Chapter 6

Treatment of Neuropathic Pain in Brachial Plexus Injuries

Nieves Saiz-Sapena,
Vicente Vanaclocha-Vanaclocha,
José María Ortiz-Criado, L. Vanaclocha and
Nieves Vanaclocha

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Abstract

Brachial plexus injuries are commonly followed by chronic pain, mostly with neuropathic characteristics. This is due to peripheral nerve lesions, particularly nerve root avulsions, as well as upper limb amputations, and complex regional pain syndrome (CRPS). The differential diagnosis between CRPS and neuropathic pain is essential as the treatment is different for each of them. Medical treatments are the first step, but for refractory cases there are two main types of surgical alternatives: ablative techniques and neuromodulation. The first group involves destruction of the posterior horn deafferented neurons and usually provides a better pain control but has a 10% complication rate. The second group provides pain control with function preservation but with limited effectiveness. Each case has to be thoroughly evaluated to apply the treatment modality best suited for it.

Keywords: brachial plexus injury, brachial plexus avulsion, chronic pain, neuropathic pain, deafferentation pain, phantom pain, pulsed radiofrequency, peripheral nerve stimulation, neuromodulation, DREZ-otomy

1. Introduction

Brachial plexus injuries are associated not only with motor and sensory functional impairment [1] but also with chronic pain in the affected upper limb [2–7]. Most of these injuries are due to motor vehicle accidents, particularly motorbikes [1, 5], but a few of them can occur

due to iatrogenia [8–16], particularly during lymph node biopsy [17, 18] or treatment of some malignancies [19].

The *pain* is chronic [20], persistent [7], constant [21], burning [22] and throbbing [17], with paroxysmal discharges [3, 6, 23], particularly upon gentle rubbing the affected area [4].

The *pain is distributed* in the distal areas of the upper limb, covering several dermatomes, mostly the caudal ones [24] and particularly the hand [5, 17, 23, 25]. The paroxysmal pain is felt in the arm [26]. Allodynia, hypersensitivity and electric-like discharges are present at the border between the normal and affected dermatomes [17, 26–29], particularly between T_1 and T_2 at the posterior aspect of the elbow [26].

The *pain severity* correlates with the magnitude of the brachial plexus injury [2, 3] and to the number of avulsed nerve roots [2–4, 21, 26, 30–33], particularly when the lower roots are affected [24, 34, 35]. Nevertheless, Bertelli et al. [21] found that in isolated C_8 and T_1 nerve root avulsions, there was no pain at all.

The *pain* does not *appear* immediately after the injury but a few days later [24] and no longer than 3 months after it [5, 6, 24, 26, 35, 36].

The *neuropathic pain can be associated with* phantom [37] or stump pain [38] in case of upper limb amputation, or to complex regional pain syndrome (CRPS) [6], inducing a complex pain condition rather difficult to control [19, 30, 31].

Self-mutilation has been described in 5–29% of obstetric brachial plexus injury cases [39, 40].

The *quality of life* is seriously impaired with sleep disorders, family troubles, unemployment, chronic depression and social withdrawal [2, 5, 6, 17, 21, 41–44]. Additionally, the chronic pain is a further hindrance to comply with a good rehabilitation programme, impairing a possible functional recovery [6, 45, 46]. Among all the disabilities induced by the brachial plexus injury, the pain has been found to be the symptom that most negatively affects the quality of life [47].

Treatment of this chronic pain can be troublesome, as the response to the different treatment modalities is poor and not all of them allow preservation of the remaining upper limb function [2, 5, 48].

2. Incidence

Although 50–82.7% of brachial plexus injuries suffer from chronic pain [2, 3, 5, 6, 17, 35, 49–51], it is severe in 41% of them [32]. The incidence and severity are higher in nerve root avulsions [2–4, 7, 21, 30, 33], especially when all the roots are avulsed [2, 17, 21]. Overtime there is a spontaneous progressive improvement, so just after the injury 90% of patients suffer from pain but affects only 30% of them 3 years later [35, 36, 49].

Predisposing factors: the strongest is alcohol abuse [17], but smoking [6, 17], other coexistent pain conditions [6], like psychiatric co-morbidities [6, 17], using a sling [5] and the marital status (both married or divorced versus being single) also increase the pain incidence [5]. A longer time using a sling increases the chance of chronic pain because limb movement restriction has a negative impact on recovery [5].

Brachial plexus injuries may also be accompanied by partial or complete traumatic upper limb amputation. About *50–85%* of these *amputees* will suffer from *chronic pain* [52, 53] particularly in more proximal amputations [53]. This pain usually starts 1 month postamputation [53], and in 54–87% of them, it is followed by *phantom limb pain* [37, 53, 54]. This kind of pain is felt also in extensive nerve root avulsions, particularly when all of them are affected [55].

CRPS is present in 21% of brachial plexus injuries [6], and once it starts it is usually lifelong unless treated [35].

3. Pathophysiology

The neuropathic pain is induced by an injury to the somatosensory pathways [56, 57] like a brachial plexus injury, an upper limb amputation or both of them simultaneously [2, 7, 58].

The peripheral nerve injury induces deafferentation [2] and damage to the C nerve fibres [59]. The dorsal horn neurons devoid of their peripheral sensorial input start to fire spontaneously and erratically [60–64], stimulating pain sensation in the higher central nervous system levels [65, 66]. In experimental studies it has been found that the spinal cord microglia and astrocytes are activated at the injury site [67] and help to maintain the neuropathic pain [68–72]. Higher levels like the thalamus and the motor cortex also undergo the same process by which deafferented neurons create new synapses and reorganize and start firing in abnormal patterns [7, 73–77]. Descending pathways modulate the neuropathic pain [78] creating new circuits that induce and maintain it [79–81]. The brain and spinal cord neuronal reorganization leads to an increased sensitivity to otherwise normal stimuli, lowering the threshold required to feel the sensation as pain and inducing secondary hyperalgesia and allodynia [4, 82]. It also explains why the pain often extends beyond the denervated area [26, 33] and why it manifests at the border areas between the partially denervated and normal dermatomes [17, 27].

As mentioned above the pain seen after brachial plexus injury has two distinct patterns: paroxysmal and continuous. The first one is thought to originate from the deafferented posterior spinal horn neurons [60, 83], while the second one comes from the thalamus [74, 84]. In the phantom limb pain, the brain cortex undergoes a functional reorganization in response to the chronic pain [40, 85, 86].

Some have suggested that the neuropathic pain after brachial plexus avulsion is generated not by the avulsed nerve roots but by the remaining ones [67] that are also injured, although not so severely [34]. Although this might be true in some cases, it does not explain why the neuropathic pain severity is maximal when all nerve roots are avulsed [2, 17, 21, 55].

4. Medical treatment

This kind of pain, particularly in case of nerve root avulsions, is difficult to treat due to partial responses and frequent relapses [5, 6, 17]. The response to pharmacological treatments decreases when the pain intensity increases [6].

The non-steroidal anti-inflammatory drugs (NSAIDs) are of little help in the chronic phase [17, 30].

The first step is *tricyclic antidepressants (TCAs)* or *serotonin* and *noradrenaline reuptake inhibitors* [6, 57, 87]. Among TCAs, amitriptyline (25–125 mg/day) and venlafaxine (150–225 mg/day) are the most commonly used [6, 57]. They not only help with the pain but also with the accompanying nervous depression [57, 87]. A regular ECG surveillance is recommended as at high doses these drugs can induce cardiac arrhythmias [88]. Duloxetine, the most commonly used serotonin-noradrenaline reuptake inhibitor, is devoid of cholinergic or cardiac side effects [87].

