Neurosurgical correction of upper brachial plexus birth injuries

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The authors review the cases of 116 infants treated consecutively for birth-related brachial plexus injuries. Twenty-eight infants with upper brachial plexus lesions who showed no neurological improvement by 4 months of age were selected for early surgical reconstruction (at a mean age of 5 months). Neurological improvement of the affected arm was observed in more than 90% (p < 0.05) of the children examined longer than 9 months after brachial plexus reconstruction. A conservatively managed control subgroup of 44 children, first examined at less than 3 months of age, demonstrated neurological improvement by 4 months of age and continued to show improvement at 1 year of age. Early surgical reconstruction is recommended for infants with birth-related upper brachial plexus injury who show no neurological improvement by the age of 4 months.

KEY WORDS • brachial plexus • birth injury • infant

The incidence of brachial plexus birth injuries varies from one to two in every 1000 live births.13 The majority of infants will recover prior to consultation with a referral physician. This report considers the neurosurgical approach to birth injuries of the upper brachial plexus that have not shown improvement with conventional conservative therapy by the time the infant has reached the age of 4 months.

Clinical Material and Methods

Patient Population

Of the 127 children consecutively evaluated for brachial plexus injury at The Texas Children's Hospital Brachial Plexus Clinic between 1987 and 1990, 116 had birth-related injuries and were assessed to determine whether surgery might be beneficial. A predominant plexus level of involvement was noted by 2 months of age in all infants. All children with upper brachial plexus injuries to the C-5, C-6, and C-7 nerve roots demonstrated classic Erb's palsy in which the arm is limp, the shoulder abducted and internally rotated, the elbow extended, the forearm pronated, and the wrist and fingers flexed.

All children were evaluated by the same clinical paradigm (Fig. 1) on a quarterly basis. The neurological assessment utilized the standard British Research Council's Muscle Movement Scale (MMS) with grades of 0 to 5 (normal = 5); movements of the deltoid, biceps, and triceps muscles were rated.21 Neurological improvement was defined as improvement in two of the three muscles. Infants were selected for surgery if no neurological improvement in upper plexus lesions had manifested by 4 months of age. Postoperative analysis involved the same muscles. Chest, clavicular, shoulder, and elbow roentgenograms were obtained at birth by the referring physicians. Computerized tomography (CT)-metrazamide myelograms were obtained prior to surgery only in those children selected for surgery. Electromyograms (EMG's) were obtained at the first clinic visit and repeated prior to surgery and at one or more postoperative visits.

The 116 children were divided into three groups according to treatment: those treated nonsurgically, those whose parents refused recommended surgery and were treated conservatively, and those who underwent surgery. Eighty-eight children were in the nonsurgical group and received physical therapy as the primary treatment modality or were not evaluable. The parents of four children received a recommendation for surgery but refused; these four were treated conservatively. The 24 infants who demonstrated no neurological improvement in upper plexus lesions by 4 months of age according to the standard described above underwent surgical reconstruction of the plexus.

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Once surgical repairs were accomplished, the wounds were closed with subcuticular sutures and the arm was placed in a shoulder sling, wrapped, and held closely to the body. The sling and body-wrap were changed daily and removed permanently 10 days postoperatively so that full physical therapy could proceed. Neurological assessment continued on a quarterly basis.

Neuromas were excised and treated with an interpositional nerve graft or end-to-end anastomosis when a drop in the muscle action potential amplitude across the neuroma was greater than 50%, using the same electrical voltage for stimulation of the areas before and after the neuroma. If the above criterion was not satisfied, extensive internal neurolysis of the neuroma was performed.

Electrophysiological Studies

After surgical exposure of the brachial plexus, evoked responses to the spinal cord were elicited by stimulation of the C-5, C-6, and C-7 nerve roots. A nerve root was considered to be avulsed (disconnected) from the spinal cord if no spinal evoked response could be elicited. Avulsed nerve roots were not used as proximal sites of nerve graft anastomoses. Rupture (neurotmesis) of the extraparavertebral nerve roots was determined by the absence of muscle action potentials measured at the deltoid, biceps, and triceps muscles when the exiting nerve roots were stimulated at the foramina. Nerve bypass grafting and/or neurolysis of the neuroma were considered the procedures of choice when ruptures of the nerve roots were diagnosed.

