Clinical article

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Object. Medial pectoral nerve (MPN) to musculocutaneous nerve (MCN) neurotization for recovery of elbow flexion by biceps reinnervation is a valid option following traumatic injury to the upper brachial plexus. A major criticism of the application of this technique in infants is the smaller size of the MPN and mismatch of viable axons. We describe our institutional experience utilizing this procedure and critically examine functional outcomes.

Methods. Office charts and hospital records of children from over an 11-year period beginning January 1997 were reviewed. Of the 53 children of various ages undergoing brachial plexus exploration for traumatic injury of any nature, 20 underwent MPN to MCN neurotization as a part of an overall procedure in the first year of life to treat birth-related brachial plexus palsy and had at least 9 months’ follow-up. Medial pectoral nerve to MCN neurotization was chosen if the results of clinical examination and intraoperative electrophysiological evidence were consistent with medial cord function. Functional recovery was defined as the ability of the child to bring their hand to their mouth.

Results. Sixteen patients (80%) gained functional recovery. The median age at surgery was 7 months. Median time to first clinic visit documenting recovery was 11.5 months and median overall follow up was 21.5 months. Preoperative hand function was a useful predictor of recovery of elbow flexion.

Conclusions. Medial pectoral nerve to MCN neurotization is a valid surgical option for the reinnervation of the biceps muscle for birth-related brachial plexus palsy when the hand is functional preoperatively. Useful elbow flexion can be expected in the majority of these children. (DOI: 10.3171/2008.11.PEDS08166)

KEY WORDS • arm • Erb palsy • pediatric neurosurgery

Clinically detectable trauma to the brachial plexus during birth occurs in approximately 1 of 1000 live births.14,20 Spontaneous recovery is thought to occur in 90% of these infants.13,20 An upper and middle trunk injury pattern (Erb palsy) is the most common finding, and a flail arm from panplexus involvement or root avulsion is the next most common. The absence of meaningful recovery by 6 months may predict the absence of long-term useful function.

A major initial description of traumatic brachial plexus injury is attributed to Wilhelm Erb, presented at the University of Heidelberg in 1874.10,39 During that presentation, Erb referenced a paper by the French neurologist Guillaume Duchenne in which obstetrical palsy was well defined.10,39 The first report of this injury, however, is attributed to Smellie in a 1768 treatise on midwifery.19,35 Kennedy is thought to have been the first to operate on children for obstetrical palsy and reported this in 1903.12,19 The results of operative intervention were initially unimpressive until the evolution of more modern methods, including electromyography and microsurgery. In 1984, Gilbert and Tassin reported a large successful series, and from that point the “modern era” of plexus repair began.12,19
Numerous surgical procedures have been performed in an effort to provide some degree of function for these children, most notably neurolysis, interposition nerve grafting, and neurotization utilizing the intercostal nerves.16,18,24,26,28,31,33

We report a 2-surgeon series at a single institution over 11 years in which MPN to MCN neurotization was performed in infants who had no return of elbow flexion following a birth-related injury.

Methods

We reviewed the office charts and hospital records of children undergoing brachial plexus exploration for persistent palsy following a traumatic event from January 1, 1997 to April 30, 2008. There were 53 children who were deemed appropriate for intervention. In 20 of these 53 cases, the children met the criteria of having received surgical treatment in the first year of life for birth-related brachial plexus palsy, having undergone MPN to MCN neurotization either alone or in combination with another reanimation procedure, and having been followed up for at least 9 months postoperatively. The results of preoperative and postoperative serial examinations were recorded through a multidisciplinary brachial plexus clinic. Success was deemed as the ability of the child to bring their hand to their mouth.

The exact method of MPN to MCN neurotization used in these children (Fig. 1) varied little between surgeons (J.C.W. and P.A.G.). The pectoralis major muscle-splitting technique was not used in the initial few children but was incorporated early. Also, an end-to-end connection between the donor and recipient nerves was used in all cases except one, in which an end-to-side connection was performed. In the cases in which additional procedures were performed to assist in recovery of humerus abduction, a supravacular nerve was performed. In those procedures in which only the MPN to MCN neurotization was performed, only an intercostal exposure was made.