The second step is the combination of the above-mentioned drugs with anti-epileptic agents [89], like *gabapentin* or *pregabalin* [6, 19, 27, 57, 87]. Clonazepam at night time is very effective, but it can induce drowsiness, and some patients find it difficult to tolerate [90]. Other anti-epileptic drugs like topiramate, carbamazepine, oxcarbazepine and lamotrigine are also used but with limited success [57].

Lidocaine (lignocaine) 5% patches applied to the painful area are the third line of medical treatment [27, 91, 92]. It controls the cold allodynia but not the mechanical one [73].

Capsaicin 8% patches are used but can cause severe local skin irritation [27].

Oral cannabinoids, which were successful in controlling brachial plexus injury pain in rats [70], have limited success in humans and are not currently recommended [93].

Opioids (tramadol [6, 89], morphine, oxycodone and tapentadol) are to be avoided as they are not very effective in the treatment of neuropathic pain [32] and because of their addictive properties [27, 57, 91, 92]. In any case the opioid dose should never exceed 180 mg/day of oral morphine equivalents [57] and should be complemented with TCAs and anti-epileptic drugs [89].

Other drugs have been tried experimentally in rats, like rapamycin [94], intrathecal Trichostatin A (TSA) [94] or intravenous immunoglobulin [95], but there are no reports of their use in humans.

Transcutaneous electrical nerve stimulation (TENS) has been used to control and prevent the development of neuropathic pain after brachial plexus injury [35, 96–98]. Its main advantage is that it can be self-applied by the patient. However, it needs constant application, and at times it can provoke local skin irritation [35, 96–98].

The common clinical features shared by neuropathic pain and CRPS hinder a pure clinical diagnosis [6]. Distinguishing between both of them is essential as the latter causes greater disabilities [99]. To differentiate them, an ultrasound examination can be performed, as the muscular architecture is preserved in neuropathic pain but not in CRPS [99].

Medical treatments can also classify the pain: *stellate ganglion blocks* will only relieve CRPS [6, 100, 101]. Other therapies for CRPS include *botulinum toxin*, which can be used to treat muscular trigger points [102] when found, and *electroacupuncture*, which has been found effective in controlling experimental brachial plexus pain in rats [103]. We have not found any publication reporting the use of electroacupuncture in human beings.

5. Surgical treatment

Brachial plexus injury repair by direct suture, by grafts or by nerve transfers, particularly sensory nerve transfers, minimizes the incidence and severity of neuropathic pain [4, 26, 34, 67, 104–109], and the sooner the repair is done the better [25, 67]. CRPS is the exception as further surgery outside trapped nerve decompression seems to have a negative impact on the outcome [101]. In these cases either an interscalene [102] or stellate ganglion block [110] or a cervical spinal cord stimulator [111–113] is recommended instead. The phantom limb pain only improves with central nervous system procedures [114, 115].

There are two main roads of action: neuromodulation and ablative procedures. The first group relies on applying electric impulses to different areas of the central or peripheral nervous system, aiming to block the transmission of the nerve impulses that are finally interpreted as pain in the sensory motor cortex. They are particularly effective for continuous pain but less so for paroxysmal painful discharges [84]. The ablative procedures aim to destroy the posterior horn spinal cord neurons that start to fire in an abnormal way after being disconnected from their peripheral sensory input [25, 64–66], controlling paroxysmal pain better than continuous pain [84].

5.1. Neuromodulation procedures

Peripheral nerve stimulation provides 50–83% pain relief in 65–80% of the patients [116–120], and the affected limb preserves the residual function remaining after the injury [121]. Allodynia and neuropathic pain are controlled with mild improvement in the sensory function [116, 118]. The results are stable long-term [118, 119, 121]. The electrodes can be implanted with an open surgical procedure [117, 119] or percutaneously under ultrasound guidance [116, 120]. Unfortunately lead fracture, displacement or infection can spoil an initial successful result [116, 120]. A further refinement is to apply the stimulating electrodes not through a cuff around the affected nerve but by direct selective nerve fascicle stimulation [122]. In this way only the affected sensory fascicles are stimulated and not the motor ones, improving the results and reducing the side effects, particularly muscle spasms [122].

Cervical spinal cord stimulation stops the transmission of the abnormal electrical impulses coming from the deafferented posterior spinal cord horn neurons [123], controlling the pain with preservation of the remaining upper limb function [112, 124, 125]. Its success rate in the treatment of neuropathic pain associated with brachial plexus injuries is 50% [51, 111–113, 124–129]. It is particularly useful in CRPS [112] but it also helpful in nerve root avulsions [129]. In cases of failed previous dorsal root entry zone (DREZ), lesioning can provide good pain control [113]. Contrariwise, when the spinal cord stimulation failed the DREZ-otomy through radiofrequency, it yields suboptimal results [130]. Nevertheless several research groups recommend to restrict the cervical spinal cord stimulation for failed previous DREZ-otomy due to its high economical costs [25, 131–133]. A trial period is needed before the definitive pulse generator implantation to predict the results [129]. The stimulation parameters can be modified according to the patient's individual needs through an external programming device. The electrodes can be implanted percutaneously or surgically. Lead fracture or dislocation

and battery exhaustion will require surgical revision of the system. Some patients experience discomfort due to paresthesias particularly when rotating the head [111, 124]. This can be minimized by reprograming the active electrodes and the intensity of the electrical stimuli.

Pulsed radiofrequency has been reported in a few cases of brachial plexus injury including one with concomitant limb amputation, with a 60–70% pain improvement in a 6-month follow-up [38, 134]. The main advantage is that radiofrequency does not induce additional motor or sensory deficit, although the results are not long-lasting [135]. The data are insufficient to draw any definitive conclusions [38, 134, 135].

In small clinical series of patients, *deep brain stimulation* has shown a 55% improvement in neuropathic pain arising from brachial plexus injury and traumatic amputation pain [20, 58, 136]. After 1 year the effectivity is reduced in many patients, and increasing the intensity of the electrical stimuli is not always successful to improve the deteriorating results [20]. There is no agreement on where is the best target for the stimulation: some recommend the sensory thalamus [20, 58] and others the periaqueductal grey matter [137, 138].

In neuropathic pain induced by brachial plexus injury, *motor cortex stimulation* has shown a 42% effectiveness in controlling the continuous pain but no effectiveness for the paroxysmal discharges [84, 139]. A major drawback is the lack of factors to be able to predict the results to be expected [84]. This is particularly important considering the high cost and surgical risks involved in this technology.

5.2. Ablative procedures

The medial thalamotomy, the spinothalamic tractotomy, and the anterolateral tractotomy have been abandoned due to the limited pain control they provide and the side effects they carry [119].

The DREZ is an anatomical area of the spinal cord composed by the dorsal rootlets, Lissauer's tract and the dorsal horn [25]. *DREZ-otomy* aims to destroy the neurons located in the posterior horn of the spinal cord that start firing abnormally once deprived of their peripheral sensory input [25, 140]. It has proved particularly effective in the control of brachial plexus-induced neuropathic pain [22, 23, 28, 48, 140, 141], but it is a destructive procedure that can be applied when no residual upper limb function has to be preserved (i.e. nerve root avulsions). It is particularly effective in controlling the paroxysmal pain but not so much in the constant aspect of it [23–25, 84, 133, 139, 142]. It provides a better pain control than the neuromodulation procedures, with a reported long-term success rates of 50–75% [22, 25, 29, 48, 143]. Unfortunately about 10% of patients develop ipsilateral leg weakness and ataxia [22–24, 28, 48, 133, 140, 141] due to the vicinity of the area to be lesioned to the motor corticospinal tract laterally and the dorsal column with proprioceptive information medially [25, 140]. This successful pain control correlates with an improvement in anxiety and depression and in a third of patients in returning to work [133, 144]. The pain improvement with this technique is independent of the time elapsed since the injury and the DREZ-otomy [25, 133]. Pain recurrence is expected in 13–20% of the patients [22, 23, 25, 28, 29, 132, 143, 145–147] particularly in those with constant type of pain [23, 24, 139] but with an acceptable pain control in over 60% of them [132, 143].

