Changes in Spontaneous Dorsal Horn Potentials after Dorsal Root Entry Zone Lesioning in Patients with Pain after Brachial Plexus Avulsion

S Dong, YS Hu, W Du, W Tao, XH Zhang, P Zhuang and YJ Li

Beijing Institute of Functional Neurosurgery, Xuanwu Hospital, Capital Medical University, Beijing, China

OBJECTIVES: This study investigated spontaneous dorsal horn potentials in patients with pain after brachial plexus avulsion and determined the effect of dorsal root entry zone (DREZ) lesioning on these potentials and on pain levels.

METHODS: Electrospinography (ESG) recordings were undertaken in seven patients using a noninvasive electrocorticography strip electrode. Measurements were taken from the DREZ on the intact side of the spinal cord before lesioning of the injured DREZ and from the injured DREZ before and after lesioning.

RESULTS: DREZ lesioning had a significant positive effect on pain at 12 months postoperatively. At 15.0 Hz, the mean ESG power from the injured DREZ before lesioning was significantly higher than that from the intact DREZ. In addition, the mean ESG power from the injured DREZ after successful DREZ lesioning was significantly lower than that from the intact DREZ and that from the injured DREZ before lesioning.

CONCLUSIONS: The ESG power from the injured DREZ increases in patients with pain after brachial plexus avulsion compared with that of the intact DREZ; this increase is reduced by successful DREZ lesioning.

KEY WORDS: BRACHIAL PLEXUS AVULSION; DORSAL HORN; SPONTANEOUS POTENTIAL; DORSAL ROOT ENTRY ZONE LESION; POWER SPECTRAL ANALYSIS; STRIP ELECTRODE

Introduction

Neuropathic pain is common after brachial plexus avulsion.\(^1\) It has been described as having two components: a constant burning pain and an intermittent electrical shooting-like pain.\(^2\) The mechanisms of pain after brachial plexus avulsion are not well understood, making it difficult to treat clinically. Although several drug treatments are available, dorsal root entry zone (DREZ) lesioning is the preferred procedure for patients who have demonstrated a poor response to drug therapy.\(^3\) – \(^5\) The spinal dorsal horn plays a key role in the modulation of pain sensations\(^6\) and its dysfunction has been linked with a number of chronic pathological pain syndromes.\(^7\)

It has been suggested that in brachial plexus avulsion the pain generators are at least partially located in the deafferented
dorsal horn.\textsuperscript{3} Loeser and Ward\textsuperscript{8} reported that dorsal rhizotomy in cats increased major hyperactivity in the deafferented dorsal horn neurons compared with nondeafferented neurons when measured using single-unit recording. Hyperactive intraoperative single-unit recordings measured using a floating microelectrode in the dorsal horns were reported in two patients with neurogenic pain.\textsuperscript{9} Guenot et al.\textsuperscript{10} analysed single-unit recordings from the human dorsal horn in patients with deafferentation pain resulting from brachial plexus avulsion and reported burst activity in the deafferented dorsal horn. These studies suggest that hyperactive spontaneous potentials are present in the deafferented dorsal horn. Furthermore, hyperactive potentials in the dorsal horn neurons indicate their dysfunction and their role in deafferentation pain.\textsuperscript{11} To the best of our knowledge, no studies have examined the impact of DREZ lesions on spinal cord electrical activity. In addition, no studies of spontaneous potentials in deafferented dorsal horn neurons using electrodes other than microelectrodes have been published.

The present study investigated the effects of brachial plexus avulsion and DREZ lesioning on spontaneous field potentials in the dorsal horn using a novel electrocorticography electrode strip.\textsuperscript{12}

**Patients and methods**

**PATIENTS**

This prospective observational study sequentially recruited Chinese patients undergoing DREZ lesioning at Beijing Institute of Functional Neurosurgery, Xuanwu Hospital, Capital Medical University, Beijing, China, between May 2007 and March 2009. All patients had a brachial plexus injury, diagnosed on the basis of their history, clinical signs, neurological examination and magnetic resonance imaging, and were experiencing chronic unbearable pain. In all patients there had been no, or only temporary, response to narcotics, analgesics, anti-epileptics and tricyclic antidepressants used alone or in combination. For inclusion in the study, the patients were to show no evidence of any injury or abnormality on the contralateral side of the spinal cord.

