Spontaneous and electrically-evoked activity in the anterolateral column of the spinal cord in dogs

ROBIN D. ILLINGWORTH, M.B., B.S., F.R.C.S.,
AND PEDRO MOLINA-NEGRO, M.D., PH.D.
Department of Neurosurgery, Notre Dame Hospital, and University of Montreal,
Montreal, Quebec, Canada

Recordings have been made from the upper cervical spinal cords of 14 intact anesthetized dogs. Small bipolar concentric electrodes were passed from posterior to anterior and the spontaneous electrical activity at different depths recorded. It has been shown that there is a difference between the activity recorded in the gray and white matter and between different regions in the gray matter. Responses evoked by contralateral electrical skin stimulation have also been recorded in the anterolateral columns. The results obtained suggest that the fibers may be arranged in the tract as a model of body image rather than segmentally. All the trajectories used in this study have been verified histologically. Possible application of this technique to the procedure of percutaneous cordotomy is discussed.

KEY WORDS  - spinal cord  - spontaneous electrical activity  - evoked responses  - spinothalamic tract  - fiber arrangement  - percutaneous cordotomy

DURING stereotaxic thalamotomy much information of value in locating the target can be obtained by electrophysiological recording. With a small bipolar electrode the margins of the thalamus can be identified and evoked potentials recorded. In percutaneous cordotomy a similar problem exists: that of identifying a small deep target and producing localized damage without injury to important neighboring structures. Radiology, including air or a positive contrast medium, can be used to demonstrate the cord. The contact with, and entry into, the cord can be detected by impedance changes, and some information about the position of the electrode can be obtained by electrical stimulation.

This study was undertaken to determine if the electrophysiological technique and electrodes used in the thalamus could provide similar information in the spinal cord. Other workers have recorded potentials from the posterior columns of anesthetized patients at laminectomy and from the spinothalamic tract of man during stereotaxic cordotomy, but the information is sparse. Using the same bipolar electrode we have already recorded the spontaneous activity of the human spinal cord during percutaneous cordotomy. With this technique we can detect contact with the anterolateral column.
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and ventral limit of the anterior horn. This paper describes the spontaneous electrical activity of the cervical spinal cord, and the responses recorded in the anterolateral column of dogs. The evoked responses recorded in the posterior columns and in the dorsal and intermediate gray matter will be reported elsewhere.

Material and Method

Observations were made on 14 intact adult mongrel dogs weighing between 6.9 and 11.8 kg (mean, 8.9 kg). The dogs were anesthetized with intravenous nembutal (30/mg/kg), paralyzed with gallamine 10 mg, repeated as necessary, and maintained on artificial ventilation with 100% oxygen. An intravenous infusion of lactated Ringer's solution was continued and small supplements of nembutal repeated to maintain anesthesia. Although barbiturate anesthesia is known to reduce neural activity, the results obtained by this method were thought more applicable to patients than results from decerebrate and spinal-sectioned animals. Body temperature was maintained by an electrical heating pad under the abdomen and measured with a rectal thermometer. Upper cervical laminectomies were performed and the animals immobilized with a special apparatus for the procedure. The pleural cavity was opened to reduce movement from breathing. The exposed spinal cord was covered with warm lactated Ringer's solution.

Unitary extracellular recordings were made with steel bipolar concentric electrodes 0.54 mm in external diameter, a tip size of 10 μ, a ring tip separation of 0.5 mm, and with external insulation of epoxy resin. Similar electrodes have been used routinely for thalamic recording during stereotaxic surgery. The electrode was placed in a holder from a small-animal stereotaxic frame and advanced with a screw gauge. The spinal cord at C-3 to C-4 was explored in each animal in a series of trajectories. The electrode entered the spinal cord through the posterior columns and was advanced in stages into the gray matter and across one-half of the cord into the anterior white matter between the median sulcus and the denticulate ligament. At each advance of the electrode there was usually a burst of potentials, particularly when the electrode tip was in gray matter, and this activity was allowed to subside before recordings were made. The recordings were displayed on a Tektronix 565 oscilloscope and monitored with a Grass AM 5 audiometer. The electrical activity was recorded on PI-200 magnetic tape and later reproduced using a Honeywell Visicorder and Kodak linograph direct-print paper type 1895. The depth of penetration into the spinal cord was measured with the screw-gauge and a series of recordings made on each trajectory at different depths.

