Lin, I. Najm, Y.-S. Lee. (2014). Frequency-dependent effects of contralateral repetitive transcranial magnetic stimulation on penicillin-induced seizures in rats. *Brain Research* **1581**: 103-116. PMID: 24937795. \* corresponding author.
- Lin C-Y.**, W. J. Huang, K. Li, R. Swanson, B. Cheung, V. W. Lin, Y.-S. Lee. (2014). Differential Intensity-dependent Effects of Magnetic Stimulation on Axons and Dendrites in Neuroscreen-1 Cells. *Journal of Neural Engineering* (submitted). \* corresponding author.
- Plow EB** and Fehlings MG (2014). [invited] Hypoxic locomotor rehabilitation for incomplete spinal cord injury: Not an oxymoron. *Neurology* 82(2): 98-99.
- Plow, E.B.**, Frost, F. S., Potter-Baker K, Chabra, P. “Testing brain stimulation’s potential to direct neuroplasticity and improve rehabilitation outcomes in spinal cord injury patients”. *Frontiers in Rehabilitation*
- Lin, VW** and Zhang, XM. “Evaluating Functional Magnetic Stimulation’s Potential to Improve Expiratory Function in Multiple Sclerosis Patients”. *Frontiers in Rehabilitation*

## **Conclusion**

### **Study 1: Magnetic stimulation and epilepsy**

The findings support the concept that MS increases BDNF expression and signaling, which sculpts axonal arborization and connectivity by which neuronal activity is regulated. Understanding the mechanism behind MS action is crucial in order to efficiently incorporate its use into potential therapeutic strategies.

### **Study 2: Directing Neuroplasticity to Improve Rehabilitative Outcomes of the Upper Limb in Incomplete Quadriplegia**

The results indicate that patients with SCI receiving brain stimulation during rehabilitation show greater benefit in upper limb function than those receiving rehabilitation alone; these improvements are greater for more-affected muscles emphasized in training. It appears that these functional improvements in the more affected muscles may be explained by reorganization of their maps in the brain, which tend to enlarge and occupy M1 territory devoted to the less-affected muscle.

### **Study 3: Expiratory Muscle Conditioning Using Functional Magnetic Stimulation for Patients with Multiple Sclerosis**

A 6-week FMS conditioning of the expiratory muscles improved voluntary expiratory functions, indicating that FMS may be a potential noninvasive therapeutic technology for training respiratory muscles in persons with MS; and continual FMS may be required to maintain gains in pulmonary functions.

### **Study 4: A prospective trial to study whether functional magnetic stimulation enhances gastrointestinal motility in patients with chronic constipation**

During the current reporting period, the study team was unable to recruit any subjects. The PI worked with HRPO to modify the protocol (remove the sham treatment). An amendment to this greater than minimal risk protocol was received by the HRPO on January 8, 2014. The amendment was approved by the Cleveland Clinic Institutional Review Board on December 13, 2013.