Following orotracheal induction of anesthesia, the infant is positioned supine with a rolled towel placed between the scapulae. No paralytics are used following intubation. Prior to establishing a sterile field, needle electrodes are placed for somatosensory evoked potential monitoring and into the supravacular muscle for monitoring of motor evoked potentials if the supravacular plexus is to be explored. The entire arm along with the ipsilateral anterior neck and chest are prepared into the field. The remainder of the muscle electrodes (diaphragm, biceps brachii, triceps brachii, flexor carpi ulnaris, flexor carpi radialis, thenar, and hypothenar muscle groups) are placed by the surgical team intraoperatively. An incision is made along the deltopectoral groove with a 1-cm portion along the lateral aspect of the medial one-third of the clavicle. The pectoralis muscle is identified and split parallel to its fibers just over the belly of the pectoralis minor. The pectoralis minor is then sectioned lateral to the neurovascular bundle that includes the lateral pectoral nerve and distal MPN branches. This muscle is then retracted medially and the nerves approaching its deep surface are identified. (In this case series, the MPN consisted of up to 4 fascicles and warranted microdissection techniques [Table 1].) The infracavular plexus is then identified under a small fat pad. The lateral cord and the medial and lateral cord contributions to the median nerve are observed and the MCN is most often identified as it pierces the coracobrachialis muscle. Intraoperative motor evoked potentials in addition to direct stimulation and examination help guide the surgeon to the appropriate nerve when the anatomy is variable. The fascicles of the MPN are then sectioned as they entered the pectoralis minor, and the epineurium is dissected away from the MCN as it exits the lateral cord. The length of the MPN dictates how far distal to the lateral cord the transaction of the MCN is made. Nerves are connected tension-free under the microscope using three 10–0 nylon sutures. The pectoralis minor is reapproximated and the fascia of the pectoralis major brought together. The skin is closed using inverted Vicryl sutures followed by a subcuticular layer. The arm is placed in a loose ACE wrap that keeps the forearm next to the chest to prevent disruption of the neurorrhaphy. This is maintained for 2 weeks and instructions are provided for wound hygiene. Following this period, the children are referred back to the occupational therapists to begin passive and active movements. Follow-up with the multidisciplinary brachial plexus clinic

![Fig. 1. Artist's illustration. The course of the MPN is seen as it enters the reflected pectoralis minor muscle. The majority of its innervation is to this muscle but can also pass through it to the pectoralis major muscle, which takes the majority of its innervation from the separate lateral pectoral nerve. The MCN is seen entering the coracobrachialis muscle. The neurorrhaphy is made here, balancing the length of MPN available with distance from the muscle (inset).](image-url)
occurs ideally every 2 months during the initial postoperative evaluation phase. Occupational therapy is undertaken aggressively during the first year following surgery and the frequency is dictated by degree and rapidity of recovery as well as concomitant muscular recovery goals.

**Results**

Twenty patients met criteria for inclusion. Initially, 22 children were identified as having undergone MPN to MCN neurotization. Unfortunately, 2 patients were lost to follow-up. Of the 20 children who did meet criteria, 10 underwent MPN to MCN neurotization only, 8 underwent MPN to MCN neurotization in conjunction with spinal accessory nerve to suprascapular nerve (CN XI to SSN) neurotization, 1 underwent MPN to MCN neurotization along with a sural nerve graft from the C-5 root to the SSN, and 1 underwent MPN to MCN neurotization along with upper trunk neurolysis (Table 1). In each case of a procedure in addition to the MPN to MCN neurotization, the goal function was humerus abduction. One exception was an early exploration of the upper trunk with neurolysis and ultimate MPN to MCN neurotization. This was performed in the setting of no hand function and guided by intraoperative evoked potentials. External neurolysis of the C5–6 nerve roots and upper trunk was performed in patients also undergoing SSN neurotization only inasmuch as necessary to identify salient anatomy and the SSN.

Sixteen (80%) of the 20 patients gained functional elbow flexion, defined as the ability to bring the hand to the mouth (Fig. 2). The median age of surgery was 7 months (range 5–10 months). The median time from operation before the first clinic visit during which infants could bring their hands to their mouths was 12.5 months (range 5 months–2 years). Nineteen of the children had either digit or wrist flexion or both prior to surgery; the single child who did not who had undergone neurolysis (Table 1). Following this case, children had to have some degree of hand function in order to be eligible for MPN to MCN neurotization. The 3 other patients who did not respond to operative intervention were noted to have no predictor for failure. One of the children in the surgical failure group who had a concomitant CN XI to SSN neurotization had gained at least 60° of humerus abduction by the most recent follow-up and may ultimately gain HTM function.

All but one of the patients took part in intensive occupational therapy prior to and following surgery. The single exception was a patient who went to no therapy follow-up despite multiple communications. This case falls in the category of communication of expectation failure by the operating team prior to intervention.

The median duration of follow-up was 21.5 months.

