Nerve Root Conduction Studies During Lumbar Disc Surgery*

CARL V. GRANGER, M.D.,† AND STEVENSON FLANIGAN, M.D.;
Yale-New Haven Hospital, New Haven, Connecticut

METHODS for assessment of motor and sensory nerve conduction in peripheral nerves have proved valuable in clinical practice.1–4,6,8 Malcomb2 reported on the reflex times of tendon jerks measured preoperatively. In addition he measured the speed of nerve conduction following stimulation within the theca of the cauda equina at the time of operation for removal of a compressing lesion; the affected root and the opposite normal one were both stimulated, and the results compared; there was slowing of the speed of the nerve-impulse conduction past the compressed segment of the nerve root.

The purpose of our study was to demonstrate the conduction deficit that exists across the segment of a nerve root as a result of compression by herniated disc material. This assessment was made at the time of operative decompression.

Most patients showed sufficient motor weakness, sensory disturbance, or reflex alteration for localization of the involved root. Only a few had preoperative myelographic or electromyographic examinations. The clinical material included 30 studies in 28 different patients, with 32 nerve root tests, four at L-4, 11 at L-5, and 17 at S-1. Three additional cases could not be categorized; in two of these, previous lumbar disc operations had caused scarring about the nerve roots which obscured the test results.

Methods

A Model B Teca Electromyograph with a stimulator synchronized to trigger the sweep of the cathode ray oscilloscope was used. A Polaroid Lane camera was mounted for a permanent record either from the direct sweep or from a Tektronix storage oscilloscope that was connected to the recording circuit.

After dissection of the disc space and removal of herniated disc material, paired electroencephalographic needle electrodes were inserted through the dural sleeve of the nerve root at locations above and below the site of compression (Fig. 1). These electrodes were used both for stimulating motor impulses to the muscles and for recording afferent combined antidromic motor and orthodromic sensory impulses following stimulation of the peroneal or tibial nerve in the popliteal space. A broad ground electrode was placed under the opposite thigh. In a few instances the studies were performed upon exposure of the nerve root, prior to manipulation or traction. Repeat studies following removal of disc material showed no change in recorded responses.

Received for publication January 6, 1967.
Revision received December 1, 1967.
† Psychiatrist, Hartford Hospital, Hartford, Connecticut; Associate Clinical Professor of Physical Medicine and Rehabilitation, Yale University School of Medicine.
‡ Professor of Neurosurgery, University of Arkansas Medical Center; formerly, Associate Professor of Neurosurgery, Yale University School of Medicine.

Fig. 1. Drawing to illustrate the exposed S-1 nerve root following partial removal of the laminae of L-5 and S-1 vertebrae. The EEG needle electrodes, 8 mm long, are inserted perpendicularly into the nerve root. The paired electrodes, preferably separated by at least 1 cm, are located above and below the disc.
Technique A, for Studying the Efferent Response. The appropriate pair of EEG electrodes was used to stimulate the nerve root above the compressed segment and again below it. A coaxial needle electrode in the appropriate muscle recorded the evoked muscle potential. In most cases the medial head of the gastrocnemius was used for recording responses to stimulation of the S-1 root and the peroneal muscle for the L-5 root. A stimulus of 0.1 ms duration was delivered to the nerve root through the paired EEG needles with rheostat control for gradual increase of output voltage. The voltage output of the stimulator had been previously measured at different settings of the rheostat dial with a storage oscilloscope. Generally, a stimulus strength from 50 to 100 V was required to assure a supramaximal stimulus delivered. Only when the threshold to stimulation was elevated was more voltage needed.

Technique B, for Studying the Afferent Response. The peroneal or tibial nerve was stimulated percutaneously and separately by a hand-held electrode in the popliteal space. The appropriate pair of EEG electrodes was used to record the compound nerve potential composed of antidromic motor and orthodromic sensory impulses, both from above and below the compressed root segment. For afferent recording it was important to maintain an equal distance between the electrodes of each pair. A distance of 1 cm was preferable since a shorter space tended to cause reduced amplitude of response. To stimulate the peroneal or tibial nerve percutaneously in the popliteal space, a stimulus of at least 0.2 ms duration was used at a maximum output of about 260 V.

