Motor Nerve-Conduction Studies in Obstetric Brachial Plexopathy for a Selection of Patients with a Poor Outcome
Background: The criteria and timing for nerve surgery in infants with obstetric brachial plexopathy remain controversial. Our aim was to develop a new method for early prognostic assessment to assist this decision process.

Methods: Fifty-four patients with unilateral obstetric brachial plexopathy who were ten to sixty days old underwent bilateral motor-nerve-conduction studies of the axillary, musculocutaneous, proximal radial, distal radial, median, and ulnar nerves. The ratio between the amplitude of the compound muscle action potential of the affected limb and that of the healthy side was called the axonal viability index. The patients were followed and classified in three groups according to the clinical outcome. We analyzed the receiver operating characteristic curve of each index to define the best cutoff point to detect patients with a poor recovery.

Results: The best cutoff points on the axonal viability index for each nerve (and its sensitivity and specificity) were <10% (88% and 89%, respectively) for the axillary nerve, 0% (88% and 73%) for the musculocutaneous nerve, <20% (82% and 97%) for the proximal radial nerve, <50% (82% and 97%) for the distal radial nerve, and <50% (59% and 97%) for the ulnar nerve. The indices from the proximal radial, distal radial, and ulnar nerves had better specificities compared with the most frequently used clinical criterion: absence of biceps function at three months of age.

Conclusions: The axonal viability index yields an earlier and more specific prognostic estimation of obstetric brachial plexopathy than does the clinical criterion of biceps function, and we believe it may be useful in determining surgical indications in these patients.

Level of Evidence: Prognostic Level II. See Instructions to Authors for a complete description of levels of evidence.

Obstetric brachial plexopathy occurs in approximately 1.5 of 1000 live births, and this prevalence seems to be increasing despite medical progress in obstetrics. Although the natural history of these lesions is not well defined, most of these children recover well without surgery. However, some have development of a severe lifelong motor impairment, and the indications for and timing of brachial plexus surgery for these patients are a matter of controversy. Patients who receive an early intervention have a better prognosis, but it can also mean that some patients have unnecessary surgery. The most frequently used clinical criterion, which was defined by Gilbert et al. twenty years ago, is based on the absence of biceps function at three months of age; however, there is some confusion regarding the exact definition of so-called biceps function. Gilbert et al. used palpable biceps contraction, while others use elbow flexion. The presence of voluntary biceps electrical activity

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in electromyography is not considered biceps function. The Gilbert criterion has been criticized because of its lack of specificity; therefore, some surgeons prefer to wait longer in order to avoid unneeded surgery.

Most surgeons do not rely on electromyography for the selection of infants for brachial plexus surgery. Needle electromyography is an uncomfortable procedure, which is difficult to perform in an uncooperative patient, and it requires a well-trained neurophysiologist with pediatric expertise. Many authors have reported that needle electromyography is usually overly optimistic in relation to clinical evaluation, and this was confirmed in a recent study by our group. On the other hand, nerve conduction studies may still be helpful. The side-to-side comparison of the amplitudes of compound muscle action potentials can provide an estimation of the amount of motor axonal degeneration of the terminal nerves arising from the brachial plexus. We have shown that the ratio between the amplitude of the compound muscle action potential of the affected side and that of the healthy side is related to clinical recovery in these patients.

The objectives of this study were to determine whether this index can be useful for the selection of infants with a poor prognosis, to establish neurophysiologic criteria, and to compare the performance of this index with the clinical criterion proposed by Gilbert et al.