### Table 1: Evaluation of results

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Surgeon</th>
<th>Op</th>
<th>No. of MPN Fascicles Used</th>
<th>Patient Age at Op (mos)</th>
<th>Preop Hand Function</th>
<th>Clinic Visit w/ 1st HTM</th>
<th>Most Recent FU Time Postop</th>
<th>HTM</th>
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<td>G</td>
<td>C-5 transverse nerve graft to SSN, MPN-MCN, rt</td>
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<td>3.5 yrs</td>
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<td>9</td>
<td>no</td>
<td>NA</td>
<td>7 yrs</td>
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<td>3.5 yrs</td>
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<td>9</td>
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<td>10 mos</td>
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</table>

* C-5 = proximal C-5 root; FU = follow-up; NA = not applicable; UT = upper trunk.
† The number of fascicles used could not be gleaned from the operative note in Case 12, but it was noted to be > 1.
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(range 9 months–7 years). There was no surgical morbidity. Of the children who had gained the ability to bring the hand to the mouth, all had functional hands preoperatively and could now bring food or other objects to the mouth (Table 1). Therapy remained essential to promote continued independent use of the affected arm.

Discussion

The MCN is composed of fibers from C-5 and C-6 and sometimes C-7. It arises from the lateral cord in ~ 90% of individuals, from the lateral and posterior cords in ~ 4%, from the median nerve in ~ 2%, as 2 separate bundles from the medial and lateral cords in 1%, and from the posterior cord in ~ 1%. This nerve pierces the coracobrachialis muscle on its medial border and supplies this muscle in addition to the biceps brachii and brachialis muscles. After piercing the coracobrachialis, the MCN travels deep to the biceps brachii and travels distally just lateral to the tendon of the biceps to become subcutaneous as the lateral cutaneous nerve of the forearm.

In about 20% of arms, the MCN does not pierce the coracobrachialis muscle but travels connected to the median nerve for variable distances into the arm before it supplies the muscles of the anterior arm. Branches to the brachioradialis and pronator teres muscles have been reported as well as a termination confined to the skin of the lateral forearm. The MCN may be accompanied by fibers from the median nerve as it traverses the coracobrachialis; a communicating branch passes from the MCN to the median nerve in up to 10% of cases. Instead of penetrating the coracobrachialis, the nerve may pass posterior to it or between it and the short head of the biceps muscle. Occasionally, the nerve may also perforate the brachialis or the short head of the biceps brachii.

The MPN arises from the medial cord of the brachial plexus via the C8–T1 ventral rami. This nerve may originate from the anterior division of the inferior trunk. It then travels posterior to the first part of the axillary artery and unites anterior to this artery to form a loop (ansa pectoralis) with a branch from the lateral pectoral nerve. The MPN next innervates the pectoralis minor muscle and normally pierces this muscle to end in 2 or 3 branches that then innervate the pectoralis major muscle. Variations of the MPN are infrequent. This nerve may supply twigs to the anterior belly of the deltoid muscle and to the acromioclavicular joint. Fibers from the MPN innervating the pectoralis minor may travel along the inferior border of the pectoralis minor instead of piercing it. One case has been described in which the MPN joined the intercostobrachial nerve.

It is well documented that repair methods for injury to the brachial plexus vary between peripheral nerve surgeons. Belzberg et al. surveyed 50 experienced surgeons on management decisions in 4 standardized scenarios and found disagreement in diagnostic approaches, surgical timing, and specific intraoperative decision-making on neuroma management and neurotization. Many publications in the medical literature detail successful means of treatment of patients of all ages with injuries to the brachial plexus, most commonly interposition nerve grafting, neurotization utilizing the intercostal nerves, and, more
recently, the Oberlin procedure. Experienced peripheral nerve surgeons are required to adapt on a case-by-case basis based on preoperative recovery patterns and intraoperative observations (for example, length of available nerves for direct neurotization and availability of proximal roots for grafting).

In the child who had a functional hand preoperatively but no significant recovery of biceps flexion, a realistic goal is for that patient to bring that functional hand to the mouth independently. The presence of hand movement at the digits or wrist implies medial cord function. Therefore, the MPN should be available for transfer. In our case series, we critically evaluated the infants for hand function prior to surgical intervention. One early patient had no wrist or finger movement preoperatively and had no functional recovery of the biceps brachii postoperatively. Intraoperative motor and sensory evoked potentials and motor stimulation were also used to confirm target muscle integrity and provide confirmation of nerve identity.