An assumption was made that, in normal nerve conduction over a long segment covering more than 60 cm from the lumbosacral region to the knee, there would be no appreciable difference in evoked response between the two locations of electrodes, the more distal of each pair being separated by 2 to 3 cm. Admittedly, precise placement of the electrodes was difficult due to limited exposure of the nerve root. Also, oozing of blood in the operative field may have acted as an electrical shunt. These could have been factors in determining the size of the nerve action potential with respect to recording sites above and below the compressed root segment.

Results

After tracings had been accumulated from several patients, a system of grouping was devised. Each nerve root was assigned to one of six such groups with 11 subcategories (Fig. 2), the first and last being theoretical since there were no actual patients in these groups.

Group I (no patients) and Group II (13 roots) showed little or no appreciable difference between the efferent responses to stimulation above and below the disc. Categories 2 and 3 showed reduction or absence of response in the afferent recording above the disc.

Group III (10 roots) showed an impaired efferent response to stimulation above the disc. Categories 4, 5, and 6 showed reduced amplitude, increased latency, or complete absence of response. There was no response in afferent recording above the disc. When there was complete or almost complete block of impulses on stimulation above the disc, the afferent response was often absent below as well as above the disc (Category 6).

Group IV (6 roots) showed preserved conductivity but an elevated threshold to stimulation below the disc. Categories 7 and 8 showed reduction in response from afferent recording above the disc. When threshold to stimulation below the disc was very high, the response may have been absent on afferent recording from below the disc as well as above (Category 8).

Group V (3 roots) showed either no change or a moderate reduction in response to stimulation above the disc (Categories 9 and 10). However, there was no response from afferent recording either above or below the disc.

Group VI (no patients) showed a degenerated root with no response to stimulation or in afferent recording either above or below the disc.

We have reproduced tracings from representative records (Fig. 3). Figure 3 A illustrates identical motor responses in the peroneal muscle following stimulation of the L-5 nerve root above and below the disc (Group II, Category 3). Afferent recording from this nerve root is illustrated in Figure 4 C.

Figure 3 B illustrates the response in the medial gastrocnemius following stimulation of the S-1 nerve root (Group III, Category 4). There was reduction in the amplitude of the response when the nerve root was stimulated.
Nerve Root Conduction During Lumbar Disc Surgery

<table>
<thead>
<tr>
<th>RELATION TO DISC</th>
<th>EFFERENT STIMULATION</th>
<th>AFFECTENT RECORDING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1</td>
<td>Orthodromic Motor</td>
<td>Combined Motor-Sensory</td>
</tr>
<tr>
<td>Above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2. Diagrams to summarize the groups and subcategories of responses and illustrate the relative latencies and amplitudes of evoked responses from stimulation or recording above and below the lesion in any given case. No comparison is made between latency or amplitude of response and "normal." Efferent Stimulation (Technique A): stimulation at nerve root of orthodromic motor impulses with recording from muscle. Afferent Stimulation (Technique B): percutaneous stimulation of a peripheral nerve with combined antidromic motor and orthodromic sensory impulses recorded from nerve root.

above the disc as compared with stimulation below the disc. There was little appreciable change in latency. Afferent recording from this nerve root is illustrated in Figure 4 E.

Figure 3 C illustrates the response in the medial gastrocnemius following stimulation of the S-1 nerve root (Group III, Category 5). Stimulation above the disc caused reduced amplitude and increased latency when compared to stimulation below it. Afferent recording from this nerve root is illustrated in Figure 4 D.

Figure 3 D illustrates the response in the medial gastrocnemius following stimulation of the S-1 nerve root (Group III, Category 6). There was complete absence of response when the nerve root was stimulated above the disc (top trace) and sharp response when stimu-
stimulus had been increased to approximately double that required to produce a maximum response on stimulation above the disc. A much greater strength of stimulus was required below the disc to evoke a response identical to that obtained on stimulation above the disc. The afferent response from the nerve root (not shown) showed a response from below the disc but none from above.