The recurrences seem to be more common in the first 12 months post-op and much rarer after 5 years of follow-up [48, 132]. Pain control and recurrences seem to be less common among nerve root avulsions than with other more peripheral brachial plexus injuries [143, 145]. Some surgeons have considered that a bad result would mean a DREZ lesion of insufficient size [25, 131] and used the intraoperative ultrasound imaging to guide the shape and size of those lesions [131]. They reported an initial 100% pain control that decreased to 87% on 47.5 months follow-up but at the price of a higher rate of lower extremity weakness and ataxia [131] (17%, compared to 10% in other patient series [22–24, 28, 48, 140, 141]). These results also reflect that apart from the spinal cord, there are other higher central nervous system areas involved in the generation and maintenance of the neuropathic pain induced after brachial plexus injury [148].

Lack of DREZ region damage confirmed in preoperative MRI seems to be an indicator of successful pain control with the DREZ procedure to the point that no patient with spinal cord dorsal horn abnormalities had a completely pain-free outcome [22]. It is suggested that if the posterior horn is abnormal, the thalamus will most likely develop deafferented neurons that will start firing in an abnormal pattern and thus the treatment should be directed there and not to the spinal cord [22]. This observation contradicts the fact that surgically amputated patients due to different medical conditions in whom a normal spinal cord anatomy is preserved fare worse with the DREZ operation than those that had a traumatic amputation [115]. In these DREZ-otomy failed cases, a cervical spinal cord stimulator is recommended [113]. Post-operative MRI examinations in radiofrequency DREZ lesions have shown that the surgically lesioned area extends beyond the posterior horn [149]. This is in concordance with the clinical fact that some patients develop post-operative leg weakness, ataxia and sensory abnormalities below the operated area [22–24, 28, 48, 133, 140, 141].

DREZ-otomy provides 83% pain control rate in phantom pain [115, 150, 151], 67% in burning pain and 29% for stump pain [115, 152]. Both amputation and nerve root avulsion phantom pain seem to benefit from DREZ-otomies [115, 150, 151]. The results in pain improvement are better in traumatic amputations than in those due to medical conditions [28, 115]. Some researchers recommend to start with neurostimulation in phantom limb pain and to recourse to the DREZ-otomy as a last resort [152].

The DREZ-otomy can be created microsurgicaly (Sindou's technique) [25], with radiofrequency (Nashold's technique) [29, 48], with laser [153–156] or even with an ultrasonic microprobe [131], but there are no major differences in pain control or patients' quality of life between them [142, 156]. The microsurgical technique is performed with the regular bipolar forceps, which is less expensive than the other options (radiofrequency, laser, ultrasonic probe), making it ideal for countries with limited resources [144, 157]. Some scientists have attempted intraoperative neurophysiological monitoring to improve the clinical results [65, 158, 159]. Freeing the spinal cord completely helps to stop pain induction with neck movements [25]. A concern that has not yet been studied in detail is the possible long-term effects of extensive cervical laminectomies required for the procedure, as it might accelerate cervical kyphotic deformity with cervical spinal cord myelopathy [147]. In any case the original full bilateral cervical C_5-T_1 laminectomies [25, 140] have been replaced in many surgical units by hemi-laminectomies.

6. Conclusions

Brachial plexus injuries can be the source of chronic pain. This pain can be neuropathic, CRPS and/or phantom limb, particularly if there is extensive nerve root avulsion or an upper limb amputation. The pain is oftentimes excruciating and leads to a bad quality of life even interfering with the physiotherapy needed to achieve a good recovery. The response to treatment of this pain is not always as successful as expected. Some patients respond to medication, but many need neuromodulation or ablative procedures. The most effective surgical technique is the DREZ-otomy, but 10% of patients develop side effects. If the ablative procedures fail, cervical spinal cord stimulation can be attempted.

Author details

Nieves Saiz-Sapena[1]*, Vicente Vanaclocha-Vanaclocha[2], José María Ortiz-Criado[3], L. Vanaclocha[4] and Nieves Vanaclocha[5]

*Address all correspondence to: nssapena@hotmail.com

1 Hospital 9 de Octubre, Valencia, Spain

2 Department of Neurosurgery, Hospital General Universitario, Valencia, Spain

3 Universidad Católica San Vicente Mártir, Valencia, Spain

4 iBSc in Clinical Sciences, UCL School of Medicine, London, United Kingdom

5 Medical School, University College London, London, United Kingdom

References

[1] Sinha S, Pemmaiah D, Midha R. Management of brachial plexus injuries in adults: Clinical evaluation and diagnosis. Neurology India. 2015;**63**(6):918-925

[2] Tantigate D, Wongtrakul S, Vathana T, Limthongthang R, Songcharoen P. Neuropathic pain in brachial plexus injury. Hand Surgery: An International Journal Devoted to Hand and Upper Limb Surgery and Related Research: Journal of the Asia-Pacific Federation of Societies for Hand Therapy. 2015;**20**(1):39-45. DOI: 10.1142/S0218810415500057

[3] Ciaramitaro P, Padua L, Devigili G, et al. Prevalence of neuropathic pain in patients with traumatic brachial plexus injury: A multicenter prospective hospital-based study. Pain Medicine (Malden, Mass.). 2017;**18**(12):2428-2432. DOI: 10.1093/pm/pnw360

[4] Berman JS, Birch R, Anand P. Pain following human brachial plexus injury with spinal cord root avulsion and the effect of surgery. Pain. 1998;**75**(2-3):199-207

[5] Santana MVB, Bina MT, Paz MG, et al. High prevalence of neuropathic pain in the hand of patients with traumatic brachial plexus injury: A cross-sectional study. Arquivos de Neuro-Psiquiatria. 2016;**74**(11):895-901. DOI: 10.1590/0004-282X20160149

[6] Subedi A, Chaudakshetrin P, Chotisukarat H, Mandee S. Effect of co-morbid conditions on persistent neuropathic pain after brachial plexus injury in adult patients. Journal of Clinical Neurology (Seoul, Korea). 2016;**12**(4):489-494. DOI: 10.3988/jcn.2016.12.4.489

[7] Teixeira MJ, da Paz MG da S, Bina MT, et al. Neuropathic pain after brachial plexus avulsion—Central and peripheral mechanisms. BMC Neurology. 2015;**15**:73. DOI: 10.1186/s12883-015-0329-x

[8] Dengler NF, Antoniadis G, Grolik B, Wirtz CR, König R, Pedro MT. Mechanisms, treatment, and patient outcome of iatrogenic injury to the brachial plexus—A retrospective single-center study. World Neurosurgery. 2017;**107**:868-876. DOI: 10.1016/j.wneu.2017.08.119

[9] Carofino BC, Brogan DM, Kircher MF, et al. Iatrogenic nerve injuries during shoulder surgery. The Journal of Bone and Joint Surgery. American Volume. 2013;**95**(18):1667-1674. DOI: 10.2106/JBJS.L.00238

[10] Desai KR, Nemcek AA. Iatrogenic brachial plexopathy due to improper positioning during radiofrequency ablation. Seminars in Interventional Radiology. 2011;**28**(2):167-170. DOI: 10.1055/s-0031-1280657

[11] Guedes-Corrêa JF, Pereira MR da C, Torrão-Junior FJL, Martins JV, Barbosa DAN. A neglected cause of iatrogenic brachial plexus injuries in psychiatric patients. Neurosurgery. 1 Mar 2018;**82**(3):307-311. DOI: 10.1093/neuros/nyx162

