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Single-lead Percutaneous Peripheral Nerve Stimulation for the Treatment of Hemiplegic Shoulder Pain: A Case Series

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Abstract

Objective—Previous studies demonstrated the efficacy of Intramuscular Nerve therapy with a 4-lead percutaneous, peripheral nerve stimulation system in reducing hemiplegic shoulder pain. This case series investigates the feasibility of a less complex, single-lead approach in reducing hemiplegic shoulder pain.

Methods—Eight participants received one percutaneous intramuscular lead in the hemiparetic deltoid muscle and were then treated 6-hours/day for three weeks. The primary outcome measure was the Brief Pain Inventory (Short-Form) Question 3 (BPI3), which queries worst pain in the last week on a 0–10 numeric rating scale. Secondary outcomes included pain interference (BPI9) and Medical Outcomes Study Short-Form 36 (SF-36v2). Primary and secondary outcomes were assessed at end of treatment and 1 and 4-wks after end of treatment.

Results—All participants tolerated the treatment well with 96% compliance. All leads remained infection free and were removed intact at end of treatment. On average, participants exhibited 70% reduction in BPI3 at end of treatment and 61% reduction at 4-weeks after end of treatment. All participants satisfied the success criterion of at least a 2-point reduction in BPI3 at end of treatment. Longitudinal analysis revealed significant treatment effect for BPI3 ($F=14.0$, $p<0.001$), BPI9 ($F=5.9$, $p<0.01$) and the bodily pain domain of SF-36v2 ($F=12.8$, $p<0.001$).

Conclusion—This case series demonstrates the feasibility of a single-lead, 3-week Intramuscular Nerve therapy for the treatment of chronic hemiplegic shoulder pain. Additional

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studies are needed to further demonstrate safety, efficacy and long-term benefit, define optimal prescriptive parameters and dose, and expand clinical indications.

Keywords

Electric Stimulation Therapy; Shoulder Pain; Peripheral Nerve Stimulation; hemiplegia; CVA; stroke

Introduction

Hemiplegic shoulder pain (HSP) is a major rehabilitation problem affecting up to 60% of moderately to severely impaired stroke survivors.¹ The onset of HSP appears to be related to the severity of motor impairment¹⁻⁴ and the associated increased risk of trauma to the glenohumeral joint and the surrounding soft tissue.^{5, 6} However, emerging data now suggest that as the pain experience becomes more chronic, HSP is associated with sensory abnormalities and may be mediated by central mechanisms, including central sensitization.⁷⁻¹⁰ Central sensitization may have an important role in chronic HSP as it does in other forms of chronic pain, which maintains the pain experience even when the causative factors are no longer active or are less severe.¹¹

Surface electrical stimulation of muscles surrounding the hemiparetic shoulder is recommended for the treatment of HSP.¹²⁻¹⁴ However, the clinical implementation of surface electrical stimulation has been difficult due to the pain of surface stimulation and the need for skilled personnel to place electrodes consistently and adjust stimulation parameters to maximize tolerance. Accordingly, Baker and Parker, the authors of the first clinical trial of surface electrical stimulation for post-stroke shoulder dysfunction, concluded “Until implanted electrode systems become available... long-term use of surface electrical stimulation can be managed by only a few patients... and their families.”(p. 1937)¹⁵

Intramuscular Nerve (IMNTM, SPR Therapeutics, Cleveland, OH) therapy is an investigational approach that delivers alternating current electrical stimulation to peripheral nerves via intramuscular leads placed percutaneously near the motor points of the muscles.¹⁶ The motor point is the location of entrance of the peripheral nerve innervating the muscle. Because the lead bypasses the cutaneous nociceptors there is no discomfort during stimulation. Since the leads are implanted percutaneously and stay in place for the duration of treatment, there is no need for daily identification of motor points and placement of electrodes. Our original 4-lead peripheral nerve stimulation (PNS) system, in which leads were placed near the motor points of upper trapezius (accessory nerve), the supraspinatus (suprascapular nerve), and posterior and middle deltoid (axillary nerve), required a subcutaneous tunneling procedure so that all four leads exited the skin in close proximity to one another to facilitate lead exit site care and connection to the stimulator. Participants received 6 hours of stimulation per day for 6 weeks and leads were removed at the end of treatment (EOT). The authors’ multicenter, randomized, controlled trial (RCT) demonstrated the safety and efficacy of IMN therapy using a 4-lead PNS System in substantially reducing HSP with maintenance of therapeutic effect for at least 1 year after EOT for a cohort of participants.¹⁶