Statistical Evaluation

The operative procedures were divided into three groups: neurolysis, grafting, and end-to-end anastomosis. The neurological evaluation was compared among these procedural groups using standard mean paired t-tests. Each individual procedural group and the total surgical group were then compared to a nonsurgical subgroup of 44 children (children with upper plexus lesions seen initially at less than 3 months of age and followed for more than 12 months) using standard mean paired t-tests. The nonsurgical subgroup was evaluated using Whitney-Mann probability testing.

Results

Among the 116 infants with birth-related injuries in this series, pure upper brachial plexus lesions (C-5, C-6, and C-7) were seen in 82 cases (two bilateral), pure lower plexus lesions (C-7, C-8, and T-1) in 10, and combined lesions in 24 (three bilateral). Sixty children had lesions on the right side, 51 had lesions on the left, and five had bilateral lesions.

Conservative Therapy Group

In the group of 88 infants not selected for surgery, 65 pure upper plexus lesions (one bilateral), 10 pure lower plexus lesions, and 16 combined lesions (two bilateral) were noted. By adding both pure and combined upper plexus lesions, 81 lesions in the 88 infants had involvement of upper plexuses. Right-sided lesions
were found in 49 patients, left-sided lesions in 36, and bilateral lesions in three.

Of these 88 nonsurgically managed children, 72 were available for further evaluation; 10 patients were lost to follow-up review. Two children with bilateral combined lesions died, and it was deemed too early in four children to perform adequate neurological evaluation for possible surgery. The nonevaluable group included 10 pure upper plexus lesions, five combined lesions, and three lower plexus lesions.

Of the 72 evaluable children, 44 (41 with pure upper plexus and three with combined lesions) were seen initially at less than 3 months of age and were followed for more than 12 months; these served as a nonsurgical control group to determine the rate of spontaneous neurological recovery. All infants in this group demonstrated neurological improvement of at least one grade in two of the three muscle groups analyzed (deltoid, biceps, and triceps) by 4 months of age (Fig. 2). All of these children attained near normal function of these muscles by 12 months of age. The remaining 28 infants in the evaluable group of nonsurgically treated infants (14 pure upper plexus lesions, eight combined lesions [one bilateral], and seven pure lower plexus lesions) were first referred for consultation at more than 4 months of age.

Group With Refusal of Surgery

All four of the children whose parents refused recommended surgery have remained unimproved at more than 12 months of age. All had pure upper plexus lesions.

Surgical Group

Twenty-four children with birth-related upper brachial plexus injuries received early surgical intervention. All infants recommended for early surgery were seen before 3 months of age, 4 months of age being the time at which the decision for surgery was made. Age at surgery ranged from 2 to 18 months (mean 5 months). In these 24 infants, 16 pure upper brachial plexus lesions (two bilateral) and 10 combined plexus lesions were noted. Seven had right-sided lesions, 15 had left-sided lesions, and two had bilateral lesions.

Of the 25 plexuses operated on (one patient required bilateral exploration), surgery was performed at less than 3 months of age in four infants, at less than 7 months in 17, and at greater than 7 months in four. In the four infants undergoing surgery at less than 3 months of age, CT-myelography demonstrated avulsions of the C-5 and C-6 nerve roots. Social and travel problems in the four infants less than 3 months of age necessitated an earlier operation.

Each plexus may have had multiple procedures performed: neurolysis (Fig. 3), grafting (Fig. 4), or end-to-end anastomosis (Fig. 5). The follow-up period for this group ranged from 18 to 48 months postoperatively; none was lost to follow-up review.