[12] Joiner ERA, Skaggs DL, Arkader A, et al. Iatrogenic nerve injuries in the treatment of supracondylar humerus fractures: Are we really just missing nerve injuries on preoperative examination? Journal of Pediatric Orthopedics. 2014;**34**(4):388-392. DOI: 10.1097/BPO.0000000000000171

[13] Po BT, Hansen HR. Iatrogenic brachial plexus injury: survey of the literature and of pertinent cases. Anesthesia and Analgesia. 1969;**48**(6):915-922

[14] Scully WF, Wilson DJ, Parada SA, Arrington ED. Iatrogenic nerve injuries in shoulder surgery. The Journal of the American Academy of Orthopaedic Surgeons. 2013;**21**(12):717-726. DOI: 10.5435/JAAOS-21-12-717

[15] Rasulić L, Savić A, Vitošević F, et al. Iatrogenic peripheral nerve injuries-surgical treatment and outcome: 10 Years' experience. World Neurosurgery. 2017;**103**:841-851.e6. DOI: 10.1016/j.wneu.2017.04.099

[16] Antoniadis G, Kretschmer T, Pedro MT, König RW, Heinen CPG, Richter H-P. Iatrogenic nerve injuries: Prevalence, diagnosis and treatment. Deutsches Ärzteblatt International. 2014;**111**(16):273-279. DOI: 10.3238/arztebl.2014.0273

[17] Zhou Y, Liu P, Rui J, Zhao X, Lao J. The clinical characteristics of neuropathic pain in patients with total brachial plexus avulsion: A 30-case study. Injury. 2016;**47**(8):1719-1724. DOI: 10.1016/j.injury.2016.05.022

[18] Park SH, Esquenazi Y, Kline DG, Kim DH. Surgical outcomes of 156 spinal accessory nerve injuries caused by lymph node biopsy procedures. Journal of Neurosurgery: Spine. 2015;**23**(4):518-525. DOI: 10.3171/2014.12.SPINE14968

[19] Shibahara H, Okubo K, Takeshita N, Nishimura D. Medical treatment including pregabalin and radiation therapy provided remarkable relief for neuropathic pain by brachial plexus invasion in a patient with esophageal cancer. Gan to Kagaku Ryoho. 2012;**39**(2): 277-280

[20] Abreu V, Vaz R, Rebelo V, et al. Thalamic deep brain stimulation for neuropathic pain: Efficacy at three years' follow-up. Neuromodulation: Journal of the International Neuromodulation Society. 2017;**20**(5):504-513. DOI: 10.1111/ner.12620

[21] Bertelli JA, Ghizoni MF, Loure Iro Chaves DP. Sensory disturbances and pain complaints after brachial plexus root injury: A prospective study involving 150 adult patients. Microsurgery. 2011;**31**(2):93-97. DOI: 10.1002/micr.20832

[22] Ko AL, Ozpinar A, Raskin JS, Magill ST, Raslan AM, Burchiel KJ. Correlation of preoperative MRI with the long-term outcomes of dorsal root entry zone lesioning for brachial plexus avulsion pain. Journal of Neurosurgery. 2016;**124**(5):1470-1478. DOI: 10.3171/2015.2.JNS142572

[23] Aichaoui F, Mertens P, Sindou M. Dorsal root entry zone lesioning for pain after brachial plexus avulsion: Results with special emphasis on differential effects on the paroxysmal versus the continuous components. A prospective study in a 29-patient consecutive series. Pain. 2011;**152**(8):1923-1930. DOI: 10.1016/j.pain.2011.03.037

[24] Haninec P, Sámal F, Tomás R, Houstava L, Dubovwý P. Direct repair (nerve grafting), neurotization, and end-to-side neurorrhaphy in the treatment of brachial plexus injury. Journal of Neurosurgery. 2007;**106**(3):391-399. DOI: 10.3171/jns.2007.106.3.391

[25] Sindou MP, Blondet E, Emery E, Mertens P. Microsurgical lesioning in the dorsal root entry zone for pain due to brachial plexus avulsion: A prospective series of 55 patients. Journal of Neurosurgery. 2005;**102**(6):1018-1028. DOI: 10.3171/jns.2005.102.6.1018

[26] Htut M, Misra P, Anand P, Birch R, Carlstedt T. Pain phenomena and sensory recovery following brachial plexus avulsion injury and surgical repairs. Journal of Hand Surgery (Edinburgh, Scotland). 2006;**31**(6):596-605. DOI: 10.1016/j.jhsb.2006.04.027

[27] Finnerup NB, Norrbrink C, Fuglsang-Frederiksen A, Terkelsen AJ, Hojlund AP, Jensen TS. Pain, referred sensations, and involuntary muscle movements in brachial plexus injury. Acta Neurologica Scandinavica. 2010;**121**(5):320-327. DOI: 10.1111/j.1600-0404.2009.01248.x

[28] Awad AJ, Forbes JA, Jermakowicz W, Eli IM, Blumenkopf B, Konrad P. Experience with 25 years of dorsal root entry zone lesioning at a single institution. Surgical Neurology International. 2013;**4**:64. DOI: 10.4103/2152-7806.112182

[29] Friedman AH, Nashold BS, Bronec PR. Dorsal root entry zone lesions for the treatment of brachial plexus avulsion injuries: A follow-up study. Neurosurgery. 1988;**22**(2):369-373

[30] Zhou Y, Liu P, Rui J, Zhao X, Lao J. The associated factors and clinical features of neuropathic pain after brachial plexus injuries: A cross-sectional study. The Clinical Journal of Pain. 2017;**33**(11):1030-1036. DOI: 10.1097/AJP.0000000000000493

[31] Privat JM, Allieu Y, Bonnel F, De Godebout J. Pain following traumatic lesions of the brachial plexus (radicular avulsions and truncular lesions). Neuro-Chirurgie. 1985;**31**(5): 435-441

[32] Bruxelle J, Travers V, Thiebaut JB. Occurrence and treatment of pain after brachial plexus injury. Clinical Orthopaedics. 1988;(237):87-95

[33] Woolf CJ. Dissecting out mechanisms responsible for peripheral neuropathic pain: Implications for diagnosis and therapy. Life Sciences. 2004;**74**(21):2605-2610. DOI: 10.1016/j.lfs.2004.01.003

[34] Bonilla G, Di Masi G, Battaglia D, Otero JM, Socolovsky M. Pain and brachial plexus lesions: Evaluation of initial outcomes after reconstructive microsurgery and validation of a new pain severity scale. Acta Neurochirurgica. 2011;**153**(1):171-176. DOI: 10.1007/s00701-010-0709-3

[35] Parry CB. Pain in avulsion of the brachial plexus. Neurosurgery. 1984;**15**(6):960-965

[36] Zorub DS, Nashold BS, Cook WA. Avulsion of the brachial plexus. I. A review with implications on the therapy of intractable pain. Surgical Neurology. 1974;**2**(5):347-353

[37] Malin JP, Winkelmüller W. Phantom phenomena (phantom arm) following cervical root avulsion. Effect of dorsal root entry zone thermocoagulation. European Archives of Psychiatry and Neurological Sciences. 1985;**235**(1):53-56

[38] Zheng B, Song L, Liu H. Pulsed radiofrequency of brachial plexus under ultrasound guidance for refractory stump pain: A case report. Journal of Pain Research. 2017;**10**:2601-2604. DOI: 10.2147/JPR.S148479

[39] Al-Qattan MM. Self-mutilation in children with obstetric brachial plexus palsy. Journal of Hand Surgery (Edinburgh, Scotland). 1999;**24**(5):547-549. DOI: 10.1054/jhsb.1999.0222