The purpose of this case series of eight chronic stroke survivors with HSP was to explore the feasibility of a simplified approach where a single lead is used to stimulate the axillary nerve via motor points in the middle and posterior deltoid for 3 weeks. In our prior studies, the trapezius was stimulated to stabilize the scapula.¹⁶⁻¹⁹ However, since it now appears that chronic HSP is not related to glenohumeral biomechanics,⁷⁻¹⁰ the stimulation of the trapezius was deemed unnecessary. In our prior studies, strong contraction of the

supraspinatus was rarely observed.^{16–19} In contrast, the middle and posterior deltoids consistently exhibited strong muscle contractions. Thus, we postulated that the contraction of the middle and posterior deltoids were responsible for the observed therapeutic effects. Since the middle and posterior deltoids are adjacent to one another, we further postulated that a single lead positioned between the motor points of these muscles could activate both muscles simultaneously. The use of a single lead eliminates the need for subcutaneous tunneling, which substantially reduces the complexity, duration, and discomfort of the implantation procedure, and increases the likelihood of broader physician adoption. The authors' review of the prior RCT data¹⁶ also suggested that the duration of treatment could be reduced to 3 weeks; pain reduction at the end of 6 weeks of stimulation therapy was similar to pain reduction at mid-treatment (unpublished). Shortening the duration of treatment may improve patient compliance and reduce the risks of infection and retained lead fragments during lead removal.²⁰ The result of the first participant in this series was published as a case report.²¹ In order to evaluate the generalizability of results from this initial case to a larger population, data from all eight participants are now presented.

The primary objective of this case series was to assess the feasibility of IMN therapy using a single lead PNS system in reducing HSP. The secondary objective was to assess the impact of IMN therapy mediated pain reduction on quality of life.

Materials and Methods

Participants

The study protocol was approved by the local Institutional Review Board (IRB). A convenience sample of eight stroke survivors was recruited from the stroke rehabilitation ambulatory clinic of an academic medical center, and informed consent was obtained. Inclusion criteria included shoulder pain with or without glenohumeral subluxation; Brief Pain Inventory (Short-Form) Question 3 (BPI3) ≥ 4 ; age ≥ 21 -yrs; ≥ 6 -mo from stroke causing the shoulder pain; and upper limb hemiparesis. Exclusion criteria included evidence of joint or overlying skin infection of the affected limb; taking any opioid medications for shoulder pain or for any other chronic pain condition; intra-articular or subacromial corticosteroid injection or botulinum toxin injection to the affected shoulder in the previous 12 weeks; evidence of pre-stroke shoulder pathology; receiving outpatient physical or occupational therapy for shoulder pain; poorly controlled diabetes ($\text{HbA1c} > 6.5\%$); and an implanted electronic device.

Stimulation Devices

The Rehabilicare® NT2000 (Empi, Inc, St. Paul, MN), a portable external stimulator, was used to deliver the electrical stimulation. The NT2000 delivers a charge-balanced, biphasic waveform with current amplitude of 20 mA at 12 Hz. The intensity of stimulation was modulated by adjusting the pulse duration between 17 μs and 220 μs . The device has a built-in compliance monitor that records the total time of stimulator usage (the sum of each treatment session duration). When the clinician interlocks the programming module of the NT2000, the display shows the accumulated treatment time since the unit was last programmed.

The percutaneous lead is a fine-wire with an anchoring barb and electrode contact that was placed through the skin into muscle. The lead is a helical coil wound-up from a seven-strand, type 316L stainless steel wire insulated with perfluoroalkoxy, and is preloaded in a 20 gauge, insulated hypodermic needle introducer.^{20, 22}

Implantation Procedure

Monopolar needle intramuscular electrical stimulation was used to identify the optimal location and depth of the percutaneous lead. The skin overlying the deltoid muscle was cleaned with povidone-iodine topical antiseptic. Two 25-gauge 3 inch Teflon coated monopolar needle electrodes (Chalgren Enterprises, Inc., Gilroy, CA) were inserted perpendicular to the skin surface at the motor points of the middle and posterior deltoids, respectively.²³ Appropriate proximity to motor points was confirmed by stimulating each muscle individually through the electrodes and demonstrating strong contractions. If the electrode is not sufficiently near the motor point, even high levels of current will not produce strong muscle contractions. A third electrode was placed near the midpoint between the two identified motor points. The position and depth of the third electrode and pulse duration were iteratively adjusted until a strong contraction of both heads of the deltoid was achieved. For those with glenohumeral subluxation, the stimulation fully reduced the subluxation. The position and depth of the third electrode were noted, and all monopolar electrodes were removed.