Written informed consent was obtained from all the patients. The study protocol was performed according to Declaration of Helsinki guidelines and was approved by the Institutional Review Board at Xuanwu Hospital, Capital Medical University, Beijing, China.

**SURGICAL PROCEDURE AND ESG RECORDING**

The operation was carried out on the cervical spinal cord under general anaesthesia (remifentanil 0.10 – 0.15 μg/kg per min; propofol 5 mg/kg per h) with the patient in the prone position. Multilevel hemilaminectomies were performed at the C4 – T1 levels. A longitudinal incision of the dura arachnoid was then made along the cervical midline to expose the spinal cord. The depth of anaesthesia was reduced by reducing the amount of propofol from 5 mg/kg per h to 1 – 2 mg/kg per h 10 min before recording the spontaneous dorsal horn potentials; the dosage of remifentanil remained unchanged.

An electrocorticography strip electrode (PSE-06A; Beijing HKHS Healthcare, Beijing, China), consisting of six platinum–iridium disks embedded evenly (1.0 cm centre-to-centre) in a silastic sheet with 2.5-mm diameter exposed surfaces, was placed on the DREZ, covering levels C4 – T1. Cotton pads were applied to the electrode to keep its spatial relationship with the spinal cord as stable as possible. A silver/silver chloride
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A dorsal horn potentials electrode placed in exposed paraspinal muscles was used as a reference. Electrostroinography (ESG) signals were recorded using a digital electroencephalogram (EEG) system (Da Vinci Digital EEG System; Micromed, Mogliano Veneto, Italy); the signals were amplified, the bandpass was filtered between 1.0 and 80.0 Hz and the sampling rate was fixed at 128 Hz.

Spontaneous dorsal horn potentials were recorded from the injured DREZ before and after DREZ lesioning and also from the intact DREZ before DREZ lesioning of the injured side. Each recording was 5 min in duration; recording was avoided during procedures that might affect the results, such as bipolar coagulation, suction of cerebrospinal fluid and touching the spinal cord. The electrocorticography strip electrode was removed as soon as the recording had been completed. DREZ lesioning was performed according to Sindou’s technique using bipolar insulated microforceps. The incision was extended and coagulated ventrally at the entrance of the dorsal rootlets into the dorsolateral sulcus of the spinal cord at the appropriate segmental levels (C4 – T1). The lesion penetrating the lateral part of the DREZ and the medial part of Lissauer’s tract was extended down to the apex of the dorsal horn under a surgical microscope. Lesion depth was approximately 3.0 mm. All data were stored for off-line analysis.

ESG ANALYSIS
Only stationary ESG recordings without pronounced baseline wander were analysed. Segments of data containing artefacts were excluded. A good quality 1-min segment of the ESG recording was selected from each of the three recordings for each patient (intact DREZ before lesioning and injured DREZ before and after lesioning). The ESG recordings were analysed offline using MATLAB® software version 7.11 (Mathworks, Natick, MA, USA). They were digitally filtered at 8.0 – 45.0 Hz and the power values of the peaks from each of the 1-min data segments were calculated by spectral averaging using the method described by Welch. The segment length was 128 points (1 s), with a 50% overlapping Hamming window and 1.0 Hz resolution.

STATISTICAL ANALYSES
Demographic and clinical characteristics were reported as means ± SD. The mean ESG power across all seven patients was calculated for each of the three types of recording. Preoperative and postoperative VAS scores and mean ESG power values were compared using the Wilcoxon signed-rank test. A P-value of < 0.05 was considered to be statistically significant. All statistical analyses were performed using SPSS® software version 16.0 (SPSS Inc., Chicago, IL, USA).