[40] McCann ME, Waters P, Goumnerova LC, Berde C. Self-mutilation in young children following brachial plexus birth injury. Pain. 2004;**110**(1-2):123-129. DOI: 10.1016/j.pain.2004.03.020

[41] Oskay D, Oksüz C, Akel S, Firat T, Leblebicioğlu G. Quality of life in mothers of children with obstetrical brachial plexus palsy. Pediatrics International : Official Journal of the Japan Pediatric Society. 2012;**54**(1):117-122. DOI: 10.1111/j.1442-200X.2011.03455.x

[42] Rasulić L, Savić A, Živković B, et al. Outcome after brachial plexus injury surgery and impact on quality of life. Acta Neurochirurgica. 2017;**159**(7):1257-1264. DOI: 10.1007/s00701-017-3205-1

[43] Bailey R, Kaskutas V, Fox I, Baum CM, Mackinnon SE. Effect of upper extremity nerve damage on activity participation, pain, depression, and quality of life. Journal of Hand Surgery. 2009;**34**(9):1682-1688. DOI: 10.1016/j.jhsa.2009.07.002

[44] Choi PD, Novak CB, Mackinnon SE, Kline DG. Quality of life and functional outcome following brachial plexus injury. Journal of Hand Surgery. 1997;**22**(4):605-612. DOI: 10.1016/S0363-5023(97)80116-5

[45] Terzis JK, Kostopoulos VK. The surgical treatment of brachial plexus injuries in adults. Plastic and Reconstructive Surgery. 2007;**119**(4):73e-92e. DOI: 10.1097/01.prs.0000254859.51903.97

[46] Raducha JE, Cohen B, Blood T, Katarincic JA. Review of brachial plexus birth palsy: Injury and rehabilitation. Rhode Island Medical Journal (2013). 2017;**100**(11):17-21

[47] Carvalho GA, Nikkhah G, Matthies C, Penkert G, Samii M. Diagnosis of root avulsions in traumatic brachial plexus injuries: Value of computerized tomography myelography and magnetic resonance imaging. Journal of Neurosurgery. 1997;**86**(1):69-76. DOI: 10.3171/jns.1997.86.1.0069

[48] Rawlings CE, el-Naggar AO, Nashold BS. The DREZ procedure: An update on technique. British Journal of Neurosurgery. 1989;**3**(6):633-642

[49] Vannier J-L, Belkheyar Z, Oberlin C, Montravers P. Management of neuropathic pain after brachial plexus injury in adult patients: A report of 60 cases. Annales Françaises d'Anesthèsie et de Rèanimation. 2008;**27**(11):890-895. DOI: 10.1016/j.annfar.2008.08.013

[50] Giuffre JL, Bishop AT, Spinner RJ, Shin AY. Surgical technique of a partial tibial nerve transfer to the tibialis anterior motor branch for the treatment of peroneal nerve injury. Annals of Plastic Surgery. 2012;**69**(1):48-53. DOI: 10.1097/SAP.0b013e31824c94e5

[51] Brill S, Aryeh IG. Neuromodulation in the management of pain from brachial plexus injury. Pain Physician. 2008;**11**(1):81-85

[52] Le Feuvre P, Aldington D. Know pain know gain: proposing a treatment approach for phantom limb pain. Journal of the Royal Army Medical Corps. 2014;**160**(1):16-21. DOI: 10.1136/jramc-2013-000141

[53] Hall GC, Carroll D, Parry D, McQuay HJ. Epidemiology and treatment of neuropathic pain: The UK primary care perspective. Pain. 2006;**122**(1-2):156-162. DOI: 10.1016/j.pain.2006.01.030

[54] Jensen TS, Krebs B, Nielsen J, Rasmussen P. Immediate and long-term phantom limb pain in amputees: Incidence, clinical characteristics and relationship to pre-amputation limb pain. Pain. 1985;**21**(3):267-278

[55] Shankar H, Hansen J, Thomas K. Phantom pain in a patient with brachial plexus avulsion injury. Pain Medicine (Malden, Mass.). 2015;**16**(4):777-781. DOI: 10.1111/pme.12635

[56] Jensen TS, Baron R, Haanpää M, et al. A new definition of neuropathic pain. Pain. 2011;**152**(10):2204-2205. DOI: 10.1016/j.pain.2011.06.017

[57] Murnion BP. Neuropathic pain: Current definition and review of drug treatment. Australian Prescriber. 2018;**41**(3):60-63. DOI: 10.18773/austprescr.2018.022

[58] Pereira EAC, Boccard SG, Linhares P, et al. Thalamic deep brain stimulation for neuropathic pain after amputation or brachial plexus avulsion. Neurosurgical Focus. 2013; **35**(3):E7. DOI: 10.3171/2013.7.FOCUS1346

[59] Schwartzman RJ, Grothusen JR. Brachial plexus traction injury: Quantification of sensory abnormalities. Pain Medicine (Malden, Mass.). 2008;**9**(7):950-957. DOI: 10.1111/j.1526-4637.2007.00394.x

[60] Guenot M, Hupe JM, Mertens P, Ainsworth A, Bullier J, Sindou M. A new type of microelectrode for obtaining unitary recordings in the human spinal cord. Journal of Neurosurgery. 1999;**91**(1 Suppl):25-32

[61] Loeser JD, Ward AA, White LE. Chronic deafferentation of human spinal cord neurons. Journal of Neurosurgery. 1968;**29**(1):48-50. DOI: 10.3171/jns.1968.29.1.0048

[62] Fujioka H, Shimoji K, Tomita M, Denda S, Hokari T, Tohyama M. Effects of dorsal root entry zone lesion on spinal cord potentials evoked by segmental, ascending and descending volleys. Acta Neurochirurgica. 1992;**117**(3-4):135-142

[63] Guenot M, Bullier J, Sindou M. Clinical and electrophysiological expression of deafferentation pain alleviated by dorsal root entry zone lesions in rats. Journal of Neurosurgery. 2002;**97**(6):1402-1409. DOI: 10.3171/jns.2002.97.6.1402

[64] Jeanmonod D, Sindou M, Mauguière F. Intraoperative electrophysiological recordings during microsurgical DREZ-tomies in man. Stereotactic and Functional Neurosurgery 1990;54-55:80-85. doi:10.1159/000100195

[65] Falci S, Best L, Bayles R, Lammertse D, Starnes C. Dorsal root entry zone microcoagulation for spinal cord injury-related central pain: Operative intramedullary electrophysiological guidance and clinical outcome. Journal of Neurosurgery. 2002;**97**(2 Suppl):193-200

[66] Loeser JD, Ward AA. Some effects of deafferentation on neurons of the cat spinal cord. Archives of Neurology. 1967;**17**(6):629-636

[67] Bertelli JA, Ghizoni MF. Pain after avulsion injuries and complete palsy of the brachial plexus: The possible role of nonavulsed roots in pain generation. Neurosurgery. 2008;**62**(5):1104-1114. DOI: 10.1227/01.neu.0000325872.37258.12

[68] Mika J, Zychowska M, Popiolek-Barczyk K, Rojewska E, Przewlocka B. Importance of glial activation in neuropathic pain. European Journal of Pharmacology. 2013;**716**(1-3):106-119. DOI: 10.1016/j.ejphar.2013.01.072

[69] Liu Y, Wang L, Meng C, Zhou Y, Lao J, Zhao X. A new model for the study of neuropathic pain after brachial plexus injury. Injury. 2017;**48**(2):253-261. DOI: 10.1016/j.injury.2016.11.007

[70] Paszcuk AF, Dutra RC, da Silva KABS, Quintão NLM, Campos MM, Calixto JB. Cannabinoid agonists inhibit neuropathic pain induced by brachial plexus avulsion in mice by affecting glial cells and MAP kinases. PLoS One. 2011;**6**(9):e24034. DOI: 10.1371/journal.pone.0024034