The skin overlying the area identified by the third electrode was anesthetized with lidocaine, as needed. The insulated needle introducer (20 gauge, 5.5 inch, stainless steel, coated in parylene, Cadence, Inc., Staunton, VA) loaded with a percutaneous lead was then inserted to the depth indicated by the third needle electrode. After lead insertion, stimulation was delivered to verify proper position. Pressure was maintained at the skin surface to anchor the barb in the belly of the muscle, and the introducer was withdrawn, leaving the lead in place. Stimulation was delivered again to ensure proper placement. The site was covered with dry sterile dressing with overlying occlusive dressing. Prior to leaving the clinic, participants were instructed on the proper care of the lead exit site. Figure 1 shows the entire system.

Stimulation Therapy

Following a one week stabilization period,²⁴ the stimulator was connected to the lead, and parameters were programmed to stimulate the middle and posterior deltoids at 12 Hz and 20 mA. Pulse duration was adjusted, and the threshold for first muscle contraction was measured and compared to the threshold for first muscle contraction observed at the lead placement visit to assess the positional stability of the lead. Pulse duration was set to produce the strongest muscle contraction without discomfort to the participant. For participants with glenohumeral subluxation the stimulation fully reduced the subluxation without causing impingement. Participants were prescribed 6 hours of stimulation per day for 3 weeks, for a total treatment time of 126 hours. Participants were permitted to divide the 6-hour daily stimulation treatment into multiple, shorter sessions if desired. The participant manually turned on the stimulator for each prescribed treatment session. The stimulator automatically turned off after the prescribed treatment time. During stimulation therapy, the stimulator completes a cycle every 30 seconds consisting of 5 seconds to ramp up, 10 seconds at maximum programmed stimulation, 5 seconds to ramp down, and 10 seconds of no stimulation. The built-in compliance monitor recorded the total time of actual stimulator usage.

At the EOT, the threshold for first muscle contraction was measured again and compared to the threshold for first muscle contraction observed at the lead placement and start of treatment visits to assess the stability of the lead. The lead was removed by gently pulling on its exposed end. All participants underwent anterior-posterior and scapular-Y view radiographs of the shoulder for identification and surveillance of retained lead fragments.

Outcomes Assessment

The lead exit site was examined 48-hrs after implantation, at the start of stimulation, at the EOT and at 1 and 4-wks after lead removal.

The primary outcome measure, BPI3, was administered in the clinic at baseline, EOT and at 1 and 4-wks after EOT as well as via telephone at the end of the first and second week of stimulation therapy. BPI3 asks the participant to rate the worst pain in the last week on a 0–10 numeric rating scale, where 0 indicates “no pain” and 10 indicates “pain as bad as you can imagine.”²⁵

Secondary outcomes were administered in the clinic at baseline, EOT and at 1 and 4-wks after EOT. BPI9 is a measure of pain-related quality of life (QOL) as it assesses the degree to which pain interferes with 7 domains, including general activity, mood, walking ability, normal work, relations with other people, sleep and enjoyment of life during the last week on a 0–10 numeric rating scale, where 0 indicates “does not interfere” and 10 indicates “completely interferes.”²⁵ The BPI9 score is the average of the scores for the seven domains. The Medical Outcomes Study Short-Form 36 (SF-36v2) assesses health related QOL within eight domains: physical function, role physical, bodily pain, general health, vitality, social function, role emotional and mental health.²⁶ The Patient Global Impression of Change (PGIC) scale asks participants to rate the change in their QOL since they enrolled in the study as a result of the stimulation therapy on a 7-point scale from “very much worse” to “very much improved.”²⁷ Medication usage was recorded at baseline, EOT, and telephone contacts. Adverse events were recorded during each study visit and telephone contacts.

The interventional protocol ended at 4-wks after EOT. However, all participants were followed per usual clinical care beyond the formal study period. Thus, BPI3 data at 12-wks after EOT were also available for analysis. Additional IRB approval was obtained to report these data.

Analysis

Treatment success was defined as a minimum of 2-point reduction²⁸ in BPI3 at EOT. Longitudinal outcomes data were analyzed at EOT and follow-up visits via repeated measures analysis of variance (ANOVA). If the analysis for a particular outcome measure resulted in a significant time effect ($p < 0.05$), post-hoc pair-wise analyses with Bonferroni correction were carried out to identify the location of significant changes relative to baseline. BPI3 data were analyzed in two ways. The first approach included data from only the formal protocol, which included data up to 4-wks after EOT. The second approach included BPI3 data collected per usual care at 12-wks after EOT.