After each advance of the electrode, the surface of the animal was systematically explored to detect areas from which stimuli would elicit evoked potentials in the spinal cord. When recording in the posterior columns, potentials were easily provoked by light touch, hair or joint movement, or by deep pressure. In the anterolateral column these methods were ineffective, and the stimulus used was bipolar electrical stimulation given through two subcutaneous needles. When recording in the posterior column, this electrical stimulus would produce a response similar to that from light touch and hair movement in the same skin area and with the same latency. Once the tip of the recording electrode had passed through the anterior horn, the whole dorsal surface of the animal except the head was explored with the subcutaneous needle electrodes until a response was obtained. The access to the ventral surface of the trunk and limbs was restricted by the position of the animals. The needles were moved to identify the area from which the greatest response could be obtained. This usually measured less than 2 cm in diameter. A single square pulse of 200 μsec width was given at a strength about 10 times the threshold and the response recorded on a Hewlett-Packard 1510A oscilloscope. Occasionally, several traces were superimposed to identify doubtful responses but averaging was not used. The sweep of the oscilloscope was triggered by the stimulus, and the distance from the point of stimulation to the recording electrode was measured with tape.

Each recorded response was photographed with a Polaroid-Land camera. After
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**TABLE 1**

The characteristics of the resting electrical activity recorded at different depths in the spinal cord in 13 trajectories

<table>
<thead>
<tr>
<th>Recording Point</th>
<th>Spikes/sec</th>
<th>Spike Height (µV)</th>
<th>Background Height (µV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>posterior column</td>
<td>60–100</td>
<td>20–50</td>
<td>10–30</td>
</tr>
<tr>
<td></td>
<td>(mean 82.5)</td>
<td>(mean 32.3)</td>
<td>(mean 19.6)</td>
</tr>
<tr>
<td>dorsal &amp; intermediate</td>
<td>65–180</td>
<td>40–70</td>
<td>25–40</td>
</tr>
<tr>
<td>gray matter</td>
<td>(mean 103.1)</td>
<td>(mean 50.9)</td>
<td>(mean 29.5)</td>
</tr>
<tr>
<td>anterior gray matter:</td>
<td>25–60</td>
<td>70–200</td>
<td></td>
</tr>
<tr>
<td>large spikes</td>
<td>(mean 36.1)</td>
<td>(mean 112.5)</td>
<td></td>
</tr>
<tr>
<td>small spikes</td>
<td>60–200</td>
<td>40–100</td>
<td>25–60</td>
</tr>
<tr>
<td>spinothalamic tract</td>
<td>60–100</td>
<td>20–50</td>
<td>15–30</td>
</tr>
<tr>
<td></td>
<td>(mean 76.5)</td>
<td>(mean 32.7)</td>
<td>(mean 19.5)</td>
</tr>
</tbody>
</table>

* Results from six trajectories passing through the central part of the anterior horn.

**Fig. 1.** Dog 13, Trajectory 1. Spontaneous electrical activity recorded in the upper cervical spinal cord. Nissl stain, X 6.
Electrical activity in the spinal cord

Each experiment, the section of the spinal cord was removed, fixed, and embedded in celloidin. Sections showing the trajectories were stained with Nissl and Loyez techniques.

Results

Spontaneous Activity

Consistent results were obtained from the 29 trajectories examined in the 14 dogs. Sixteen trajectories were excluded, 10 because of problems with the taped recording and six because of lack of histological verification. A typical recording from the remaining 13 trajectories is shown in Fig. 1. A clear pattern is seen despite some artifact from cord pulsation.

The characteristics of the electrical activity recorded at different depths are summarized in Table 1. As the electrode tip approached the surface of the cord, 60-cycle activity was seen. On contact this disappeared and was replaced by small irregular spikes. Within the posterior column a pattern of small spikes not much larger than the background appeared (Fig. 1 a). Deeper in the white matter the height of the spikes tended to increase, becoming sharply increased and more frequent after entry into the dorsal gray matter (Fig. 1 b). Deeper in the gray matter the spikes tended to increase further in size and frequency (Fig 1 c). In the most anterior part of the gray matter the spikes became much higher (Fig. 1 d). Six trajectories passed through the central part of the anterior horn, and in each of these, with an increased background activity, two types of spikes appeared. Large spikes, up to 200 µV, appeared at frequencies of 25 to 60/sec, and smaller spikes, up to 100 µV at frequencies of between 60 and 200/sec. The remaining seven trajectories passed through the extreme medial and lateral margins of the anterior horn, where only small spikes were recorded. As the electrode tip passed out of the anterior horn into the spinthalamic tract, the size and frequency of the spikes were sharply reduced (Fig. 1 e), and the record became similar to that found in the posterior columns.

