The evolution of microsurgical nerve repair techniques has allowed surgeons to perform early intervention in OBPP. Currently, the consensus is that surgical intervention is indicated if there is insufficient spontaneous recovery within the first few months of life.\textsuperscript{1,3,5} Whereas most surgeons would concur on the management of a clear avulsion injury, the management of neuroma-in-continuity remains controversial.\textsuperscript{1,3,5,10} Recently, Lin et al.\textsuperscript{10} reported that the functional outcome of nerve grafts after 4 years of follow-up is superior to neurolysis alone in the management of neuroma-in-continuity.

The lack of upper trunk recovery and the unfavorable preoperative neurophysiological findings in a child with Narakas Group 4 OBPP at 5 months of age prompted an urgent exploration with the intention of performing neurotization. This procedure was abandoned and neurolysis was performed due to the favorable intraoperative neurophysiological findings. At 4 years of age, the child scored 12 of 15 on Mallet classification and has an excellent range of motion. No secondary operation was needed. The authors hope to highlight the idea that the surgical option for neurolysis alone should be kept open and that intraoperative electromyography can be a valuable tool to add to the surgeon’s armamentarium. (DOI: 10.3171/2010.9.PEDS10193)

Abbreviations used in this paper: EMG = electromyography; MAP = motor action potential; MRC = Medical Research Council; NAP = nerve action potential; NCS = nerve conduction study; OBPP = obstetric brachial plexus palsy; ROM = range of motion.

Intraoperative neurophysiological studies are said to be overly optimistic, and thus some groups have recommended resection of neuroma-in-continuity regardless of its conductivity, and grafting as a method of choice.\textsuperscript{5,10} Although Capek et al.\textsuperscript{2} proposed that resection of neuroma-in-continuity does not create further loss of function, nerve graft repair does not regularly and reliably produce the expected result. In a case series consisting of 100 patients, Birch et al.\textsuperscript{1} showed that good results were only reported in 33% of C-5, 55% of C-6, and 24% of C-7 nerve repairs. Patient selection could explain the differential results reported in the literature.\textsuperscript{1,3,5,7,13,14} Hence, the key to this problem is to identify a reasonable strategy for s-
lecting patients who will benefit from nerve grafts while sparing those with the potential for recovery.

In this report, we used preoperative and intraoperative evoked EMG/neuropathological studies to aid decision making and to decide whether a nerve graft was appropriate in a 5-month-old infant with presumed severe C5–6 rupture and a recovering middle and lower trunk lesion. We aim to convey that the combination of preoperative and intraoperative evoked EMG/electrophysiology studies is a useful adjunct for decision making, and that the option for neurolysis alone should not be disregarded.

Case Report

History. This 4-month-old infant with Narakas Group 4 OBPP was referred to the Peripheral Nerve Injury Unit due to lack of shoulder and elbow motor function recovery. The baby was born by vaginal delivery but suffered shoulder dystocia, and his mother needed an episiotomy. His birth weight was 4.67 kg. Apart from mild flexion of the fingers and wrist, there was no other discernible movement at birth. The weak finger movement signified that there was some degree of injury to the lower trunk, albeit a milder one. He also had Horner syndrome at birth, which resolved a few weeks later.

Examination. During the first outpatient visit, muscles innervated by the C-7, C-8, and T-1 nerves were recovering. Weak wrist extension (MRC Grade 2) but good grip and hand intrinsic functions (MRC Grade 3) were observed. However, shoulder and elbow muscle function was still completely absent, and this prompted us to perform urgent EMG and NCSs to evaluate his potential for recovery and the prognosis. The results of the findings are presented below.

Electroneuropathological Findings. The preoperative NCS showed that the left median and ulnar sensory NAPs were small compared with the right side. This indicated postganglionic brachial plexus axonal degeneration. An EMG examination of the deltoid, biceps, and triceps muscles did not show spontaneous activity, but there were reinnervated motor units recruiting to a fairly reduced interference pattern. The extensor digiti communis and wrist extensors showed a more complete interference pattern. These findings indicated a partial injury to the left C5–7, and the poor interference pattern would make it a relatively unfavorable injury. Based on the neuropsychological findings and lack of clinical signs of improvement, we performed urgent exploration of the brachial plexus with the intention of possible nerve grafting. The operation was performed when the infant was 5 months, 2 weeks old, with intraoperative neurophysiology assessments that included EMG and sensory evoked responses.