Results

Eight chronic stroke survivors enrolled in the study. Their demographic and stroke characteristics are shown in Table 1. All leads were placed without complications. Durations of implantation procedures were between 15 and 29 minutes for three participants, between 30 and 44 minutes for four participants and between 44 and 60 minutes for one participant. Participants were prescribed 126 hours of stimulation. The compliance monitor recorded an average of 121 ± 3.8 (SD) hours of stimulation per participant for an average compliance rate of 96% (range 92–100%). Contraction motor thresholds were consistent throughout the study indicating that leads remained stable. Post-explant radiographs revealed no evidence of retained fragments after lead removal.

Four participants experienced mild erythema and or skin irritation at the lead site or bandage site, which resolved without intervention. Three participants exhibited a small granuloma at the lead exit site, which resolved with little or no intervention after lead removal. One participant developed a blister along the superior margin of the bandage, which resolved by the end of the 4-wk follow-up.

Individual BPI3 data are shown in Table 2. Averaged group data are shown in Figure 2. Based on the 2-point pain reduction criterion at EOT, all eight participants experienced treatment success. At 4-wks after EOT, seven of eight participants maintained at least a 2-point reduction relative to baseline. The inclusion of the 12-wk clinical data reduced the success rate to 6/8 participants. Thus, for 2 of 8 participants, pain returned within 12-wks of EOT. On average, participants experienced 70%, 61% and 63% pain reduction at EOT and at 4 and 12-wks after EOT, respectively. Longitudinal analysis yielded a significant time effect ($F=14.0$, $p<0.001$). Post-hoc pair-wise comparisons with Bonferroni correction yielded significant pain reduction at all follow-up assessments relative to baseline. The inclusion of 12-wk clinical data yielded similar longitudinal ($F=11.0$, $p<0.001$) and post-hoc pair-wise comparisons results.

Results of longitudinal analyses of secondary measures are shown in Table 3. There was a significant time effect for average BPI9. Post-hoc analysis detected significant improvement at one week after EOT. Significant time effects were seen for all BPI9 domains except for relations with other people. The strongest effect was seen in the sleep domain where post-hoc analyses detected significant improvements at EOT and at one week after EOT. Significant time effects were seen for the bodily pain, role emotional and mental health domains of SF-36v2. However, post-hoc analyses detected significant improvements only in the bodily pain domain, which occurred at all follow-up periods. Patient Global Impression of Change data are shown in Table 4. At EOT five participants reported that their pain was “much improved” or “very much improved”. The results were similar at four weeks after EOT.

At baseline, six participants were taking non-steroidal anti-inflammatory drugs (NSAIDs) and seven were taking non-opioid, non-NSAID pain medications. During the first and second week treatment phase telephone calls, no participants reported taking pain medications for their shoulder pain. At the EOT, one participant was taking acetaminophen for shoulder pain.

Discussion

This case series describes the first eight stroke survivors treated with IMN therapy using a single-lead, percutaneous PNS system for HSP. All participants experienced clinically important pain reduction and in 6 of 8 cases, pain reduction was maintained at 12-wks after EOT. Results from secondary measures suggest that pain reduction translates to improvement in QOL.

The results of this single-lead case series are comparable to the results using the 4-lead approach. In our prior RCT of the 4-lead system, participants experienced an average of 60% and 58% reduction in BPI3 by the EOT and at 12-wks after EOT, respectively.¹⁶ Although participants received only 3 weeks of stimulation, this case series yielded similar results with average pain reduction at EOT and 12-wks after EOT of 70% and 63%, respectively.

The significant reduction in shoulder pain translated to significant improvement in pain-related QOL. By the EOT, participants exhibited an average reduction in pain interference (BPI9) of 52%, which is comparable to the 57% reduction in the 4-lead RCT. BPI9 results

were corroborated by SF-36v2 results, which showed significant improvements in the Bodily Pain domain. This is consistent with the 4-lead approach case-series by Renzenbrink and associates, which showed similar improvements in the Bodily Pain component of SF-36.¹⁸

An important difference between the present series and prior studies of IMN therapy is that participants without glenohumeral subluxation were included. All three participants without subluxation experienced excellent pain reduction with average reduction in BPI3 of 76% at EOT. Another important observation is that five participants exhibited clinical evidence of subacromial bursitis or supraspinatus impingement based on positive Neer's sign and test.^{29, 30} These participants exhibited an average reduction in BPI3 of 74% at EOT. These observations suggest that IMN therapy may be appropriate for HSP without glenohumeral subluxation. They further suggest that IMN therapy may be appropriate for non-stroke patients with shoulder pain due to subacromial bursitis or supraspinatus impingement.

