Dorsal root entry zone localization using direct spinal cord stimulation: an experimental study

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Direct spinal cord stimulation and recording was performed in five dogs to identify the dorsal root entry zone (DREZ) and long tracts within the dorsal and dorsolateral spinal cord using electrophysiological mapping techniques. Intrathecal recordings were obtained from sites distal to the site of stimulation. Conduction velocity in the fastest conducting fibers was higher following low-intensity stimulation of the dorsolateral spinal cord than after dorsal spinal cord stimulation. The evoked response was larger following dorsolateral than dorsal spinal cord stimulation at a specific stimulus intensity. This technique is useful in identifying the DREZ using electrophysiological criteria alone.

**Key Words** • dorsal root entry zone • spinal cord • evoked potential • intraoperative recording • dog

**Materials and Methods**

Five healthy purebred beagle dogs weighing 14 to 15 kg each were used in the study. All animals were anesthetized with nitrous oxide and halothane and paralyzed with pancuronium bromide. The animals were ventilated so that arterial blood gases were within the normal range. They were placed on heating blankets, and body temperature was maintained near 37°C as measured by a rectal temperature probe. Laminectomies were performed at C4–6, T1–3, and T8–12. The dura was opened under an operating microscope at each level. In addition, the right sciatic nerve was exposed in the thigh.

A cordotomy needle with a 200-Å tip was connected to a stimulator and stimulus isolation unit and placed over the pia-arachnoid for low-intensity spinal cord stimulation at the C4–6 level. The reference electrode was a plate that was placed on the shoulder. The square-wave stimulus pulse duration was 50 µsec, the stimulation rate was one stimulus per second, and the stimulus intensity was measured in volts. Recordings were obtained from silver ball electrodes (1-mm diameter round tip, insulated except for the tip). One recording electrode was placed over the dorsal spinal cord and the other over the dorsolateral spinal cord between the posterior rootlets and the dentate ligaments at the T3–4 and T8–12 levels. A needle electrode was inserted into the paraspinal muscles lateral to each laminectomy site and served as a reference electrode for each silver ball electrode. Recordings were amplified by amplifiers with a gain of 100,000 and a bandpass of 3 to 3,000 Hz. Responses were averaged using a computer with an analog-to-digital converter and a sampling rate of 17.1 kHz. Usually, two averages (epochs) containing up to 250 sweeps were superimposed for waveform reproducibility. The display time was 10 to 30 msec.

Initially, the cordotomy needle stimulating electrode was placed over the dorsal spinal cord between the posterior rootlets and the dentate ligaments at the T3–4 and T8–12 levels. A needle electrode was inserted into the paraspinal muscles lateral to each laminectomy site and served as a reference electrode for each silver ball electrode (G1). Recordings were amplified by amplifiers with a gain of 100,000 and a bandpass of 3 to 3,000 Hz. Responses were averaged using a computer with an analog-to-digital converter and a sampling rate of 17.1 kHz. Usually, two averages (epochs) containing up to 250 sweeps were superimposed for waveform reproducibility. The display time was 10 to 30 msec.

Initially, the cordotomy needle stimulating electrode was placed over the dorsal spinal cord between the posterior rootlets and the dentate ligament and the stimulation intensity was increased gradually until a low-amplitude evoked potential was obtained from the recording electrode over the dorsolateral spinal cord. Then the stimulating electrode was moved dorsally at 1-mm intervals, and

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* Stimulus isolation unit, Model S44 stimulator, and Model 12A amplifiers manufactured by Grass Instruments, Quincy, Massachusetts.
† Datacon A-D board obtained from Clark-Davis Medical, London, Ontario, Canada.
DREZ localization and spinal cord stimulation

<table>
<thead>
<tr>
<th>Stimulation Site</th>
<th>Recording Site</th>
<th>Conduction Velocity (m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dorsolateral</td>
<td>Dorsal</td>
<td>83.9</td>
</tr>
<tr>
<td>Dorsal</td>
<td></td>
<td>44.6</td>
</tr>
</tbody>
</table>

Table 1

Mean conduction velocity in meters/second of evoked potentials following spinal cord stimulation

Results

Evoked potentials were recorded directly from the spinal cord in all five dogs. A stimulus intensity of 10.2 to 15 V applied to the dorsolateral spinal cord was necessary to evoke a reproducible response from the recording electrode in the dorsolateral spinal cord. The mean conduction velocity in the fastest conducting fibers across both spinal cord segments (first segment: stimulator to midthoracic region; second segment: mid- to lower-thoracic region) was significantly higher following dorsolateral than dorsal spinal cord stimulation (paired t-test; T = 5.1, p < 0.0001 for dorsolateral recording site and T = 5.6, p < 0.0001 for dorsal recording site). The conduction velocity of the spinal cord evoked potential was dependent on the position of the stimulating electrode.

The conduction velocity of the evoked potential was not significantly different for recordings obtained at dorsal versus dorsolateral recording sites. The mean conduction velocity was 80 m/sec and 84 m/sec when recording from dorsal and dorsolateral sites, respectively, using dorsolateral stimulation. Following dorsal spinal cord stimulation, mean conduction velocity was 45 m/sec for both dorsal and dorsolateral recording sites. An example of this phenomenon is shown in Fig. 1 and the conduction velocity results are summarized in Table 1.