Intraoperative Findings. Via a supraclavicular approach, the brachial plexus was found to be extensively fibrotic. There was large constrictive scar tissue around and within the C-5 and C-6 postganglionic roots. The fibrotic reaction was less severe for the C-7 postganglionic root. After decompression and opening of the thickened epineurium, a few intact fascicles surrounded by dense fibrous tissue were seen. The fascicles were stimulated directly. The cortical and spinal somatosensory potential from C-5 was present but was poorly formed (Fig. 1 left), whereas the somatosensory-evoked potentials from C-6 and C-7 were normal (Fig. 1 right).

We stimulated the C-5, C-6, and C-7 roots proximal to the ruptures and detected good, visible contractions in the deltoid, supraspinatus, biceps, and triceps muscles. The EMG signals were also recorded simultaneously through a concentric needle electrode, and compound MAPs were recorded from wrist extensors, triceps, deltoid, biceps, and supraspinatus muscles. The motor potentials from stimulation proximal to the area of scarring and neurolysis evoked only very small MAPs (Fig. 2 left), whereas stimulation distal to this area evoked considerably larger MAPs (Fig. 2 right). Because this suggested focal conduction block across the lesion, we abandoned the nerve transfer procedure and instead continued neurolysis for the whole length of the C-5, C-6, and C-7 nerves, and upper and middle trunks, until the level of brachial plexus division.

Postoperative Course. The infant was reviewed in the clinic 2 weeks postoperatively, and his biceps power recovered to MRC Grade 2, while the wrist extension was continuing to improve to MRC Grade 4. Nevertheless, shoulder movement was still lagging behind. The plan for neurotization of the spinal accessory nerve to the suprascapular nerve was still a possibility. The physical therapy program concentrated on improving elbow function and performing passive shoulder ROM exercises to prevent contracture deformity of the shoulder.

The baby showed steady recovery, and when he was 10 months old, he had active shoulder abduction of 70°. On the basis of this encouraging clinical picture, the plan for neurotization was then completely abandoned. We continued to follow him up on a 6-month basis. By 2 years of life, power in his bicep and shoulder muscles was MRC Grade 4/5. There was no sign of shoulder subluxation or dislocation, and there was minimal internal rotation contracture.

During his most recent review at 3 years of age, his Mallet score was 12 of 15; his Gilbert and Raimondi scores were both 5. Figure 3 illustrates abduction, forward flexion, external rotation, “hand to mouth” without trumpet sign, “hand on the spine,” and hand function. Table 1 shows the baby’s ROM, which we routinely measure in our practice for all patients with OBPP.
**Discussion**

The prognosis of upper and middle trunk obstetric brachial plexus injuries is generally favorable, because infants have good reinnervative potential and brain plasticity. However, this spontaneous reinnervation can occur to a variable degree, and furthermore aberrant regeneration can lead to inadequate axons reaching the target motor units.\(^{11,12}\) In our case reported here, the relatively unfavorable findings from preoperative neurophysiological studies, along with the clinical picture, provided a clear indication for surgical exploration.

Bisinella et al.\(^2\) showed that preoperative neurophysiological studies have a high positive predictive value for patients with favorable C-6 and C-7 nerve lesions (92% and 96%, respectively), but they were lower (78%) for favorable C-5 lesions. Hence, the role of intraoperative neurophysiological studies is all the more important in the presence of unfavorable C-5 lesions and failure of recovery of shoulder function.

Recently, there have been growing numbers of reports advocating early nerve grafting irrespective of conductivity in the neuroma.\(^{5-10}\) Their rationale is to provide a straight rather than a tangled path in the neuroma for the axons to regenerate across, enhancing the functional recovery. However, the result of nerve grafting versus neurolysis alone has not yet been compared prospectively in any randomized control trials. In most studies, the sample size was small and the samples were not matched.\(^9,10\) König et al.\(^9\) reported that 5 infants, who underwent neurolysis alone due to recordable compound NAP or gross motor response to stimulation, achieved Stage 1 or 2 on the Mallet shoulder classification at 12 months of follow-up, whereas another 5 infants with nerve grafting achieved Stage 2–3. König et al. recorded infraclavicular NAPs, which is different from our technique of recording intraoperative muscle MAPs. Lin et al.\(^10\) showed that the initial improvement with the neurolysis alone (8 patients with Erb palsy and 8 with total palsy) was not sustainable at 4 years of follow-up. However, it is worth pointing out that in our case the improvement was sustained, and no secondary procedure was needed at almost 4 years of follow-up. The average age for infants undergoing neurolysis alone in these 2 studies\(^9,10\) was approximately 9–10 months, which we believe may be too late and would possibly diminish the benefit of neurolysis alone.