When IMN therapy was initially developed it was believed that its therapeutic benefit was mediated by reduction of glenohumeral subluxation. However, our prior RCT¹⁶ did not demonstrate any clinical improvements in glenohumeral subluxation and in the present series, the three participants without subluxation experienced substantial reduction in shoulder pain. Although pain relief from improvements in the stability of the glenohumeral joint cannot be ruled out, these observations suggest that electrical stimulation mediated sensory neuromodulation has a mechanistic role. As proposed by Melzak and Wall, stimulation of low-threshold myelinated primary afferents may decrease the response of the dorsal horn neurons to unmyelinated nociceptors.³¹ However, it is unclear if this mechanism will lead to maintenance of effect substantially beyond treatment, as observed in this study.³²

An additional hypothesis is that muscle contraction mediated sensory modulation results in sustained functional reorganization or neuroplasticity of the central nervous system. There is growing evidence that chronic pain, in general, is associated with changes at the spinal and supraspinal level that maintain the pain experience even when the causative factors are no longer active or are less active.¹¹ This is consistent with emerging data that suggest that chronic HSP is associated with sensory abnormalities and may also be mediated by central mechanisms, including central sensitization.⁷⁻¹⁰ Thus, it is possible that IMN therapy partially reverses this maladaptive process. Exploration of the effects of sensory modulation on spinal and supraspinal neuroplasticity may provide insights on further refinement of IMN therapy for the treatment of chronic pain in general.

The simplification of IMN therapy increases the likelihood of its clinical adoption. With the requirement of only a single lead percutaneously placed in muscle, the technically challenging tunneling procedure of the 4-lead approach is not needed. This reduces the time required for implantation and patient discomfort. Treatment duration limited to 3-wks reduces the risk of infection and retained lead fragments.²⁰ Thus, the revised approach also has the potential for an improved safety profile over the prior 4-lead approach.

IMN therapy using a single-lead PNS system is a promising new tool in the treatment armamentarium for HSP. Available treatment options include noninvasive approaches such as oral medications, physical and occupational therapies, and modalities; minimally invasive approaches such as corticosteroid and botulinum toxin injections;³³⁻³⁵ and surgery.^{36, 37} However, the efficacy of these approaches has not been established,³⁸ and in fact, a recent review of RCTs concluded that IMN therapy using a PNS system was the only treatment option for HSP shown to be effective at 3-mo after EOT.³⁹ Additional studies are needed to

determine when, in the continuum of care for HSP, IMN therapy should be offered to patients.

Considerations for future studies that were not addressed in this case series include the following. As an open-label case-series, placebo effect, assessor bias and natural recovery cannot be ruled out. In order to demonstrate efficacy, blinded RCTs are needed. Success criterion defined only at EOT and follow-up period limited to 12-wks after EOT do not provide sufficient data for fully assessing the clinical importance of the intervention. Controlled trials that follow participants for at least 6-mo after EOT with success criterion defined as minimum of 2-pt reduction at EOT that is maintained throughout the follow-up period will provide a more robust assessment of clinical relevance. It is uncertain whether 6-hrs/day of stimulation for 3 weeks are the optimal treatment intensity and duration, respectively. Dose response trials would allow optimization of enduring treatment outcomes. The characteristics of patients most likely to experience long-term benefit from the therapy are not known. Clinical trials should compare specific patient populations to assess the differential effects of IMN therapy. As noted above, the mechanism of IMN therapy is not known, and understanding the mechanism(s) of action will help guide the refinement and optimization of the treatment paradigm. Finally, 2 of 8 participants experienced recurrence of HSP. Thus, it is unlikely that all patients who initially experience pain reduction will maintain this reduction in the long-term. A longer duration of percutaneous stimulation, a redosing paradigm or a long-term implant may be necessary for this population.