Figure 4 A illustrates afferent recording from the S-1 nerve root following stimulation of the peroneal nerve at a consistent latency. There was reduction in the amplitude of response above the disc as compared with that below it.

Figure 4 B illustrates afferent recording from the S-1 nerve root following stimulation of the tibial nerve. There was much greater reduction in amplitude of response from above the disc than below it. Both Figures 4 A and B are examples from Group II, Cat-

**Fig. 3.** Traces of evoked potentials recorded from a coaxial needle electrode in the muscle in response to stimulation of orthodromic motor impulses at the nerve root (Technique A). Stimulation is above the disc in the top trace and below the disc in the bottom trace. The stimulating cathode is more distal in each pair. Negative deflection is up.

lated below (bottom trace). The distance between the stimulating cathode placement in the top and bottom traces was 1.0 cm. The middle traces are responses following stimulation at two levels within the compressed root segment. As the stimulating cathode was moved distally on the nerve root through the zone of injury, a rising amplitude of response was recorded. Afferent recording from the nerve root showed no response above or below the disc when either the tibial or peroneal nerve was stimulated alone. However, placing the stimulator high in the popliteal space evoked a small response from below the disc but not above.

Figure 3 E illustrates the response in the medial gastrocnemius following stimulation of the S-1 nerve root (Group IV, Category 8). Stimulation above the disc produced a maximum response with a low intensity stimulus. However, when the same intensity stimulus was used below the disc, there was no response (not shown in Fig. 3 E). The response was obtained only after the strength of the

**Fig. 4.** Traces of evoked potentials recorded from the nerve root following percutaneous stimulation of the peroneal or tibial nerve in the popliteal space (Technique B). In A, B, C, and E, the top trace is recorded from above the disc and the bottom trace is from below the disc. In D, both traces are recorded from below the disc. The polar relationship of recording electrodes was kept constant in all tracings, negative deflection being up. This is of particular interest in interpreting the middle trace in E. Low amplitude responses in B and D are indicated by "R."
Nerve Root Conduction During Lumbar Disc Surgery

egory 2, since the efferent responses were of the type shown in Figure 3 A.

Figure 4 C illustrates afferent recording from the L-5 nerve root following stimulation of the tibial nerve. There was no detectable response from above the disc when compared with the response recorded from below.

Figure 4 D illustrates afferent recording from the S-1 nerve root following stimulation of the tibial nerve. The absence of a response from above the disc is not shown. The top trace shows the response obtained from below the disc when the tibial nerve was stimulated at the popliteal space. The bottom trace shows the response obtained from below the disc when the tibial nerve was stimulated at the ankle. From these traces nerve conduction velocity between the ankle and knee was calculated to be 54 m/s. This compares with motor conduction velocity between the knee and ankle of 48 m/s when recording from a foot muscle supplied by the tibial nerve.

Figure 4 E illustrates the afferent response in the S-1 nerve root following stimulation of the tibial nerve. There was no response from above the disc as compared with below. It is interesting to note that with the more distal electrode placed within the zone of injury an inverted response is recorded.

Discussion

It was surprising to see the various combinations of responses. No doubt the changes in nerve conduction are not only a reflection of the degree of compression but also the chronicity and length of nerve compressed by the disc. Since only clinically involved roots were studied, we do not have a series of normal roots for comparison. Insofar as this could be determined by observation and palpation in the operating room, stimulation of the L-5 root characteristically produced contraction of the medial hamstring (more than in the lateral), ankle dorsiflexors, and peroneals. Stimulation of the S-1 root characteristically produced contraction of the lateral hamstring (more than in the medial) and the triceps surae.

There are several points of interest:

1. The technique of recording afferent response from the root was more sensitive for demonstrating an abnormality in conduction than an efferent response from the muscle. The compound nerve action potential represents simultaneous arrival of impulses. Minimal interference with conduction may be sufficient to spread the time of arrival and therefore reduce the amplitude of response.

2. The afferent responses recorded from the nerve root after stimulation at the popliteal space did not necessarily favor the L-5 root for the peroneal nerve nor the S-1 root for the tibial nerve (Table 1).