**Materials and Methods**

From July 2000 to February 2007, seventy-seven patients with obstetric brachial plexopathy who were less than sixty days old were referred to our hospital. Thirteen patients showed remarkable clinical recovery after a few days and were not considered for neurophysiologic evaluation. We also excluded one

<table>
<thead>
<tr>
<th>Motor Nerve</th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
<th>P Value†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axillary</td>
<td>47% (16%-90%)</td>
<td>17% (1%-52%)</td>
<td>0% (0%-50%)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Musculocutaneous</td>
<td>45% (0%-123%)</td>
<td>3% (0%-43%)</td>
<td>0% (0%-6%)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Proximal radial</td>
<td>68% (22%-136%)</td>
<td>43% (14%-83%)</td>
<td>0% (0%-44%)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Distal radial</td>
<td>106% (47%-142%)</td>
<td>83% (55%-145%)</td>
<td>3% (0%-113%)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Median</td>
<td>89% (8%-275%)</td>
<td>88% (10%-190%)</td>
<td>54% (0%-300%)</td>
<td>0.14</td>
</tr>
<tr>
<td>Ulnar</td>
<td>104% (44%-193%)</td>
<td>82% (62%-157%)</td>
<td>36% (0%-147%)</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

*The values are given as the median, with the range in parentheses. †Kruskal-Wallis test.
patient who had cerebral palsy develop, two patients with bilateral lesions, and seven patients who were lost to follow-up. The remaining fifty-four patients are the subjects of this prospective cohort study. Sample size was determined by convenience.

The birth weight ranged from 2695 to 5515 g (median, 3820 g). There were thirty-four normal vaginal deliveries (63%), including two breech presentations (4%); nineteen forceps-assisted deliveries (35%); and one cesarean section delivery (2%). Thirty patients (56%) were boys, and twenty-four were girls. The right side was affected in thirty-eight patients (70%) and the left side, in sixteen (30%). Thirty-five subjects (65%) had clinical evidence of a lesion of the C5-C6 levels, thirteen (24%) had involvement of the C5-C7 levels, five (9%) had complete lesions, and one (2%) had C7-T1 involvement. This last patient with Klumpke palsy was evaluated two days after a breech delivery and showed hand paralysis and wrist drop with preserved shoulder abduction and elbow flexion.

The patients underwent bilateral motor-nerve-conduction studies between ten and sixty days of age (median, twenty days), with forty patients (74%) who were seen during the first month. The hospital ethics committee approved the study, and parents provided written informed consent. The nerves (and muscles) evaluated included the axillary (deltoid), musculocutaneous (biceps), proximal radial (triceps), distal radial (extensor digitorum communis), median (thenar eminence), and ulnar (hypothenar eminence). Technical data concerning electrode type and placement are provided in our previous study. The placement of recording electrodes should be as symmetrical as possible, as this is the main source of variability. We compared the side-to-side amplitudes of compound muscle action potentials and defined the axonal viability index as the amplitude of the affected side expressed as a percentage of the corresponding value of the healthy side.

All of the patients were followed on a monthly basis by the same pediatric neurologist (C.O.H.), who used a standard evaluation protocol that included power assessment of shoulder abduction and external rotation, elbow flexion and extension, forearm supination, wrist extension and flexion, extension and flexion of the fingers, and thumb opposition. We used a modified Medical Research Council motor scale, ranging from 0 (no contraction) to 5 (normal findings) for each movement (see Appendix). This modification incorporates some concepts from the motor scale of The Hospital for Sick Children. For infants older than six months, we also used a modification of the so-called towel test, in which the child should be able to remove a blindfold from the face, while in the sitting position, using the affected limb and without flexing the neck.

The infants were divided into three groups. Patients in group A showed complete recovery at six months of age, with no muscle strength asymmetry and a normal towel test with the affected limb. Patients in group B had a good outcome at twelve months of age. These patients were able to perform the towel test with the affected limb at this age and fulfilled the criteria for...
a good outcome according to Narakas (see Appendix\textsuperscript{26}). Patients in group C were considered to have a poor outcome. These patients were not able to perform the towel test with the affected limb and did not fulfill the Narakas criteria for a good outcome at twelve months of age.

We calculated the average axonal viability index for each group and used the Kruskal-Wallis test to verify group differences for each motor nerve evaluated.

Our objective was to detect patients in group C with use of neurophysiologic criteria by that of the clinical criterion. We also calculated the 95% confidence interval for its sensitivity and specificity.

In order to compare the methods, we divided the sensitivity and specificity obtained from the neurophysiologic criteria by that of the clinical criterion. We also calculated the 95% confidence interval of that ratio. If the confidence interval included the number one, there was no significant difference between the two methods.