Avulsions, Ruptures, and Neuromas. Table 1 summarizes the lesions found in the 24 infants at surgery. Avulsions of 22 nerve roots and ruptures of 43 nerve roots were observed in 25 upper brachial plexus explo-
Neuromas were common. Twenty-two of the 25 brachial plexuses explored had neuromas, many of which incorporated the roots, trunks, and cords of the upper brachial plexus and required extensive dissection. Fibrosis of both scalenus and omohoid muscles was seen in conjunction with the neuroma. The C-5 and C-6 nerve roots were involved with neuromas in all repaired plexuses (22 each), and neuromas were observed on the C-7 nerve root in 12 cases. Extensive internal neurolysis of neuromas with identification of connecting fascicles was completed in 18 of the 22 repairable brachial plexuses explorations, six times each involving the C-5, C-6, and C-7 nerve roots. In those plexuses requiring neuroma removal, multiple sural nerve grafting from different roots was carried out; 14 grafts originated from the C-5 nerve root, seven from the C-6, and two from the C-7. Direct end-to-end anastomosis was completed on two brachial plexuses after neuroma removal.

Neurological Assessment. For purposes of neurological evaluation of the operative technique, three surgical groups were defined: neurolysis, grafting, and end-to-end anastomosis. In general, the plexuses requiring only neurolysis and/or end-to-end anastomosis exhibited better preoperative neurological examinations (Figs. 6 and 7). Nine months postoperatively in all surgical groups, all muscles evaluated (deltoid, biceps, and triceps) showed neurological improvement of at least one grade. By 12 months or more postoperatively, the mean improvement of the deltoid and biceps muscles was at least an MMS grade of 3 (antigravity). Improvement was most dramatically seen in those plexuses that had been treated with the grafting technique (Fig. 8).

Although pre- and postoperative EMG's were obtained, they had no predictive value for neurological improvement in our series. The intraoperative electrophysiological studies described above were exceedingly useful in determining surgical options (neurolysis or neuroma excision). Intraoperative evoked responses detected avulsed nerve roots. Computerized tomography-myelography was useful only as confirmation of nerve root avulsions detected with intraoperative evoked responses (correlation coefficient = 0.8).

Statistical Analysis

The preoperative mean cumulative MMS grade for all three surgery groups involving the three muscle groups was 13 ± 1, while the value at 12 months postoperatively was 31 ± 1. Using the paired difference t-test, the probability that the improvement in neurological function was due to the surgery was significant (p < 0.05) as compared to what would be expected from chance alone.

The mean MMS grade of the muscle groups of the 44 children in the nonsurgical subgroup at 4 months of age was 3 ± 1, compared to the mean grade of 1.6 ± 1 in the 20 children in the surgical group at 4 months of age (four infants undergoing surgery at less than 4 months of age were not included in the above analysis). Using the paired t-test, the probability that the two groups were significantly different (p < 0.05) exceeds chance alone.
Brachial plexus repair in infants

<table>
<thead>
<tr>
<th>TABLE 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesions observed during upper brachial plexus exploration*</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Nerve Roots</th>
<th>Total Neurons</th>
<th>Avulsions No.</th>
<th>Percent</th>
<th>Ruptures No.</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-5</td>
<td>22</td>
<td>4</td>
<td>18</td>
<td>21</td>
<td>49</td>
</tr>
<tr>
<td>C-6</td>
<td>22</td>
<td>10</td>
<td>46</td>
<td>15</td>
<td>35</td>
</tr>
<tr>
<td>C-7</td>
<td>12</td>
<td>8</td>
<td>38</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>total cases</td>
<td>56</td>
<td>22</td>
<td>100</td>
<td>43</td>
<td>100</td>
</tr>
</tbody>
</table>

* Percentages are of total lesions observed.

FIG. 8. Graph showing Muscle Movement Scale grade related to the postoperative period in 23 infants with sural nerve grafting after neuroma removal. Average age at surgery was < 5 months. All obtained a grade of 3 or greater by 12 months postoperatively (arrow).

Discussion

History in the Literature

Smellie31 is credited with the initial description in 1768 of a brachial plexus injury related to a face birth presentation in an infant with bilateral brachial plexus palsies that resolved in a few days. Duchenne de Boulogne7 published an authoritative book in 1872 on the physical findings in an infant with brachial plexus palsy. Erb6 described an electrical stimulation point in normal individuals, thus gaining credit for description of upper brachial plexus injuries. Combined upper and lower plexus injuries were first characterized by Seeligmüller27 in 1877; however, Klumpke9 gave a more complete description in 1885 which made his name synonymous with injuries of the lower brachial plexus.