3. If an efferent response following stimulation above the disc was absent or almost absent, or if there was a very high threshold below the disc, afferent recording demonstrated loss of response from below as well as above the disc.

4. The finding of an elevated threshold to stimulation below the disc, as illustrated in Group IV, was unexpected. In this group a relatively low intensity stimulus delivered above the disc was sufficient to excite a maximum response from the muscle. However, a stimulus delivered below the disc had to be stronger than that above the disc just to evoke a minimum response which usually had an increased latency. A stimulus delivered below the disc had to be 2 to 3 times stronger than a stimulus above the disc in order to obtain maximum response. On stimulation below the disc the slower conducting fibers had the lower threshold.

5. In two Group V patients, the response on afferent recording was absent from above and below the disc without severe alteration in the efferent response, and the underlying causes for peripheral neuropathy were identified as chronic alcoholism and diabetes mellitus. These patients did not have clinical signs of sensory or motor neuropathy nor was there slowing of peripheral motor nerve conduction velocity.

| TABLE 1 |
| Distal segment afferent recording |
| (combined motor-sensory) |
| | L-5 | S-1 |
| Amplitudes showing more than \( \frac{1}{2} \) rd's difference: |
| Tibial more than peroneal | 2 | 2 |
| Peroneal more than tibial | 3 | 2 |
| Amplitudes showing less than \( \frac{1}{2} \) rd's difference: |
| Peroneal and tibial about equal | 3 | 6 |
6. One patient with compression of the S-1 nerve root had a depressed ankle jerk. Preoperatively, an H-reflex with 34 ms latency was recorded following stimulation of the tibial nerve in the popliteal space. At operation, the motor latency of the gastrocnemius muscle response to stimulation at the nerve root was 16 ms. The latency to the afferent response at the nerve root following stimulation of the tibial nerve in the popliteal space was 11 ms. A period of 8 ms remained for the impulse to complete the reflex arc from the lumbosacral interspace, synapse within the spinal cord, and return.

7. In some recordings it was difficult to be certain of technical accuracy. For example, one could not be sure that the paired EEG electrodes were actually bridging and were not including some of the segment of nerve root which had been compressed by the disc. In afferent recording it was necessary to maintain equal distances between the electrodes of each pair. A distance less than 1 cm tended to cause reduced amplitude of response. The extent of the surgical exposure did not always provide the desired length of nerve root. At times, on afferent recording, a nerve action potential was registered from the pair of electrodes above the disc but not from below it. We presumed that volume-conducted voltages from an adjacent nerve root were being registered, since the polarity of response was reversed. However, the inverted response seen in the middle trace of Figure 4 E was recorded from within the zone of injury of the nerve root. This was clear since there was a response recorded below the disc but not above.

From the standpoint of clinical correlation, patients in Group II (without motor conduction deficits) demonstrated rather prompt and uncomplicated postoperative recoveries. Patients in Groups III and IV, who had obvious motor conduction deficits, whether these were demonstrable in the segment above or below the site of compression, did less well and were frequently subject to muscle cramping and more prolonged convalescence. From a prognostic point of view, at least on theoretical grounds, a discrepancy between responses above and below the compressed segment suggests that functional improvement in the motor or sensory deficit was possible once the compression had been removed; that is, the changes were reversible.

This form of direct and objective evidence of conduction deficit across the nerve root can be of specific diagnostic interest and on occasion has been of diagnostic assistance. Unfortunately the method involves surgical exposure of the nerve root.

Summary

Nerve root stimulation and recording techniques were used to evaluate changes in conduction through the zone of injury in 32 lumbar nerve roots compressed by herniated disc material. A technique of recording the compound nerve action potential composed of antidromic motor and orthodromic sensory impulse was more sensitive for demonstrating an abnormality in conduction than one which simply recorded the muscle action potential. The type of motor response was of some value in predicting the postoperative course of symptoms. This type of testing has been of diagnostic assistance in confirming compression of the nerve root in problem cases.

Acknowledgments

We have appreciated the cooperation and assistance of Dr. Robert G. Selker, who included some of his patients in this study, and also the help and advice offered by Dr. William J. German.

References