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References

1. Wanklyn P, Forster A, Young J. Hemiplegic shoulder pain (HSP): natural history and investigation of associated features. *Disabil Rehabil.* 1996; 18(10):497–501. [PubMed: 8902421]
2. Gamble GE, Barberan E, Laasch HU, Bowsher D, Tyrrell PJ, Jones AK. Poststroke shoulder pain: a prospective study of the association and risk factors in 152 patients from a consecutive cohort of 205 patients presenting with stroke. *Eur J Pain.* 2002; 6(6):467–74. [PubMed: 12413435]
3. Lindgren I, Jonsson AC, Norrving B, Lindgren A. Shoulder pain after stroke: a prospective population-based study. *Stroke.* 2007; 38(2):343–8. [PubMed: 17185637]
4. Ratnasabapathy Y, Broad J, Baskett J, Pledger M, Marshall J, Bonita R. Shoulder pain in people with a stroke: a population-based study. *Clin Rehabil.* 2003; 17(3):304–11. [PubMed: 12735538]
5. Huang YC, Liang PJ, Pong YP, Leong CP, Tseng CH. Physical findings and sonography of hemiplegic shoulder in patients after acute stroke during rehabilitation. *J Rehabil Med.* 2010; 42(1): 21–6. [PubMed: 20111840]
6. Pong YP, Wang LY, Wang L, Leong CP, Huang YC, Chen YK. Sonography of the shoulder in hemiplegic patients undergoing rehabilitation after a recent stroke. *J Clin Ultrasound.* 2009; 37(4): 199–205. [PubMed: 19253350]
7. Roosink M, Buitenweg JR, Renzenbrink GJ, van Dongen RTM, Geurts AC, IJzerman MJ. Altered cortical somatosensory processing in chronic stroke: a relationship with post-stroke shoulder pain. *Neurorehabil.* 2011; 28:331–44.
8. Roosink M, Renzenbrink GJ, Buitenweg JR, van Dongen RT, Geurts AC, IJzerman MJ. Somatosensory symptoms and signs and conditioned pain modulation in chronic post-stroke shoulder pain. *J Pain.* 2011; 12(4):476–85. [PubMed: 21167792]
9. Roosink M, Renzenbrink GJ, Buitenweg JR, Van Dongen RTM, Geurts AC, IJzerman MJ. Persistent shoulder pain in the first 6 months after stroke: Results of a prospective cohort study. *Arch Phys Med Rehabil.* 2011; 92:1139–45. [PubMed: 21704795]

10. Roosink M, van Dongen RT, Renzenbrink GJ, Ijzerman MJ. Classifying post-stroke shoulder pain: can the DN4 be helpful? *Eur J Pain*. 2011; 15(1):99–102. [PubMed: 20547465]
11. Petersen-Felix S, Curatolo M. Neuroplasticity--an important factor in acute and chronic pain. *Swiss Med Wkly*. 2002; 132(21–22):273–8. [PubMed: 12362284]
12. Bates B, Choi JY, Duncan PW, Glasberg JJ, Graham GD, Katz RC, et al. Veterans Affairs/Department of Defense Clinical Practice Guideline for the Management of Adult Stroke Rehabilitation Care: executive summary. *Stroke*. 2005; 36(9):2049–56. [PubMed: 16120847]
13. Khadiolkar A, Phillips K, Jean N, Lamothe C, Milne S, Sarnecka J. Ottawa panel evidence-based clinical practice guidelines for post-stroke rehabilitation. *Top Stroke Rehabil*. 2006; 13(2):1–269. [PubMed: 16939981]
14. Teasell RW, Foley NC, Bhogal SK, Speechley MR. An evidence-based review of stroke rehabilitation. *Top Stroke Rehabil*. 2003; 10(1):29–58. [PubMed: 12970830]
15. Baker LL, Parker K. Neuromuscular electrical stimulation of the muscles surrounding the shoulder. *Phys Ther*. 1986; 66(12):1930–7. [PubMed: 3491372]
16. Chae J, Yu DT, Walker ME, Kirsteins A, Elovic EP, Flanagan SR, et al. Intramuscular electrical stimulation for hemiplegic shoulder pain: a 12-month follow-up of a multiple-center, randomized clinical trial. *Am J Phys Med Rehabil*. 2005; 84(11):832–42. [PubMed: 16244520]
17. Yu D, Chae J, Walker M, Hart R. Muscular factors preventing inferior subluxation of the shoulder in hemiplegia (abstract). *Arch Phys Med Rehabil*. 1998; 79:1151.
18. Renzenbrink GJ, Ijzerman M. Percutaneous neuromuscular electrical stimulation (P-NMES) for treating shoulder pain in chronic hemiplegia. Effects on shoulder pain and quality of life *Clin Rehabil*. 2004; 18(4):359–65.
19. Yu DT, Chae J, Walker ME, Fang ZP. Percutaneous intramuscular neuromuscular electric stimulation for the treatment of shoulder subluxation and pain in patients with chronic hemiplegia: a pilot study. *Arch Phys Med Rehabil*. 2001; 82(1):20–5. [PubMed: 11239281]
20. Knutson JS, Naples GG, Peckham PH, Keith WM. Electrode fracture rate and occurrences of infection and granuloma associated with percutaneous intramuscular electrodes in upper-limb functional electrical stimulation application. *J Rehabil Res Dev*. 2003; 39:671–84. [PubMed: 17943669]
21. Wilson RD, Bennett ME, Lechman TE, Stager KW, Chae J. Single-lead percutaneous peripheral nerve stimulation for the treatment of hemiplegic shoulder pain: A case-report. *Arch Phys Med Rehabil*. 2011; 92:837–40. [PubMed: 21530732]
22. Memberg WD, Peckham PH, Thorpe GB, Keith MW, Kicher TP. An analysis of the reliability of percutaneous intramuscular electrodes in upper extremity FNS applications. *IEEE Trans Rehabil Eng*. 1993; 1:126–32.
23. Lee, HJ.; DeLisa, JA. Deltoid. In: Lee, HJ.; deLisa, JA., editors. *Surface Anatomy for Clinical Needle Electromyography*. New York: Demos Medical Publishing; 2000. p. 72
24. Bhadra N, Mortimer JT. Extraction forces and tissue changes during explant of CWRU-type intramuscular electrodes from rat gastrocnemius. *Ann Biomed Eng*. 1997; 25(6):1017–25. [PubMed: 9395047]
25. Cleeland CS, Ryan KM. Pain assessment: global use of the Brief Pain Inventory. *Ann Acad Med Singapore*. 1994; 23(2):129–38. [PubMed: 8080219]
26. Anderson C, Laubscher S, Burns R. Validation of the Short Form 36 (SF-36) health survey questionnaire among stroke patients. *Stroke*. 1996; 27(10):1812–6. [PubMed: 8841336]
27. Hurst H, Bolton J. Assessing the clinical significance of change scores recorded on subjective outcome measures. *J Manipulative Physiol Ther*. 2004; 27(1):26–35. [PubMed: 14739871]
28. Farrar JT, Young JP Jr, LaMoreaux L, Werth JL, Poole RM. Clinical importance of changes in chronic pain intensity measured on an 11-point numerical pain rating scale. *Pain*. 2001; 94(2):149–58. [PubMed: 11690728]
29. Dromerick AW, Kumar A, Volshteyn O, Edwards DF. Hemiplegic shoulder pain syndrome: interrater reliability of physical diagnosis signs. *Arch Phys Med Rehabil*. 2006; 87(2):294–5. [PubMed: 16442988]
30. Joynt RL. The source of shoulder pain in hemiplegia. *Arch Phys Med Rehabil*. 1992; 73(5):409–13. [PubMed: 1580765]