[71] Iwasaki R, Matsuura Y, Ohtori S, Suzuki T, Kuniyoshi K, Takahashi K. Activation of astrocytes and microglia in the C3-T4 dorsal horn by lower trunk avulsion in a rat

model of neuropathic pain. Journal of Hand Surgery. 2013;**38**(5):841-846. DOI: 10.1016/j.jhsa.2013.01.034

[72] Clark AK, Old EA, Malcangio M. Neuropathic pain and cytokines: Current perspectives. Journal of Pain Research. 2013;**6**:803-814. DOI: 10.2147/JPR.S53660

[73] Rodrigues-Filho R, Santos ARS, Bertelli JA, Calixto JB. Avulsion injury of the rat brachial plexus triggers hyperalgesia and allodynia in the hindpaws: A new model for the study of neuropathic pain. Brain Research. 2003;**982**(2):186-194

[74] Rinaldi PC, Young RF, Albe-Fessard D, Chodakiewitz J. Spontaneous neuronal hyperactivity in the medial and intralaminar thalamic nuclei of patients with deafferentation pain. Journal of Neurosurgery. 1991;**74**(3):415-421. DOI: 10.3171/jns.1991.74.3.0415

[75] Grüsser SM, Mühlnickel W, Schaefer M, et al. Remote activation of referred phantom sensation and cortical reorganization in human upper extremity amputees. Experimental Brain Research. 2004;**154**(1):97-102. DOI: 10.1007/s00221-003-1649-4

[76] Tasker RR, Gorecki J, Lenz FA, Hirayama T, Dostrovsky JO. Thalamic microelectrode recording and microstimulation in central and deafferentation pain. Applied Neurophysiology. 1987;**50**(1-6):414-417

[77] Jeanmonod D, Magnin M, Morel A. Thalamus and neurogenic pain: Physiological, anatomical and clinical data. Neuroreport. 1993;**4**(5):475-478

[78] Zhang L, Zhang Y, Zhao Z-Q. Anterior cingulate cortex contributes to the descending facilitatory modulation of pain via dorsal reticular nucleus. The European Journal of Neuroscience. 2005;**22**(5):1141-1148. DOI: 10.1111/j.1460-9568.2005.04302.x

[79] Kim CH, Oh Y, Chung JM, Chung K. The changes in expression of three subtypes of TTX sensitive sodium channels in sensory neurons after spinal nerve ligation. Brain Research. Molecular Brain Research. 2001;**95**(1-2):153-161

[80] Campbell JN, Meyer RA. Mechanisms of neuropathic pain. Neuron. 2006;**52**(1):77-92. DOI: 10.1016/j.neuron.2006.09.021

[81] Nickel FT, Seifert F, Lanz S, Maihöfner C. Mechanisms of neuropathic pain. European Neuropsychopharmacology: Journal of the European College of Neuropsychopharmacology. 2012;**22**(2):81-91. DOI: 10.1016/j.euroneuro.2011.05.005

[82] Woolf CJ, Shortland P, Coggeshall RE. Peripheral nerve injury triggers central sprouting of myelinated afferents. Nature. 1992;**355**(6355):75-78. DOI: 10.1038/355075a0

[83] Guenot M, Bullier J, Rospars J-P, Lansky P, Mertens P, Sindou M. Single-unit analysis of the spinal dorsal horn in patients with neuropathic pain. Journal of Clinical Neurophysiology. 2003;**20**(2):143-150

[84] Ali M, Saitoh Y, Oshino S, et al. Differential efficacy of electric motor cortex stimulation and lesioning of the dorsal root entry zone for continuous vs paroxysmal pain after brachial plexus avulsion. Neurosurgery. 2011;**68**(5):1252-1258. DOI: 10.1227/NEU.0b013e31820c04a9

[85] Makin TR, Scholz J, Filippini N, Henderson Slater D, Tracey I, Johansen-Berg H. Phantom pain is associated with preserved structure and function in the former hand area. Nature Communications. 2013;**4**:1570. DOI: 10.1038/ncomms2571

[86] Karl A, Birbaumer N, Lutzenberger W, Cohen LG, Flor H. Reorganization of motor and somatosensory cortex in upper extremity amputees with phantom limb pain. Journal of Neuroscience: The Official Journal of the Society for Neuroscience. 2001;**21**(10):3609-3618

[87] Finnerup NB, Attal N, Haroutounian S, et al. Pharmacotherapy for neuropathic pain in adults: A systematic review and meta-analysis. Lancet Neurology. 2015;**14**(2):162-173. DOI: 10.1016/S1474-4422(14)70251-0

[88] Davis G, Curtin CM. Management of pain in complex nerve injuries. Hand Clinics. 2016;**32**(2):257-262. DOI: 10.1016/j.hcl.2015.12.011

[89] Moulin D, Boulanger A, Clark AJ, et al. Pharmacological management of chronic neuropathic pain: Revised consensus statement from the Canadian Pain Society. Pain Research & Management. 2014;**19**(6):328-335

[90] Corrigan R, Derry S, Wiffen PJ, Moore RA. Clonazepam for neuropathic pain and fibromyalgia in adults. Cochrane Database of Systematic Reviews. 2012;**5**:CD009486. DOI: 10.1002/14651858.CD009486.pub2

[91] Provinciali L, Lattanzi S, Chiarlone R, et al. Topical pharmacologic approach with 5% lidocaine medicated plaster in the treatment of localized neuropathic pain. Minerva Medica. 2014;**105**(6):515-527

[92] Krumova EK, Zeller M, Westermann A, Maier C. Lidocaine patch (5%) produces a selective, but incomplete block of Aδ and C fibers. Pain. 2012;**153**(2):273-280. DOI: 10.1016/j.pain.2011.08.020

[93] Boychuk DG, Goddard G, Mauro G, Orellana MF. The effectiveness of cannabinoids in the management of chronic nonmalignant neuropathic pain: A systematic review. Journal of Oral & Facial Pain and Headache. 2015;**29**(1):7-14

[94] Zhao Y, Wu T. Histone deacetylase inhibition inhibits brachial plexus avulsion-induced neuropathic pain. Muscle & Nerve. 2018;**58**(3):434-440. DOI: 10.1002/mus.26160

[95] Morishima R, Nagaoka U, Nagao M, Isozaki E. Chronic brachial plexus neuritis that developed into typical neuralgic amyotrophy and positively responded to immunotherapy. Internal Medicine (Tokyo, Japan). 2018;**57**(7):1021-1026. DOI: 10.2169/internalmedicine.9482-17

[96] Goroszeniuk T, Pang D. Peripheral neuromodulation: A review. Current Pain and Headache Reports. 2014;**18**(5):412. DOI: 10.1007/s11916-014-0412-9

[97] Chakravarthy K, Nava A, Christo PJ, Williams K. Review of recent advances in peripheral nerve stimulation (PNS). Current Pain and Headache Reports. 2016;**20**(11):60. DOI: 10.1007/s11916-016-0590-8

[98] DeSantana JM, Walsh DM, Vance C, Rakel BA, Sluka KA. Effectiveness of transcutaneous electrical nerve stimulation for treatment of hyperalgesia and pain. Current Rheumatology Reports. 2008;**10**(6):492-499

[99] Vas L, Pai R. Musculoskeletal ultrasonography to distinguish muscle changes in complex regional pain syndrome type 1 from those of neuropathic pain: An observational study. Pain Practice: The Official Journal of World Institute of Pain. 2016;**16**(1):E1-E13. DOI: 10.1111/papr.12338

[100] Zinboonyahgoon N, Vlassakov K, Abrecht CR, Srinivasan S, Narang S. Brachial plexus block for cancer-related pain: A case series. Pain Physician. 2015;**18**(5):E917-E924