The amplitude of the evoked response recorded from the dorsolateral spinal cord following dorsolateral stimulation varied from 1.2 to 19.1 μV (4.1 to 19.1 μV from the high thoracic level and 1.2 to 4.1 μV from the low thoracic level). Using the same stimulus intensity, larger responses could be obtained from the dorsolateral recording site following dorsolateral stimulation than were obtained from the dorsolateral site following dorsal spinal cord stimulation. This was true only if the amplitude of the response recorded from the dorsolateral spinal cord following dorsolateral stimulation was between 10 and 20 μV (paired t-test, T = 6.3, p = 0.0032).

There was an abrupt decrease in the amplitude of the evoked potential when the DREZ (visually identified by dorsolateral root entry to the spinal cord) was stimulated. As the stimulator was moved more posteriorly, the spinal cord evoked potential reappeared but was longer in latency (Fig. 2). In two animals a dorsal column section showed abolition of the evoked potential following dorsal stimulation, but the evoked potential following dorsolateral stimulation was not affected.

Discussion

Nashold, et al., used spinal cord evoked potentials following peripheral nerve stimulation to identify the appropriate spinal cord level for DREZ lesioning in patients with intractable pain. Lesions were made at the level at which the largest amplitude evoked potential was recorded following stimulation of a peripheral nerve or nerve root supplying the painful area. These authors concluded that spinal cord evoked potentials were useful in identifying the appropriate level for DREZ lesions. Unfortunately, this technique cannot be used in patients whose nerves or nerve roots have been totally avulsed.

Thomas and Jones showed that posterior tibial nerve somatosensory evoked potentials recorded from the spinal cord were not helpful in differentiating the DREZ from the dorsal columns. This may be due to the small segment of spinal cord monitored by spinal cord evoked potentials following stimulation of a single peripheral nerve or nerve root.

Our studies indicate that direct spinal cord stimulation and recording techniques are useful in localizing the DREZ. Low-intensity stimulation of the pathways adjacent to the DREZ (the dorsal and dorsolateral spinal cord) produced responses with significantly different conduction velocities and amplitudes, whereas stimulation at the DREZ failed to evoke a response at all.

Stimulation of the dorsolateral spinal cord between the posterior lateral sulcus (the DREZ) and the dentate liga-
The fastest conducting fibers within motor pathways have conduction velocities between 100 and 164 m/sec for fastest conducting fibers following dorsal and dorsolateral spinal cord stimulation, respectively) are slightly slower than others reported in the literature. This may be due to differences in species and/or slightly subnormal spinal cord temperature at the laminectomy sites.

In summary, direct spinal cord stimulation and recording techniques are useful in identifying the DREZ. Stimulation of the dorsal and dorsolateral spinal cord evokes responses with significantly different conducting velocities and amplitudes. Stimulation of the DREZ fails to evoke a response. These spinal cord mapping techniques may prove useful for accurate localization of the DREZ during DREZ lesion surgery. It is hoped that this localization technique will reduce the incidence of neurological deficits resulting from such surgery.

Fig. 2. Evoked potential recordings showing results of stimulation of the dorsolateral (LATERAL) and dorsal spinal cord and the dorsal root entry zone (DREZ). The evoked potential is absent following DREZ stimulation. In contrast, stimulation of the dorsolateral and dorsal spinal cord produced evoked potentials with different conduction velocities.

ments may depolarize fibers in the corticospinal tract, dorsal spinocerebellar tract, rubrospinal tract, and/or a member of smaller extrapyramidal tracts. It is possible that we stimulated some combination of these tracts despite the use of low-intensity stimuli intended to prevent stimulus current spread. Nevertheless, we found that dorsolateral spinal cord stimulation evoked responses in the fastest conducting fibers with a mean conduction velocity of 84 m/sec. In contrast, dorsal spinal cord stimulation evoked responses with a mean conduction velocity of 45 m/sec. Spinal cord evoked potentials with similar conduction velocities were simultaneously recorded from dorsal and dorsolateral recording sites.

In previous animal studies it has been shown that fibers in the dorsal column have conduction velocities of 35 to 70 m/sec.3,5,9,13 There is also a wide variation in conduction velocity within the motor pathways. Conduction velocity in the fastest conducting fibers in the dorsolateral motor tracts of cats is 90 to 120 m/sec.6 Fibers in the rubrospinal tract also have fast conduction velocities.3 The conduction velocity of some motor fibers is as low as 12 to 16 m/sec, whereas other medium-speed conducting motor fibers have conduction velocities ranging between 35 and 70 m/sec, similar to dorsal column conduction velocities.1,2,5,7,10 The fastest conducting fibers within motor pathways have conduction velocities between 100 and 164 m/sec.4,12,13

The mean conduction velocities measured in the present study (45 and 84 m/sec for fastest conducting fibers fol-

References

Manuscript received February 17, 1994. Accepted in final form June 12, 1994.

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