31. Melzak R, Wall PD. Pain mechanisms: A new Theory. *Science*. 1965; 150:971–9. [PubMed: 5320816]
32. Brosseau L, Milne S, Robinson V, Marchand S, Shea B, Wells G, et al. Efficacy of the transcutaneous electrical nerve stimulation for the treatment of chronic low back pain: a meta-analysis. *Spine*. 2002; 27(6):596–603. [PubMed: 11884907]
33. Snels IA, Beckerman H, Lankhorst GJ, Bouter LM. Treatment of hemiplegic shoulder pain in the Netherlands: results of a national survey. *Clin Rehabil*. 2000; 14(1):20–7. [PubMed: 10688341]
34. Pomeroy VM, Niven DS, Barrow S, Faragher EB, Tallis RC. Unpacking the black box of nursing and therapy practice for post-stroke shoulder pain: a precursor to evaluation. *Clin Rehabil*. 2001; 15(1):67–83. [PubMed: 11237164]
35. de Boer KS, Arwert HJ, de Groot JH, Meskers CG, Mishre AD, Arendzen JH. Shoulder pain and external rotation in spastic hemiplegia do not improve by injection of botulinum toxin A into the subscapular muscle. *J Neurol Neurosurg Psychiatry*. 2008; 79(5):581–3. [PubMed: 18408090]
36. Caldwell CB, Wilson DJ, Braun RM. Evaluation and treatment of the upper extremity of the hemiplegic stroke patient. *Clin Orthop*. 1969; 63:69–93. [PubMed: 5769375]
37. Braun RM, West F, Mooney V, Nickel VL, Roper B, Caldwell C. Surgical treatment of the painful shoulder contracture in the stroke patient. *J Bone Joint Surg Am*. 1971; 53(7):1307–12. [PubMed: 5114694]
38. Bender L, McKenna K. Hemiplegic shoulder pain: defining the problem and its management. *Disabil Rehabil*. 2001; 23(16):698–705. [PubMed: 11732559]
39. Koog YH, Jin SS, Yoon K, Min BI. Interventions for hemiplegic shoulder pain: systematic review of randomised controlled trials. *Disabil Rehabil*. 2010; 32(4):282–91. [PubMed: 20055567]

Figure 1.
Schematic of the single-lead peripheral nerve stimulation system.

Figure 2. Mean BPI3 scores. Bars indicate standard error. * indicates significant reduction relative to baseline on post-hoc pair-wise comparisons with Bonferroni correction.

Table 1

Participant Characteristics.