[101] Toshniwal G, Sunder R, Thomas R, Dureja GP. Management of complex regional pain syndrome type I in upper extremity-evaluation of continuous stellate ganglion block and continuous infraclavicular brachial plexus block: A pilot study. Pain Medicine (Malden, Mass.). 2012;**13**(1):96-106. DOI: 10.1111/j.1526-4637.2011.01285.x

[102] Fallatah SMA. Successful management of complex regional pain syndrome type 1 using single injection interscalene brachial plexus block. Saudi Journal of Anaesthesia. 2014;**8**(4):559-561. DOI: 10.4103/1658-354X.140903

[103] Liu H, Qian X-Y, An J-X, et al. Analgesic effects and neuropathology changes of electroacupuncture on curing a rat model of brachial plexus neuralgia induced by cobra venom. Pain Physician. 2016;**19**(3):E435-E447

[104] Bertelli JA. Distal sensory nerve transfers in lower-type injuries of the brachial plexus. Journal of Hand Surgery. 2012;**37**(6):1194-1199. DOI: 10.1016/j.jhsa.2012.02.047

[105] Kato N, Htut M, Taggart M, Carlstedt T, Birch R. The effects of operative delay on the relief of neuropathic pain after injury to the brachial plexus: A review of 148 cases. Journal of Bone and Joint Surgery. British Volume (London). 2006;**88**(6):756-759. DOI: 10.1302/0301-620X.88B6.16995

[106] Anand P, Birch R. Restoration of sensory function and lack of long-term chronic pain syndromes after brachial plexus injury in human neonates. Brain: A Journal of Neurology. 2002;**125**(Pt 1):113-122

[107] Ho ES, Curtis CG, Clarke HM. Pain in children following microsurgical reconstruction for obstetrical brachial plexus palsy. Journal of Hand Surgery. 2015;**40**(6):1177-1183. DOI: 10.1016/j.jhsa.2015.02.003

[108] Mohammad-Reda A. Early post-operative results after repair of traumatic brachial plexus palsy. Turkish Neurosurgery. 2013;**23**(1):1-9. DOI: 10.5137/1019-5149.JTN.5654-11.3

[109] Berman J, Anand P, Chen L, Taggart M, Birch R. Pain relief from preganglionic injury to the brachial plexus by late intercostal nerve transfer. Journal of Bone and Joint Surgery. British Volume (London). 1996;**78**(5):759-760

[110] Datta R, Agrawal J, Sharma A, Rathore VS, Datta S. A study of the efficacy of stellate ganglion blocks in complex regional pain syndromes of the upper body. Journal

of Anaesthesiology Clinical Pharmacology. 2017;**33**(4):534-540. DOI: 10.4103/joacp.JOACP_326_16

[111] Deer TR, Skaribas IM, Haider N, et al. Effectiveness of cervical spinal cord stimulation for the management of chronic pain. Neuromodulation: Journal of the International Neuromodulation Society. 2014;**17**(3):265-271; discussion 271. DOI: 10.1111/ner.12119

[112] Chang Chien GC, Candido KD, Saeed K, Knezevic NN. Cervical spinal cord stimulation treatment of deafferentation pain from brachial plexus avulsion injury complicated by complex regional pain syndrome. Case Reports. 2014;**3**(3):29-34. DOI: 10.1213/XAA.0000000000000041

[113] Lai H-Y, Lee C-Y, Lee S-T. High cervical spinal cord stimulation after failed dorsal root entry zone surgery for brachial plexus avulsion pain. Surgical Neurology. 2009;**72**(3):286-289; discussion 289. DOI: 10.1016/j.surneu.2008.06.019

[114] Parmar VK, Gee L, Smith H, Pilitsis JG. Supraspinal stimulation for treatment of refractory pain. Clinical Neurology and Neurosurgery. 2014;**123**:155-163. DOI: 10.1016/j.clineuro.2014.05.026

[115] Saris SC, Iacono RP, Nashold BS. Dorsal root entry zone lesions for post-amputation pain. Journal of Neurosurgery. 1985;**62**(1):72-76. DOI: 10.3171/jns.1985.62.1.0072

[116] Bouche B, Manfiotto M, Rigoard P, et al. Peripheral nerve stimulation of brachial plexus nerve roots and supra-scapular nerve for chronic refractory neuropathic pain of the upper limb. Neuromodulation: Journal of the International Neuromodulation Society. 2017;**20**(7):684-689. DOI: 10.1111/ner.12573

[117] Obiglio M, Mendelevich A, Jeffrey S, et al. Peripheral nerve stimulation effectiveness in the upper limb function recovery of patients with a stroke sequel: Systematic review and meta-analysis. Revista de Neurologia. 2016;**62**(12):530-538

[118] Johnson S, Goebel A. Long-term treatment of chronic neuropathic pain using external noninvasive external peripheral nerve stimulation in five patients. Neuromodulation: Journal of the International Neuromodulation Society. 2016;**19**(8):893-896. DOI: 10.1111/ner.12365

[119] Stevanato G, Devigili G, Eleopra R, et al. Chronic post-traumatic neuropathic pain of brachial plexus and upper limb: A new technique of peripheral nerve stimulation. Neurosurgical Review. 2014;**37**(3):473-479-480. DOI: 10.1007/s10143-014-0523-0

[120] Kim JH, Shin SH, Lee YR, et al. Ultrasound-guided peripheral nerve stimulation for neuropathic pain after brachial plexus injury: two case reports. Journal of Anesthesia. 2017;**31**(3):453-457. DOI: 10.1007/s00540-017-2315-5

[121] Van Calenbergh F, Gybels J, Van Laere K, et al. Long term clinical outcome of peripheral nerve stimulation in patients with chronic peripheral neuropathic pain. Surgical Neurology. 2009;**72**(4):330-335; discussion 335. DOI: 10.1016/j.surneu.2009.03.006

[122] Duncan CC, Kluger DT, Davis TS, et al. Selective decrease in allodynia with high-frequency neuromodulation via high-electrode-count intrafascicular peripheral nerve interface after brachial plexus injury. Neuromodulation: Journal of the International Neuromodulation Society. 17 Aug 2018. DOI: 10.1111/ner.12802. [Epub ahead of print]

[123] Linderoth B, Foreman RD. Physiology of spinal cord stimulation: Review and update. Neuromodulation: Journal of the International Neuromodulation Society. 1999;**2**(3): 150-164. DOI: 10.1046/j.1525-1403.1999.00150.x

[124] Wolter T, Kieselbach K. Cervical spinal cord stimulation: An analysis of 23 patients with long-term follow-up. Pain Physician. 2012;**15**(3):203-212

[125] Abdel-Aziz S, Ghaleb AH. Cervical spinal cord stimulation for the management of pain from brachial plexus avulsion. Pain Medicine (Malden, Mass.). 2014;**15**(4):712-714. DOI: 10.1111/pme.12313

[126] Deer TR, Mekhail N, Provenzano D, et al. The appropriate use of neurostimulation of the spinal cord and peripheral nervous system for the treatment of chronic pain and ischemic diseases: The Neuromodulation Appropriateness Consensus Committee. Neuromodulation: Journal of the International Neuromodulation Society. 2014;**17**(6): 515-550; discussion 550. DOI: 10.1111/ner.12208

[127] Haider S, Owusu-Sarpong S, Peris Celda M, et al. A single center prospective observational study of outcomes with tonic cervical spinal cord stimulation. Neuromodulation: Journal of the International Neuromodulation Society. 2017;**20**(3):263-268. DOI: 10.1111/ner.12483