Pathophysiology

The pathophysiology for birth-related brachial plexus injuries was initially thought to be external compression. Sever28 determined that excessive lateral neck flexion at delivery could cause a stretch injury to exiting nerve roots of increasing severity from the upper to lower plexus roots. Taylor12 found that less force was required to avulse the lower brachial plexus roots than the upper roots. In our series, rupture injuries were more common in the upper roots of the brachial plexus (Table 1) while avulsions were common in the lower roots.

With acceptance of the stretch theory of birth-related injuries to the brachial plexus in the 1900's, obstetrical factions began to be identified in the literature.13,29 Multiparous mothers, prolonged labor, increased birth weight, and shoulder dystocia have all been reported,14 and our experience in the Brachial Plexus Clinic confirms these reports. Prematurity and Caesarean deliveries with resultant brachial plexus injury were seen in our series. Our most severe case of bilateral combined birth-related brachial plexus injury was a child born by Caesarean delivery.

Clinical Presentation

Families and obstetricians commonly observe combined plexus injuries at birth. If the injury does not resolve quickly, a relatively predominant lesion will be established within 6 to 8 weeks after delivery. Pure upper brachial plexus lesions were common in our series (82 cases). Isolated lower brachial plexus lesions were seen in only 10 infants. Laterality of the lesions likely relates to random head rotation through the birth canal.

Justification for Surgery

Before surgical intervention can be judged beneficial, the neurological outcome of conventional conservative treatment of birth-related upper brachial plexus injuries must be examined. Wickstrom15 reported that 60% of birth-related brachial plexus injuries did not recover to provide good functional status in the upper extremity. Gjørup16 studied 103 patients with birth-related brachial plexus injuries for 33 years; 70% of these had no functional recovery while the remaining 30% had some recovery. All of these patients described themselves as handicapped. Other authors have endorsed this long-term pessimistic viewpoint.2,30

Rate of Recovery

The rate of spontaneous recovery offers the possibility of prediction of functional recovery. The Collaborative Perinatal Study reported complete return of function in 95% of infants with birth-related brachial plexus injuries; 93% showed some recovery by 4 months of age.13 Bennet and Harrold14 reported that infants showing some sign of spontaneous recovery before 5 months of age will have complete return of function. Wyeth and Sharpe24 recommended surgery in infants with birth-related brachial plexus injuries if no recovery was demonstrated by 3 months of age. Metaizeau, et al.,22 and Gilbert and Tassin26 found that infants exhibiting no spontaneous recovery of the biceps by 3 months of age will not have satisfactory return of function.

In our nonsurgery group of 44 infants with upper brachial plexus birth injuries, seen initially at less than 3 months of age and followed until at least 12 months of age, all showed neurological improvement by 4 months of age and continued to progress. Historically, the most common waiting period for functional improvement to occur has been 3 months (Table 2).15,8

Surgical History

In 1903, Kennedy18 described the first surgical intervention for birth-related brachial plexus injury: resection of neuromas and suturing of nerves; he recom-
TABLE 2
Historical review of surgical timing for birth-related brachial plexus injury*