**Source of Funding**
There was no external funding source for this study.

**Results**
Twenty patients (37%) had a fast recovery, showed no muscle strength or movement asymmetry at six months of age, and were assigned to group A (a complete recovery). These patients were not able to perform the towel test with the affected limb and did not fulfill the Narakas criteria for a good outcome at twelve months of age.
included seventeen patients (85%) presenting initially with C5-C6 involvement, two patients (10%) with C5-C7 involvement, and one (5%) with Klumpke palsy. At six months of age, ten of these patients showed only minor deep tendon reflex asymmetries during the clinical evaluation. In the remaining patients, it was not possible to determine by clinical evaluation which was the originally affected limb.

Seventeen patients (31%) had a good recovery and were assigned to group B. All were able to perform the towel test with the affected limb, while in the sitting position, without assistance at twelve months of age. Five of these patients showed no clear movement asymmetry. All five of them presented initially with C5-C6 involvement. These patients were not assigned to group A, since such delayed recoveries are probably not truly complete. Seven patients, including six patients presenting initially with C5-C6 involvement and one with C5-C7 involvement, showed minor asymmetries or scapular winging. Five patients showed obvious motor deficits or the trumpet sign. These motor deficits were related to shoulder external rotation and abduction or forearm supination. Four of these children initially had C5-C6 involvement, and one had C5-C7 involvement.

Seventeen patients (31%) were assigned to group C, as they were unable to perform the towel test at twelve months of age. The follow-up period for this group actually ranged from eighteen to seventy-three months, and none fulfilled the Narakas criteria for a good outcome after the twelve-month observation period. All five patients presenting initially with global paralysis, as well as nine patients with C5-C7 involvement and three with motor deficits restricted to the C5-C6 levels, were included in this group. Eight patients in this group underwent external neurolysis between six and twelve months of age, but none showed muscle power deterioration after surgery. Eight patients in group C had biceps muscle power of less than grade 3 at one year of age, and another patient had transient finger-biting behavior develop.

The compound muscle action-potential amplitudes obtained from the control side of the patients are shown in a table in the Appendix. The distribution is not gaussian, so median values are presented instead of means.

We analyzed the distribution of axonal viability index values in each group for every motor nerve studied. Figure 1 shows an example of a scatterplot of the values. The axonal viability index median and range for each group are shown in Table I. A significant difference was detected among the groups for all motor nerves, except for the median nerve. The median nerve also showed marked dispersion of axonal viability index

<p>| TABLE II Cutoff Point, Sensitivity, and Specificity of Each Criterion for Poor Outcome |
|--------------------------------------|--------------------------------------|--------------------------------------|</p>
<table>
<thead>
<tr>
<th>Criteria</th>
<th>Cutoff Point</th>
<th>Sensitivity (95% Confidence Interval)</th>
<th>Specificity (95% Confidence Interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neurophysiologic criteria (axonial viability index)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Axillary nerve</td>
<td>&lt;10%</td>
<td>88% (64%-98%)</td>
<td>89% (75%-97%)</td>
</tr>
<tr>
<td>Musculocutaneous nerve</td>
<td>0%</td>
<td>88% (64%-98%)</td>
<td>73% (56%-86%)</td>
</tr>
<tr>
<td>Proximal radial nerve</td>
<td>&lt;20%</td>
<td>82% (57%-96%)</td>
<td>97% (86%-100%)</td>
</tr>
<tr>
<td>Distal radial nerve</td>
<td>&lt;50%</td>
<td>82% (57%-96%)</td>
<td>97% (86%-100%)</td>
</tr>
<tr>
<td>Ulnar nerve</td>
<td>&lt;50%</td>
<td>59% (33%-82%)</td>
<td>97% (86%-100%)</td>
</tr>
<tr>
<td>Clinical criterion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biceps score on Medical Research Council motor scale at 3 mo</td>
<td>&lt;2</td>
<td>94% (71%-100%)</td>
<td>81% (65%-92%)</td>
</tr>
</tbody>
</table>

Fig. 6
The receiver operating characteristic curve for the axonal viability index of the ulnar motor nerve. From the lower left corner to the upper right corner (excluding the upper right corner itself), the three dots represent, respectively, the axonal viability index cutoff points of 0%, <10% to 20%, and <50%. The cutoff points of <10% and <20% overlapped. The best cutoff point was an axonal viability index of <50%.
values, with values of up to 300%. Therefore, the axonal viability index for the median nerve was excluded from the receiver operating characteristic curve analysis.