Results
Seven patients (six males, one female) of mean ± SD age 53.4 ± 7.9 years (range 43 – 67 years) with chronic pain due to brachial plexus injury and undergoing DREZ lesioning were included in the study (Table 1). Mean ± SD duration of pain experienced by the patients was 7.1 ± 3.9 years. Preoperative VAS pain scores for the seven patients were all ≥ 8 and all had good pain relief after the operation; no patient
TABLE 1: Clinical and demographic characteristics of the seven patients with neuropathic pain following brachial plexus avulsion and the effects of dorsal root entry zone lesioning on pain at 12 months postoperatively measured using a visual analogue scale (VAS)

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Sex</th>
<th>Age (years)</th>
<th>Duration of pain (years)</th>
<th>Avulsed side</th>
<th>VAS score</th>
<th>12 months postoperative</th>
<th>Level of pain relief</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Male</td>
<td>47</td>
<td>10</td>
<td>Left</td>
<td>10</td>
<td>0</td>
<td>Good</td>
</tr>
<tr>
<td>2</td>
<td>Male</td>
<td>59</td>
<td>9</td>
<td>Left</td>
<td>9</td>
<td>2</td>
<td>Good</td>
</tr>
<tr>
<td>3</td>
<td>Male</td>
<td>51</td>
<td>10</td>
<td>Left</td>
<td>8</td>
<td>1</td>
<td>Good</td>
</tr>
<tr>
<td>4</td>
<td>Female</td>
<td>55</td>
<td>11</td>
<td>Left</td>
<td>8</td>
<td>1</td>
<td>Good</td>
</tr>
<tr>
<td>5</td>
<td>Male</td>
<td>43</td>
<td>6</td>
<td>Left</td>
<td>10</td>
<td>1</td>
<td>Good</td>
</tr>
<tr>
<td>6</td>
<td>Male</td>
<td>67</td>
<td>3</td>
<td>Left</td>
<td>9</td>
<td>0</td>
<td>Good</td>
</tr>
<tr>
<td>7</td>
<td>Male</td>
<td>52</td>
<td>1</td>
<td>Left</td>
<td>8</td>
<td>1</td>
<td>Good</td>
</tr>
</tbody>
</table>

*Good, pain reduction > 75%; fair, pain reduction of 25 – 75%; poor, pain reduction < 25% or pain worse after surgery.

experienced poor pain relief or had any severe surgery-related complications. Across all seven patients, significant relief in pain between the preoperative and postoperative assessments was seen: mean ± SD VAS pain score 8.9 ± 0.9 preoperatively versus 0.9 ± 0.7 at 12 months postoperatively ($P = 0.016$).

The ESG recordings of spontaneous dorsal horn potentials from all seven patients were suitable for analysis. Representative ESG

![FIGURE 1: Representative electrospinography recordings from a 59-year-old male patient (patient No. 2 in Table 1) with neuropathic pain following brachial plexus avulsion: (A) injured dorsal root entry zone (DREZ) before DREZ lesioning; (B) intact DREZ before DREZ lesioning of the injured side; and (C) injured DREZ after DREZ lesioning](image-url)
Dorsal horn potentials in dorsal root entry zone lesioning

recordings from a male patient (patient No. 2 in Table 1) for each of the three types of recording are shown in Fig. 1. One spectral peak in the high $\alpha$ and low $\beta$ bands was detected in all patients. The power spectra of the ESG recordings were dominated by a maximum peak at about 15.0 Hz. At this frequency, the power of the ESG recordings from the injured DREZ before lesioning was higher than from the intact DREZ before lesioning on the injured side and higher than from the injured DREZ after lesioning (Fig. 2). Across all frequency bands, the power of the ESG recording from the injured DREZ after lesioning was lower than that from the injured DREZ before lesioning and that from the intact DREZ before lesioning on the injured side.