The timing of surgical intervention has been a source of controversy in this population as well. The fact that > 90% of these children will achieve normal or near-normal function with therapy alone puts the “burden of proof” on the individual patient to show the clinic that improvement has either not occurred or not progressed. Ideally, these children are seen initially at 2 months of age for evaluation and assignment of therapy. Group movements are recorded for 3 main actions: shoulder abduction, elbow flexion, and wrist or digit flexion. These are tracked at 2-month intervals. Surgical timing and planning is then made based on recovery pattern and function. If an infant’s active shoulder abduction recovers to 90° but the elbow flexion recovery plateaus and the child is unable to flex the arm to any significant degree, then we would record that the child’s shoulder abduction had improved past the point of surgical intervention and concentrate on elbow flexion. This explains why 10 of 20 infants underwent MPN to MCN neurotization only. If the child or family were to later find that this degree of improvement was not satisfactory or SSN neurotization failed, then the patient would become a candidate for rotational osteotomy of the humerus at an older age. Our patients’ median age of surgery was 7 months, and we felt that this allowed enough time for the patient to recover spontaneously but not excessive time to pass for risk of target muscle atrophy.

Prior publications, including one from our institution, have detailed some concerns over the use of the MPN for transfer. In a 2001 cadaveric study, our group reported the finding of an occasional lack of adequate distance for direct transfer as well as cross sectional area mismatch. In this current surgical case series, there were no instances of using interposition grafting due to inadequate MPN length. Perhaps evolution of surgical technique contributed to this, including further directed cadaveric dissections. Most commonly, more than 1 fascicle of the MPN was used in the neurorrhaphy to reduce the cross-sectional mismatch issue. These were microdissected as far into the belly of the pectoralis minor as possible prior to sectioning the nerve. In addition, sectioning of the ansa pectoralis was helpful in increasing available length for neurorrhaphy. In the majority of cases, we section the MCN just after it arises from the medial cord, but we recognize that this may not be optimal. Distance of the nerve connection to the target muscle is controversial.5

Transfer of the MPN to either the MCN or axillary nerve is well documented in the literature following non-birth injury. Samardzic et al. described 25 patients aged 9–55 years who underwent neurotization from the MPN to the MCN or axillary nerve. More than 80% in both groups had useful functional recovery. Merrell et al., in a 2001 case series and meta-analysis, reported using MPN transfer in 1 patient out of a total of 35 explorations. The ages of all patients in the case series ranged from 4 months to 67 years, with a median age at time of surgery of 28 years. Two other publications are mentioned in the meta-analysis, and they discuss one successful MPN to MCN transfer and another successful group of transfers in which MPN was used.31,33 A major conclusion of the Merrell et al. paper was that nerve transfers have a high success rate and that intercostal nerves were more effective donors for MCN grafting. The large St. Louis Children’s Hospital series was summarized in a 2006 publication and detailed indications for intervention as well as the overall successful treatment for pediatric brachial plexus injuries. Neurotization was used in a few repairs, but this did not include utilization of the MPN. Kline and Tiel reported a 30-year experience with incorporating interposition grafting as well as nerve transfers into injuries of the brachial plexus, including lacerations, gunshot wounds, and traction injuries. Their approach has evolved to direct repair and, when possible, supplementation by nerve transfers. Blaauw and Slooff reported 25 cases of obstetric brachial palsy in which the MPN was used; the outcome was excellent in 17 and fair in 5.

Inherent in any case series is lack of randomization and therefore inability to determine procedural superiority in an unbiased fashion. Our method of determining pre- and postoperative function is not to the detailed level that used in the paper by Ashley et al., in which a motor score composite was defined, calculated, and tracked in 64 patients in the St. Louis Children’s Hospital series. In fact, our outcome criterion was purposely made binary (hand to mouth: yes or no) for the purpose of determining success of the surgical procedure as initially stated and ease of reproducibility. Only after years of follow-up will we be able to determine whether children incorporate the injured arm into their daily lives. Clear measures of surgical success range from the simple to the complex; examples include: 1) dominant handedness, 2) usefulness in activities of daily living, 3) ability to work and in what capacity, 4) validated quality of life scales, and 5) presence of Social Security disability claims. Only when age- and sex-matched nonsurgically treated controls are incorporated into longitudinal cohort studies will the outcomes of these complex procedures be truly understood.

Conclusions

Medial pectoral nerve to MCN neurotization is a valid surgical option in the restoration of elbow flexion following birth-related brachial plexus injury. Of the patients in this series who gained HTM function, all were able to bring their hand to their mouth by 2 years of age. In our experience, preoperative hand function is necessary for success.
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Aggressive targeted occupational rehabilitation is as critical as well. Longitudinal studies are needed to determine if these outcomes translate to useful arm function into adulthood.

**Disclaimer**

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

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