The empirical receiver operating characteristic curves for each motor nerve are shown in Figures 2 through 6. From the lower left corner to the upper right corner, the five dots represent, respectively, the Medical Research Council score cutoff points of 0, <2, <3, <4, and <5. The best cutoff point was a Medical Research Council score of <2 (no elbow flexion).

We also analyzed the distribution of the Medical Research Council scores for the biceps at three months of age among the groups, as shown in the Appendix. There was a significant difference among the groups (p < 0.01). We also constructed an empirical receiver operating characteristic curve to select the best cutoff point to define patients with a poor prognosis (Fig. 7). Despite the good specificity for the absence of biceps contraction, the best cutoff value was considered the absence of elbow flexion, which showed a much higher sensitivity. The sensitivity, specificity, and 95% confidence intervals are shown in Table II.

The comparison of sensitivity between the neurophysiologic criteria and the clinical criterion is shown in Figure 8. The sensitivity was higher for the clinical criterion, but this was significant only for the ulnar nerve (p < 0.05), with a sensitivity of 37% less than that of the clinical criterion. The comparison of specificity between the neurophysiologic criteria and the clinical criterion is shown in Figure 9. The specificity was usually higher for the neurophysiologic criteria, and this was significant for the proximal radial, distal radial, and ulnar nerves (p < 0.05), with the specificity being 20% higher than that of the clinical criterion.

Seven patients were lost to follow-up, and six of the seven were evaluated until at least three months of age. At the time of the last evaluation, two patients had active elbow flexion and four did not. If we assume all lost patients had a poor outcome, the specificity of motor conduction studies would be 75% (95% confidence interval, 53% to 90%) for the axillary nerve, 87% (95% confidence interval, 68% to 97%) for the musculocutaneous nerve, 67% (95% confidence interval, 43% to 84%) for the proximal and the distal radial nerve, and 42% (95% confidence interval, 22% to 63%) for the ulnar nerve. The sensitivity of absent elbow flexion at three months of age would be 87% (excluding the patient lost before this age), which would be significantly higher than that of the motor conduction study of the ulnar nerve. If we assume all of the lost patients had a good outcome, the specificity of motor conduction studies would be 84% (95% confidence interval, 70% to 93%) for the axillary nerve, 64% (95% confidence interval, 48% to 78%) for the musculocutaneous nerve, 93% (95% confidence interval, 81% to 99%) for the proximal and the distal radial nerve, and 98% (95% confidence interval, 88% to 100%) for the ulnar nerve. The specificity of absent elbow flexion at three months would be 74%, which is still substantially less than that of the motor conduction studies of the proximal radial, distal radial, and ulnar nerves.
lesions. Other authors have also reported poor results after neurolysis\textsuperscript{33,34}. We now have adopted a more aggressive approach, and nerve grafts are usually used in these patients after intraoperative monitoring of nerve action potentials. Patients having nerve graft surgery were not included in this series.

An axonal viability index of >100% seems unusual, but this only reflects a compound muscle action-potential amplitude on the affected side that is larger than that on the healthy side. The normal asymmetry of compound muscle action-potential amplitudes in adults can range up to 50%\textsuperscript{29,35}, but there are no similar studies in newborns. Assuming an asymmetry similar to that in adults, axonal viability index values of up to 200% would be expected. This was true for all except the median nerve. The great dispersion of axonal viability index values in the median nerve was due to low compound muscle action-potential amplitudes, even on the healthy side. Our electrodes had a diameter of 1 cm, and this usually covered all of the thenar muscles and possibly caused phase cancellation of the motor unit potentials or short circuits beneath the electrode. For larger muscles, the electrode size was not a problem. Reproducibility of compound muscle action-potential amplitudes in newborns was not addressed in our study. This is also a concern in similar tests such as the facial motor-nerve-conduction study for prognostic assessment of facial nerve palsy in adults\textsuperscript{36,37}, despite the fact that it has been commonly used for a long time. Perhaps most of the so-called normal 50% asymmetry between sides is, in fact, related to minor differences in the placement of the recording electrodes, which also would affect reproducibility. This precludes motor nerve-conduction studies as a diagnostic test, since minor differences could not be noted. However, in the case of prognostic assessment, we are dealing with major differences between the two arms.

