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Neurophysiological Assessment of Electrode Placement in the Spinal Cord

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Abstract. The use of neurophysiological techniques in addition to radiographic methods to determine the location of electrodes to be introduced into the epidural space for spinal cord stimulation is beneficial. Information on the distribution of paresthesias and muscle twitches provides an indication of the level and lateral location in relation to the midline of the spinal cord. For electrodes placed posteriorly, the threshold currents necessary for sensation are lower than those for muscle responses. Somatosensory evoked potentials resulting from epidural stimulation demonstrate effective depolarization of ascending structures. Evoked potentials recorded from the electrodes in response to peripheral nerve or spinal cord stimulation at a distant segment illustrate the possibility of activation of underlying generators of the spinal cord.

Introduction

When stimulation is applied for suppression of increased muscle tone (spasticity) and modification of other motor control abnormalities, the position of the electrodes relative to spinal cord structures is a critical parameter in determining the resulting effects of stimulation. For modification of abnormal motor control or bladder dysfunction, the experience of many active professional groups in this field is that midline placement over the posterior columns is optimal [1, 3, 5]. While radiographic techniques are essential for the establishment of electrode position during and after placement, neurophysiological parameters add physiological information to assist proper placement.

Our experience obtained during 117 procedures performed on 88 patients (59 of whom suffered from spinal injuries, 14 from multiple

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sclerosis, 5 from head injuries and 10 from other motor disorders) is described, including the use of somatosensory evoked potentials elicited through stimulation of spinal cord structures, segmental and distant muscle twitches and electrical events recorded from spinal cord structures for neurophysiological assessment of electrode placement in the spinal cord. We also correlate our observations with some results obtained in experimental animals.

Procedures

Stimulation

When using stimulation frequencies of 20 Hz or greater, patients describe a 'tingling' sensation. In patients without pathological changes in spinal cord structure, stimulation with electrodes placed over anterior structures results in a 'pulling' sensation in the area of the activated muscle groups. When the electrodes are dorsally placed, the threshold for sensation is lower than the threshold for muscle twitches. When the electrodes are ventrally placed, muscle twitches occur before or simultaneously with sensation from direct electrical activation of spinal cord sensory afferents. In patients where there is a pathological change in the spinal cord, findings reflect the newly established anatomy and therefore may not follow these criteria.

Using stimulation frequencies of approximately 1 Hz, clinically observable muscle twitches can be elicited. The initial muscle groups responding to stimulation are local to the segment where the electrode is placed, with distant myotomes recruited at higher stimulus levels. Generation of muscle twitches from the posterior aspect of the cord results from indirect reflex activation of motor neurons. By observing the recruitment order of the muscle twitches visually and with palpation, longitudinal and lateral positions can be determined. Ideally, symmetrical twitches result from midline placement of the electrodes. By using surface electromyographic recordings over the activated muscle groups, further definition of relative contraction intensity and latency can be determined. Distant muscle twitch responses result from higher stimulation intensities. The origin is thought to be from antidromic activation of posterior column neurons, which then activate distant motor neurons via collateral branches to segmental interneurons. The latencies relative to the segmental responses are longer and the response is more variable [2].

Averaged cortical somatosensory potentials reflect the capability of the electrodes to produce ascending volleys as well as demonstrate asymmetries of electrode placement. By using electrodes placed at C4-Fz and C3-Fz, the relative amplitude of the potentials indicates site of depolarization of the dorsal columns. However, this procedure has limited value in cases where somatosensory potentials are abnormal due to impaired conduction in ascending tracts.

Recording

When the electrodes are placed percutaneously for evaluation of the clinical effectiveness of stimulation or are externalized during implantation of a permanent stimula-