Mean power spectra for the ESG recordings calculated from the data of all seven patients were consistent with the results from each individual patient (Fig. 3). At 15.0 Hz, the mean power of the ESG recordings from the injured DREZ before lesioning was significantly higher than that from the intact DREZ before lesioning on the injured side ($P = 0.018$). In addition, the mean power of the ESG recordings from the injured DREZ after successful DREZ lesioning was significantly lower than that from the intact DREZ and that from the injured DREZ before lesioning ($P = 0.018$ for both).

Discussion

In the present study, spontaneous dorsal horn potentials from seven patients before and after DREZ lesioning were measured using a novel strip electrode. One spectral peak in the high $\alpha$ and low $\beta$ bands with a maximum at about 15.0 Hz was detected in the ESG recordings from a 59-year-old male patient (patient No. 2 in Table 1) with neuropathic pain following brachial plexus avulsion from the intact dorsal root entry zone (DREZ) before lesioning and the injured DREZ before and after lesioning.
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Pain experienced after brachial plexus injury parallels the generation of abnormal activity within the dorsal horn of the spinal cord. It is believed that DREZ lesioning can abolish this abnormal spinal activity. Edgar et al. reported abnormal focal hyperactivity in the DREZ area in patients with post-traumatic spinal deafferentation pain using a monopolar needle electrode inserted into the DREZ. Using the same technique, Falci et al. substantially corroborated these earlier results. In contrast to animal experiments, however, no significantly higher firing rate has been observed in deafferented dorsal horn neurons.

Synchronicity in neuronal activity is an important process for information transmission. The presence of spontaneous potentials reflects overall activity in the dorsal horn. The increased power seen in recordings from the injured DREZ before lesioning in the present study is in agreement with previous studies on dorsal horn potentials. An animal study has shown that the neurons involved in the generation of spontaneous dorsal horn potentials are located in laminae III – VI. Lissauer's tract and laminae I – V are selectively ablated during the DREZ lesioning procedure, thus the ESG power of the injured DREZ after lesioning was reduced.

The strip electrode used in the present study can cover a wide area of the spinal cord surface and record potentials from a

FIGURE 3: Mean power spectral density (PSD) values of electrospinography recordings for all seven patients with neuropathic pain following brachial plexus avulsion from the intact dorsal root entry zone (DREZ) before lesioning and the injured DREZ before and after lesioning.
number of points simultaneously. Using a strip electrode to record potentials is easy and noninvasive as the electrode rests on the surface of the spinal cord. It is also less time-consuming than using microelectrodes. Low frequency noise was common in the raw data, however the ESG recordings were digitally filtered at 8.0 – 45.0 Hz before analysis; the frequency of 8.0 Hz was chosen because it is the border between the α and β band frequencies.

Although preliminary, the findings of the present study were consistent with those of previous studies and have provided additional information on the electrophysiological expression of pain after brachial plexus avulsion. Two noteworthy limitations need to be considered. First, for ethical reasons, data were collected from patients without comparison with healthy control subjects. To provide an internal control, the intact side of the spinal cord was considered to be normal, but this might not have been the case. Secondly, the sample size of the study was small and further investigations are needed.

In conclusion, the present study showed that ESG power in the high α and low β bands of the injured dorsal horn was increased in patients with pain after brachial plexus avulsion and that successful DREZ lesioning reduced this increase. Using an electrocorticography strip electrode provided a practical, noninvasive method for ESG signal recording.

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Conflicts of interest
The authors had no conflicts of interest to declare in relation to this article.


Author’s address for correspondence

**Dr Yongsheng Hu**
Beijing Institute of Functional Neurosurgery, Xuanwu Hospital, Capital Medical University, 45 Changchun Street, Beijing 100053, China.
E-mail: hysh69@sohu.com