Participant	Gender	Age (yr)	Subluxation (FB)	Stroke Onset (mo)	Stroke Type	Hemisphere	Aphasia	Sensory Impairment	Neglect
1	Male	58	1.5	91	Ischemic	Right	No	No	Yes
2	Female	40	1.0	16	Hemorrhagic	Right	No	Yes	No
3	Female	49	0.0	37	Ischemic	Left	Yes	No	No
4	Male	62	0.0	18	Hemorrhagic	Left	Yes	No	No
5	Male	53	0.0	70	Ischemic	Left	No	No	No
6	Male	50	1.0	15	Hemorrhagic	Right	No	No	No
7	Female	42	1.0	9	Ischemic	Left	No	No	No
8	Female	48	1.0	146	Ischemic	Left	Yes	No	No
4/8 male		50.3 ± 7.4 (SD)	5/8 subluxation	50.3 ± 48.6 (SD)	3/8 hemorrhagic	3/8 right hemisphere	3/8 aphasia	1/8 sensory impairment	1/8 neglect

FB: Fingerbreadth; SD: Standard deviation

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Table 2

BPI3 Data

Participant	Treatment Phase				Follow-up Phase			
	Baseline	Week 1	Week 2	EOT	Week 1	Week 4	Week 12	
1	8	5	4	3	2	2	0	
2	10	5	5	5	7	8	5	
3	8	1	1	3	2	1	1	
4	7	1	1	0	0	0	0	
5	6	6	2	2	2	2	6	
6	10	4	7	6	10	10	7	
7	10	4	0	0	0	1	1	
8	8	1	3	2	1	2	5	

EOT: End of Treatment; Values represent patient reported pain intensity on a 0–10 numeric rating scale.

Table 3

Results of Repeated Measures ANOVA of Secondary Measures.

Model	Baseline (SD)	EOT (SD)	1-wk (SD)	4-wks (SD)	F	p-value
BPI9						
General activity	6.4 (2.9)	4.3 (3.7)	2.0 (3.4)	3.4 (4.1)	4.1	<0.05
Mood	7.7 (2.3)	4.9 (4.7)	3.0 (3.9) ^{a,b}	3.0 (4.8) ^a	6.3	<0.01
Walking ability	5.0 (3.8)	1.3 (2.8)	2.0 (3.4)	2.9 (4.2)	3.9	<0.05
Normal work	6.1 (3.2)	1.9 (3.6) ^{a,b}	2.4 (3.6)	4.0 (4.8)	3.2	<0.05
Relations with other people	4.9 (3.3)	3.4 (4.2)	1.5 (3.5)	3.5 (4.8)	1.7	NS
Sleep	8.0 (1.7)	3.2 (4.2) ^{a,b}	1.3 (3.5) ^{a,b}	3.8 (4.9)	9.3	<0.001
Enjoyment of life	6.6 (3.2)	3.9 (4.3)	1.8 (3.6) ^{a,b}	4.0 (5.0)	4.0	<0.05
Average	6.4 (1.6)	3.1 (3.3) ^a	1.9 (3.4) ^{a,b}	3.6 (4.5)	5.9	<0.01
SF-36v2						
Physical Function	32.0 (11.3)	35.1 (12.8)	37.9 (15.1)	36.1 (13.8)	1.1	NS
Role Physical	29.2 (9.0)	34.6 (11.8)	35.1 (12.9)	38.8 (14.4)	2.6	NS
Bodily Pain	31.2 (8.1)	45.8 (8.8) ^{a,b}	46.9 (12.1) ^{a,b}	45.9 (11.8) ^{a,b}	12.8	<0.001
General Health	42.4 (9.9)	43.1 (12.3)	44.4 (12.3)	42.9 (14.0)	0.5	NS
Vitality	43.0 (9.6)	47.2 (11.3)	50.1 (13.5)	49.0 (13.6)	2.4	NS
Social Functioning	36.9 (9.1)	40.0 (11.7)	42.3 (15.2)	44.3 (12.5)	1.0	NS
Role Emotional	31.1 (12.3)	37.2 (17.0)	41.5 (16.8)	41.0 (13.0)	3.5	<0.05
Mental Health	40.0 (11.9)	46.5 (14.4)	46.8 (16.2)	49.1 (12.5)	3.4	<0.05

EOT: End of Treatment; SD: Standard deviation; NS: Not significant; post-hoc pair-wise comparison relative to baseline:

^a p<0.05 without correction for multiple comparisons,^b p<0.05 with Bonferroni correction.

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Table 4

Patient Global Impression of Change

Visit	Very much worse (n)	Much worse (n)	Minimally worse (n)	No change (n)	Minimally improved (n)	Much improved (n)	Very much improved (n)
EOT	0	0	0	0	3	2	3
1-wk after EOT	0	0	0	1	1	2	4
4-wks after EOT	0	0	1	0	2	1	4

EOT; End of Treatment; Values represent numbers of participants reporting each response.