[128] Piva B, Shaladi A, Saltari R, Gilli G. Spinal cord stimulation in the management of pain from brachial plexus avulsion. Neuromodulation: Journal of the International Neuromodulation Society. 2003;**6**(1):27-31. DOI: 10.1046/j.1525-1403.2003.03004.x

[129] Bennett MI, Tai YM. Cervical dorsal column stimulation relieves pain of brachial plexus avulsion. Journal of the Royal Society of Medicine. 1994;**87**(1):5-6

[130] Garcia-March G, Sánchez-Ledesma MJ, Diaz P, et al. Dorsal root entry zone lesion versus spinal cord stimulation in the management of pain from brachial plexus avulsion. Acta Neurochirurgica. Supplementum (Wien). 1987;**39**:155-158

[131] Dreval ON. Ultrasonic DREZ-operations for treatment of pain due to brachial plexus avulsion. Acta Neurochirurgica. 1993;**122**(1-2):76-81

[132] Prestor B. Microcoagulation of junctional dorsal root entry zone is effective treatment of brachial plexus avulsion pain: long-term follow-up study. Croatian Medical Journal. 2006;**47**(2):271-278

[133] Samii M, Bear-Henney S, Lüdemann W, Tatagiba M, Blömer U. Treatment of refractory pain after brachial plexus avulsion with dorsal root entry zone lesions. Neurosurgery. 2001;**48**(6):1269-1277

[134] Magistroni E, Ciclamini D, Panero B, Verna V. Ultrasound-guided pulse-dose radiofrequency: Treatment of neuropathic pain after brachial plexus lesion and arm revascularization. Case Reports in Medicine. 2014;**2014**:429618. DOI: 10.1155/2014/429618

[135] Ku B, Jun M, Lee J-H, et al. Short-term efficacy of pulsed radiofrequency thermal stimulation on acupoints for chronic low back pain: A preliminary study of a randomized, single-blinded, placebo-controlled trial. Evidence-Based Complementary and Alternative Medicine. 2018;**2018**:4510909. DOI: 10.1155/2018/4510909

[136] Boccard SGJ, Pereira EAC, Moir L, Aziz TZ, Green AL. Long-term outcomes of deep brain stimulation for neuropathic pain. Neurosurgery. 2013;**72**(2):221-230; discussion 231. DOI: 10.1227/NEU.0b013e31827b97d6

[137] Pereira EAC, Aziz TZ. Neuropathic pain and deep brain stimulation. Neurotherapeutics. Jul 2014;**11**(3):496-507. DOI: 10.1007/s13311-014-0278-x

[138] Levy R, Deer TR, Henderson J. Intracranial neurostimulation for pain control: A review. Pain Physician. 2010;**13**(2):157-165

[139] Aly MM, Saitoh Y, Kishima H, Hosomi K, Yoshimine T. Importance of distinction between paroxysmal and continuous patterns of pain during evaluation of pain after brachial plexus injury. Acta Neurochirurgica. 2011;**153**(2):437-438; author reply 439. DOI: 10.1007/s00701-010-0874-4

[140] Nashold BS. Current status of the DREZ operation: 1984. Neurosurgery. 1984;**15**(6):942-944

[141] Campbell JN, Solomon CT, James CS. The Hopkins experience with lesions of the dorsal horn (Nashold's operation) for pain from avulsion of the brachial plexus. Applied Neurophysiology. 1988;**51**(2-5):170-174

[142] Konrad P. Dorsal root entry zone lesion, midline myelotomy and anterolateral cordotomy. Neurosurgery Clinics of North America. 2014;**25**(4):699-722. DOI: 10.1016/j.nec.2014.07.010

[143] Chen HJ, Tu YK. Long term follow-up results of dorsal root entry zone lesions for intractable pain after brachial plexus avulsion injuries. Acta Neurochirurgica. Supplement. 2006;**99**:73-75

[144] Zhang X, Li Y, Hu Y, Tao W, Zheng Z. Dorsal root entry zone coagulation for treatment of deafferentation pain syndromes. Chinese Medical Journal. 2008;**121**(12):1089-1092

[145] Ruiz-Juretschke F, García-Salazar F, García-Leal R, et al. Treatment of neuropathic deafferentation pain using DREZ lesions; long-term results. Neurology (Barcelona, Spain). 2011;**26**(1):26-31. DOI: 10.1016/j.nrl.2010.10.003

[146] Tomycz ND, Moossy JJ. Follow-up 26 years after dorsal root entry zone thermocoagulation for brachial plexus avulsion and phantom limb pain. Journal of Neurosurgery. 2011;**114**(1):196-199. DOI: 10.3171/2010.5.JNS091520

[147] Thomas DG, Kitchen ND. Long-term follow up of dorsal root entry zone lesions in brachial plexus avulsion. Journal of Neurology, Neurosurgery, and Psychiatry. 1994;**57**(6):737-738

[148] Tasker RR, DeCarvalho GT, Dolan EJ. Intractable pain of spinal cord origin: clinical features and implications for surgery. Journal of Neurosurgery. 1992;**77**(3):373-378. DOI: 10.3171/jns.1992.77.3.0373

[149] Yoshida M, Noguchi S, Kuga S, et al. MRI findings of DREZ-otomy lesions. Stereotactic and Functional Neurosurgery. 1992;**59**(1-4):39-44. DOI: 10.1159/000098915

[150] Zheng Z, Hu Y, Tao W, Zhang X, Li Y. Dorsal root entry zone lesions for phantom limb pain with brachial plexus avulsion: A study of pain and phantom limb sensation. Stereotactic and Functional Neurosurgery. 2009;**87**(4):249-255. DOI: 10.1159/000225978

[151] Saris SC, Iacono RP, Nashold BS. Successful treatment of phantom pain with dorsal root entry zone coagulation. Applied Neurophysiology. 1988;**51**(2-5):188-197

[152] Chivukula S, Tempel ZJ, Chen C-J, Shin SS, Gande AV, Moossy JJ. Spinal and nucleus caudalis dorsal root entry zone lesioning for chronic pain: Efficacy and outcomes. World Neurosurgery. 2015;**84**(2):494-504. DOI: 10.1016/j.wneu.2015.04.025

[153] Stranjalis G, Torrens M. Dorsal root entry zone lesion performed with Nd:YAG laser. British Journal of Neurosurgery. 1997;**11**(3):238-240

[154] Levy WJ, Nutkiewicz A, Ditmore QM, Watts C. Laser-induced dorsal root entry zone lesions for pain control. Report of three cases. Journal of Neurosurgery. 1983;**59**(5): 884-886. DOI: 10.3171/jns.1983.59.5.0884

[155] Powers SK, Adams JE, Edwards MS, Boggan JE, Hosobuchi Y. Pain relief from dorsal root entry zone lesions made with argon and carbon dioxide microsurgical lasers. Journal of Neurosurgery. 1984;**61**(5):841-847. DOI: 10.3171/jns.1984.61.5.0841

[156] Young RF. Clinical experience with radiofrequency and laser DREZ lesions. Journal of Neurosurgery. 1990;**72**(5):715-720. DOI: 10.3171/jns.1990.72.5.0715

[157] Prestor B. Microsurgical junctional DREZ coagulation for treatment of deafferentation pain syndromes. Surgical Neurology. 2001;**56**(4):259-265

[158] Tomás R, Haninec P. Dorsal root entry zone (DREZ) localization using direct spinal cord stimulation can improve results of the DREZ thermocoagulation procedure for intractable pain relief. Pain. 2005;**116**(1-2):159-163. DOI: 10.1016/j.pain.2005.03.015

[159] Fazl M, Houlden DA, Kiss Z. Spinal cord mapping with evoked responses for accurate localization of the dorsal root entry zone. Journal of Neurosurgery. 1995;**82**(4):587-591. DOI: 10.3171/jns.1995.82.4.0587