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>No. of Cases Reviewed</th>
<th>Surgically Explored Cases</th>
<th>Time for Initial Improvement</th>
<th>Surgery Recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wyeth &amp; Sharpe, 1917</td>
<td>—</td>
<td>81</td>
<td>≤ 3 mos</td>
<td>yes</td>
</tr>
<tr>
<td>Taylor, 1920</td>
<td>—</td>
<td>70</td>
<td>≤ 3 mos</td>
<td>yes</td>
</tr>
<tr>
<td>Gordon, et al., 1973 (Collaborative Perinatal Study)</td>
<td>—</td>
<td>—</td>
<td>≤ 4 mos</td>
<td>—</td>
</tr>
<tr>
<td>Eng, et al., 1978</td>
<td>135</td>
<td>—</td>
<td>≤ 2 mos</td>
<td>yes</td>
</tr>
<tr>
<td>Nagano, et al., 1984</td>
<td>198</td>
<td>—</td>
<td>≤ 9 mos</td>
<td>yes</td>
</tr>
<tr>
<td>Narakas &amp; Herzberg, 1985</td>
<td>192</td>
<td>15</td>
<td>≤ 6 mos</td>
<td>yes</td>
</tr>
<tr>
<td>Meyer, 1986</td>
<td>—</td>
<td>6</td>
<td>≤ 3 mos</td>
<td>yes</td>
</tr>
<tr>
<td>Gilbert &amp; Tassin, 1987</td>
<td>357</td>
<td>152</td>
<td>≤ 3 mos</td>
<td>yes</td>
</tr>
<tr>
<td>Jackson, et al., 1988</td>
<td>21</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Kawabata, et al., 1987</td>
<td>—</td>
<td>6</td>
<td>≤ 6 mos</td>
<td>yes</td>
</tr>
<tr>
<td>Boome &amp; Kaye, 1988</td>
<td>70</td>
<td>22</td>
<td>≤ 3 mos</td>
<td>yes</td>
</tr>
<tr>
<td>Piatt, et al., 1988</td>
<td>—</td>
<td>5</td>
<td>≤ 15 mos</td>
<td>yes</td>
</tr>
<tr>
<td>Sjoberg, et al., 1988</td>
<td>48</td>
<td>—</td>
<td>≤ 3 mos</td>
<td>yes</td>
</tr>
<tr>
<td>Alonen, et al., 1990</td>
<td>—</td>
<td>26</td>
<td>≤ 3 mos</td>
<td>yes</td>
</tr>
<tr>
<td>Kanaya, et al., 1990</td>
<td>—</td>
<td>52</td>
<td>≤ 3 mos</td>
<td>yes</td>
</tr>
<tr>
<td>totals</td>
<td>1021</td>
<td>436</td>
<td>median ≤ 3 mos</td>
<td></td>
</tr>
</tbody>
</table>

* Average recommended age at surgery was 3 months.
† Time required for initial motor improvement without surgery.

mended operation by 2 months of age if no electrical evoked responses could be elicited. Clark, et al., Wyeth and Sharpe,29,30 and Taylor31 also reported their surgical experience in the early 1900's. In 1930, Lawer32 was pessimistic about the surgical treatment of birth-related brachial plexus injury; he used neurolysis as the primary surgical technique.

The unhappy experiences of many surgeons caused an interruption in neurosurgical reports on surgical intervention for birth-related brachial plexus injuries. Except for the report of Piatt, et al.,25 in 1988, neurosurgical publication on this subject has been mainly anecdotal. Referral of these patients has been directed toward orthopedic and plastic surgeons, physiatrists, and rehabilitative centers, removing the neurosurgeon from involvement.

Modern Treatment

Technological advances have aided in the diagnosis and treatment of birth-related brachial plexus palsies. Although electrophysiological testing is useful in confirming suspicions, it has not replaced the clinical evaluation. Electrophysiological techniques have been most beneficial in the operating room on the exposed brachial plexus.2 The absence of evoked responses in the parietal regions in very young children may be related to the rate of myelination and lack of significant voltage potential ascending the spinal cord, influencing our selection of C1-2 as the evoked response area. Morrison stated that stimulation greater than 15 MV was required to obtain a response in the parietal areas in younger children (unpublished data). In some of our infants, evoked responses from intact nerve fibers could be recorded at the C1-2 spinous process without evidence of a parietal response.

Conclusions

The decision for surgery in birth-related upper brachial plexus injuries should be based primarily on clinical examination. Surgery is advisable if no significant muscle recovery is seen by 4 months of age. Surgery on these selected infants has been successful in more than 90% of cases. Electrophysiological testing of the exposed brachial plexus aids in selecting operative options. Interpositional grafts can improve the neurological outcome. Neurolysis should be reserved for neuromas showing adequate conduction through the neuroma (less than 50% amplitude drop of muscle action potential to distal muscle groups). Other options, including tendon and muscle transfers, orthopedic procedures, and physical and occupational therapies, must be available and must be considered to ensure the optimum outcome for a child with a birth-related upper brachial plexus injury.

References

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