Evoked Responses

Twenty-eight responses were recorded in the spinothalamic tract, but in three of these the trajectories could not be identified histologically. The remaining 25 potentials were recorded in 12 trajectories passing through the tract. In many of the other trajectories it appeared that the electrode had not passed through the tract, but five trajectories without spinothalamic responses passed across the tract. Following the stimulus, the response was shown on the oscilloscope by a rounded wave between 50 and 75 µV in height (mean 59.7 µV) which lasted between 12.5 and 30 msec (mean, 17.8 msec). Once located these responses were easily recognized and constantly reproducible. The latencies were constant, and the responses could be lost by small movements of the spinal electrode.

Typical recordings are shown in Fig. 2. By stimulating the opposite side of the body, 20 contralateral responses were obtained, as in Fig. 2 a. On five of these occasions a stimulus applied to almost the same area on the other side of the body (the same side as the recording electrode) also evoked an ipsilateral response as in Fig. 2 b. Figure 3 shows the histologically-verified positions where these 25 responses were recorded. The velocity of conduction of the fastest part of these responses was similar for contralateral stimuli (mean 37.3 m/sec) and ipsilateral stimuli (mean 38.4 m/sec) (Fig. 4). Conduction was faster from the hind leg (42.8 m/sec), than from the fore leg (34.3 m/sec), suggesting that transmission may be faster in the spinal cord than in the peripheral nerves.

Discussion

Our results show that in the anesthetized dog it is possible to record characteristic spontaneous activity from different depths in the cervical spinal cord. There is a marked difference between the activity recorded in the white fiber pathways and the central gray matter of the cord, and this difference is most marked at the junction between the anterior horn and the spinothalamic tract. The evoked responses were not always easy to obtain and it seems possible that barbiturate anesthesia contributed to this difficulty. The use of small bipolar electrodes allows the recording of single spikes,
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**Figure 2.** Dog 13. Responses recorded at C3-4 after bipolar electrical stimulation of contralateral forepaw (a), and ipsilateral forepaw (b). The upper trace of each pair shows one response, the lower, 10 superimposed responses. The trajectory is shown by the black discoloration in the gray matter. The position of the electrode tip has been marked on the section, and the margin of the central gray matter outlined to increase clarity. Recordings are drawn from the original Polaroid photographs. Spinal cord section: Loyez stain, X 15.

and also from local fibers, and similar electrodes are widely used to record the resting activity and evoked potentials in the human thalamus during stereotaxic surgery.1,2,6,16

Figure 3 shows, as expected, that responses from hind-limb stimulation were recorded in the lateral and posterior part of the tract, and responses from fore-limb stimulation, medial and anterior. In addition, responses from stimulation of the distant half of each limb were recorded medial and anterior to responses from stimulation of the proximal half of the limb. This leads us to suggest that the ascending fibers in the spinothalamic tract may be arranged as a model of body image rather than segmentally. The arrangement appears to be as shown in Fig. 5. The hind limb and tail areas lie laterally, the fore limb medially, and the trunk (represented in this work by only one response) lies between. The distal parts of each limb occupy a larger area in the tract than the proximal part, and this appears particularly true of the fore limb.

The original description of the fiber arrangement in the spinothalamic tract8,17 was made from the results of cordotomy and arranged the fibers segmentally. However, other workers also studying the results of cordotomy in man have suggested that the fibers are arranged in arm and leg areas which considerably overlap.12 In our study, as the electrode passed through the posterior column, potentials evoked by light touch, hair and joint movement were recorded. Subcutaneous bipolar stimulation with iso-
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Fig. 3. Diagram to show the histologically verified positions at which responses were recorded in the upper cervical spinothalamic tract. Sites where responses from contralateral stimuli were recorded are shown on the right side, and the same positions at which responses were also obtained from ipsilateral stimuli are shown on the left and joined by broken lines.

Fig. 4. Graph showing the velocities (meters/sec) of conduction of the 25 responses recorded in the spinothalamic tract. The abscissa shows the number of responses at a given velocity.

Fig. 5. Diagram showing the suggested arrangement of the ascending fibers in the spinothalamic tract of the dog.

Acknowledgments

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References