Analyzing the area under the receiver operating characteristic curves, we concluded that the proximal radial motor-nerve-conduction study was the best test of all, but axillary and distal radial nerves were also good. The musculocutaneous nerve-conduction study had a low specificity, while the ulnar nerve study had a low sensitivity. The low sensitivity of the ulnar nerve study was related to the pathophysiology, since we were analyzing the lower part of the brachial plexus and most obstetric lesions do not affect that portion. An absent compound muscle action potential was always associated with a poor prognosis, except for the musculocutaneous nerve, and the low specificity of this nerve may be related to stimulation problems. The musculocutaneous nerve was stimulated at the axilla, very close to the median nerve. High currents could not be used since the current spread would activate the median nerve and cause a volume-conducted potential from the forearm muscles. Conversely, selective stimulation of the axillary and proximal radial nerves was impossible (both were stimulated at Erb's point), but volume-conducted potentials from other than the target muscles were not a problem. Variability in test performance could affect the result in borderline cases, so we recommend that several nerves should be evaluated and that all data be analyzed together, instead of relying on a single axonal viability index.
In our previous study, we found that an axonal viability index of >10% was related to recovery of the corresponding level of the brachial plexus. This continues to be our opinion, but our approach was different this time since we were interested in the recovery of the patient as a whole. An axonal viability index of the ulnar nerve of 30% would mean that the chance of recovering finger flexion is good, but the overall prognosis is poor. A lesion severe enough to cause ulnar axonal degeneration probably is associated with a major axonal degeneration of the upper levels, assuming the usual cranial-caudal gradient of the lesion.

We found good specificity of the clinical criterion in our study. In fact, it was better than has been previously reported by other authors. Nevertheless, nerve conduction studies provided higher specificity values, with similar sensitivity. The patients lost to follow-up did not affect this result. Some may say that the clinical criterion proposed by Gilbert et al. was actually the absence of biceps contraction, and if this criterion were used, the specificity would be 100%. This is true, but this interpretation would decrease the sensitivity to only 47%. If absent compound muscle action potentials were used as the neurophysiologic criteria, the specificity of motor conduction studies of the axillary, proximal radial, distal radial, and ulnar nerves would also be 100%. The receiver operating characteristic curve analysis is particularly useful in this matter, since it provides sensitivity and specificity with different cutoff values. We selected the most accurate cutoff value, but different values could be used depending on specific needs, for example, to maximize sensitivity or specificity.

Perhaps the great advantage of motor conduction studies in relation to clinical evaluation is the timing of the prognostic estimation. Motor conduction studies can provide prognostic information with high specificity as soon as ten days after birth, whereas we would have to wait at least three months using the standard approach. We are not proposing surgery before three months of age yet, but this period could be used to perform elective imaging studies in selected patients. This extra time could be helpful for parents who are considering surgery, and it could provide time to refer the child to other centers with expertise in obstetric brachial plexopathy management for a second opinion.

The value of clinical examination, which remains a hallmark surgical indication, should not be diminished. However, nerve conduction studies can be very helpful in the treatment decision process. Our protocol is easy to perform, is widely available, and is more objective than the standard neurophysiologic approach.

Appendix

Tables showing the modified Medical Research Council motor scale, the Narakas criteria, the compound muscle action potentials on the normal limb, and a figure depicting the spread of Medical Research Council scores for the biceps are available with the electronic versions of this article, on our web site at jbj.org (go to the article citation and click on “Supplementary Material”) and on our quarterly CD/DVD (call our subscription department, at 781-449-9780, to order the CD or DVD).

References