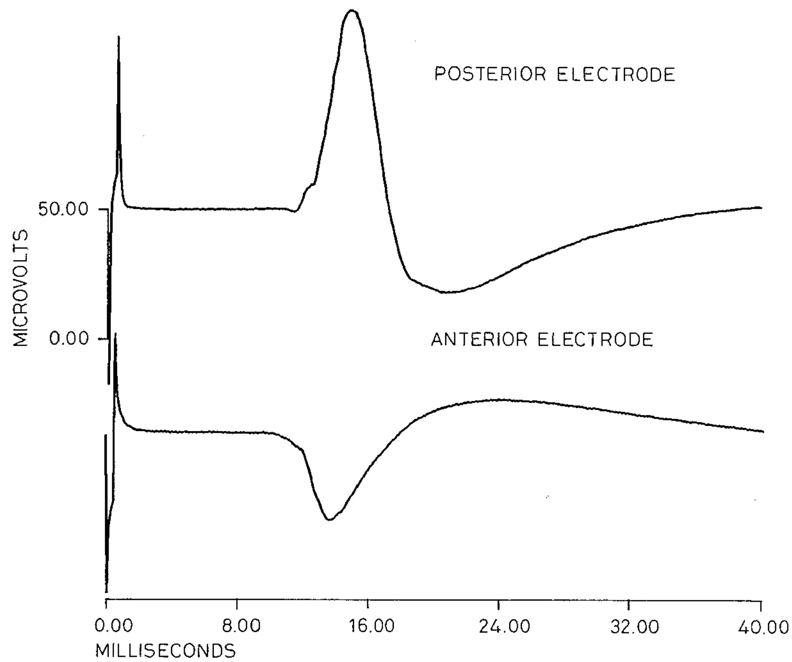

Fig. 1. Potentials recorded from epidurally placed electrodes at the posterior and anterior aspect of the spinal cord at the T-11 level in response to tibial nerve stimulation. Note the reduction and inversion of the signal recorded from the anterior as compared to the posterior aspect, reflecting the field distribution resulting from postsynaptic activity in the dorsal horn.

tion system, they can be used for recording. Potentials can be recorded from the epidural electrodes in response to peripheral nerve stimulation or stimulation through other epidural electrodes placed over a distant spinal cord segment.

If the epidural electrode used for recording is several segments rostral to the root entry level of the stimulated peripheral nerve, the potentials recorded will be short-duration triphasic conduction waves. If the epidural electrode is near the root entry level of the peripheral nerve, the potential recorded will exhibit an initial triphasic conduction wave followed by a slower negative wave of 5–10 ms duration, followed by a longer duration positive wave (fig. 1). This is indicative of postsynaptic activity in the dorsal horn of the cord. If the electrode is positioned at the lateral aspect of the cord, the size of the components of the waveform will decrease. If the electrode is placed on the anterior side of the cord, an inverted form of the negative and positive potentials recorded on the posterior side of the cord can be seen (fig. 1). The conduction waves recorded change in amplitude when measured from other aspects of the cord, but the polarity remains the same.

We have been able to reproduce these observations in anesthetized cats by recording evoked electrical events with epidurally placed electrodes during electrical stimulation of spinal structures and peripheral nerves. These recordings correlate with those of

Willis [6] and others who have performed detailed recordings with microelectrodes as well as with epidurally placed electrodes. Furthermore, similar recordings of spinal cord potentials in humans, resulting from epidural stimulation at a distant segment, have been demonstrated [4].

Conclusion

Use of neurophysiological methods supplements radiological assessment of the electrode location within the epidural space. Patient reports of the distribution and character of paresthesia resulting from stimulation at frequencies of 20 Hz and greater provide information about location and functional efficacy in depolarization of spinal cord structures. Use of somatosensory evoked potentials resulting from epidural stimulation adds to patient reports, providing an objective index of polarization of ascending fibers. Observation of the distribution of muscle twitches elicited by low rates of stimulation defines segmental level and relation to the midline. Recording of electrical potentials from the epidural space resulting from stimulation of peripheral or spinal cord structures adds another dimension to functional definition. Results correlate well with recordings in animal preparations. Use of these methods can provide objective definition of the effectiveness of spinal cord stimulation and therefore more information to assist in optimal placement.

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References

1 Campos, R.J.; Dimitrijevic, M.M.; Faganel, J.; Sharkey, P.C.: Clinical evaluation of the effects of spinal cord stimulation on motor performance in patients with upper motor neurone lesions. Proc. 3rd Int. Meet. on Spinal Cord Stimulation, Houston 1980. Appl. Neurophysiol. *44:* 141–151 (1981).

2 Dimitrijevic, M.R.; Faganel, J.; Sherwood, A.M.; Vodusek, D.B.: Modification of induced descending spinal cord activation of motor units in man. Abstr. 12th Annu. Conf. Soc. for Neurosci., Minneapolis 1982, vol. 8, p. 967 (1982).
3 Read, D.J.; Matthews, W.B.; Higson, R.H.: The effect of spinal cord stimulation on function in patients with multiple sclerosis. Brain *103:* 803-833 (1980).
4 Shimizu, H.; Shimoji, K.; Maruyama, Y.; Matsuki, M.; Kuribayashi, H.; Fujioka, H.: Human spinal cord potentials produced in lumbosacral enlargement by descending volleys. J. Neurophysiol. *48:* 1108-1120 (1982).
5 Siegfried, J.: Treatment of spasticity by dorsal column stimulation. Int. Rehab. Med. *2:* 31-34 (1980).
6 Willis, W.D.: Spinal cord potentials; in Windle, The spinal cord and its reaction to traumatic injury, pp. 159-187 (Dekker, New York 1980).

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