Birch et al.\(^1\) reported good results in 33% of C-5, 55% of C-6, 24% of C-7, and 57% of C-8 and T-1 repairs in 100 cases of obstetric brachial plexus injuries. Failure of recovery of elbow flexion in untreated obstetric brachial plexus injury is extremely rare, and the only cases of failure of recovery of the functional flexion of the elbow in more than 1500 cases referred to Birch et al. were seen in children in whom the C-6 branch needed to be repaired. Gilbert
et al. reported that the end result for shoulder and elbow function was less satisfactory in the complete lesion group compared with the upper type lesion group. Hence, the decision to sacrifice the conducting neuroma for nerve grafting needs to be made with careful consideration. In our opinion, a blanket guideline cannot be applied to all cases, and each case has to be assessed on its own merit. In the case reported here, in a patient with Narakas Group 4 complete brachial plexus injury, neurophysiological studies proved to be useful in the decision making.

The benefit of intraoperative EMG is that the needle electrode can be placed accurately and with relative ease in the anesthetized infant. Detection of MAPs in the muscle on stimulation of the nerve proximal to the lesion confirms the presence of viable axons traversing the lesion and reaching the motor end plates. The presence of a poor action potential proximal to the lesion and a good action potential on distal stimulation would suggest that the axons are not degenerative, but instead there is a conduction block across the lesion. In addition, in the presence of visible muscle contraction on direct nerve stimulation (in contrast to surface stimulation) in a standard preoperative NCS, one can infer that a reasonable amount of viable axons are present and recovery can be anticipated.

Lin et al. demonstrated that excision of neuroma in continuity did not adversely diminish motor activity, and speculated that central plasticity allows the remaining intact plexus to take over the function of the damaged nerve, and that the neuroma does not contribute to the remaining function observed preoperatively. The functional loss evident within the first 6 months of neuroma excision cannot be explained adequately with this hypothesis, and hence some recovering and functional fibers must be resected with the conducting neuroma. It is worth reiterating that in our case, the elbow and shoulder function continued to improve steadily over the 6-month postneurolysis period.

Intraoperatively, the presence of NAP across the lesion sites requires 3000–4000 nerve fibers with a diameter of more than 5 μm. Therefore, the presence of NAP across the lesion and muscle contraction on intraoperative stimulation means that intact fascicles must have been present across the lesion. It is therefore reasonable to expect some recovery. Hence, the recommendation of excision of a conducting neuroma irrespective of conductivity, unless distinct intact fascicles are seen, appears contradictory. Furthermore, distinct fascicles may not be easily seen in the presence of interfascicular fibrosis.

Uniquely in our case, the low-amplitude motor responses recorded directly from the muscle by stimulating it proximal to the lesion, compared with the much higher amplitude recorded on stimulating it distal to the lesion, suggested conduction block in the nerve fascicles rather than major axonal disruption and degeneration. This strongly predicted that the patient would spontaneously have a good outcome, and the decision was made to treat the patient with neurolysis alone and not to proceed to nerve transfer.

Conclusions

Neuroma in continuity in obstetric brachial plexus injury continues to pose a major challenge to surgeons. There is not enough evidence to support the idea of resection of conducting neuroma in favor of nerve grafting, and our understanding of infantile CNS and peripheral nervous system regeneration remains very limited. We should use all the tools available in our armamentarium to assist in decision making. Intraoperative stimulation is an additional useful tool in this respect.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Chin, Misra. Acquisition of data: Chin, Di Mascio, Holmes, Misra. Analysis and interpretation of data: Chin, Misra. Drafting the article: Chin. Critically revising the article: Di Mascio, Sinisi. Reviewed final version of the manuscript and approved it for submission: Sinisi.
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