Specific Challenges in Brachial Plexus Surgery

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Thomas J. Wilson and Lynda J.-S. Yang

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6.1   Introduction

Brachial plexus injuries are devastating, resulting in loss of function of the upper extremity, which carries significant morbidity. In adults, trauma is the most common etiology of brachial plexus injury. In neonates, the exact pathophysiology of brachial plexus injuries is unclear but occurs before or during labor and parturition [1]. Neonatal brachial plexus palsy (NBPP) occurs in approximately 1 in 1000 live births [5]. A significant proportion of these patients will demonstrate spontaneous recovery with therapy alone and no operative intervention. However, there remains a subset of these patients that will not recover without operative intervention.

Until only recently, adult and neonatal brachial plexus palsies were thought of as nonsurgical pathologies. Little was available in the way of surgical treatment. Early efforts had poor results which discouraged continuing surgical treatment [32]. World

T.J. Wilson
Department of Neurosurgery, Stanford University, Palo Alto, CA, USA
e-mail: thowil@med.umich.edu

L.J.-S. Yang, MD, PhD (✉)
Department of Neurosurgery, University of Michigan, Ann Arbor, MI, USA
e-mail: ljsyang@med.umich.edu

War II ultimately revived the interest in repair of adult brachial plexus injuries, and during this time, Seddon pursued repair with improved outcomes, sparking a renewed interest. Neonatal brachial plexus palsy, however, remained a nonsurgical condition until the work of Gilbert revived interest when he reported improved outcomes and, in particular, improved safety of operative intervention [27, 29]. As surgery has increasingly become an option and new innovative techniques have been employed, a number of challenges have arisen that span the gamut from preoperative evaluation and decision-making to intraoperative decisions regarding the optimal nerve reconstruction strategy to be performed to evaluating outcomes in these patients postoperatively. In this chapter, we highlight specific challenges facing the peripheral nerve surgeon in each phase of care and highlight the areas needing further research. While the majority of these specific challenges pertain to the NBPP population, decisions regarding whether to perform nerve graft repair or nerve transfer pertain to both the NBPP population and adult population, and both will be highlighted. As research continues and new innovative techniques for evaluation and treatment are developed, these specific challenges are likely to be overcome, but with progress, new challenges and new questions are likely to be raised.

6.2   Challenges in the Preoperative Evaluation

Preoperatively, the main challenges facing the peripheral nerve surgeon when evaluating a patient with NBPP are (1) determining whether or not to operate and (2) the optimal timing of operative intervention. This begs the question, what is the optimal method of evaluation to guide this decision-making? While a significant proportion of patients with NBPP will recover spontaneously if given time, data also have shown that earlier operative intervention is associated with improved outcomes following graft repair or nerve transfer [8, 36]. Thus, early dichotomization of patients into those likely to spontaneously recover and those unlikely to spontaneously recover has great importance. The most fundamental question to be addressed by all methods of evaluation that informs the likelihood of recovery is: what is the nature of the injury? Lesions likely to recover include neurapraxic injuries and axonotmetic injuries. Those lesions with no hope of spontaneous recovery include nerve root avulsions (preganglionic) and postganglionic, neurotmetic lesions (ruptures).

The mainstay of evaluation of these patients remains the physical examination. While documenting a baseline examination shortly after birth is extremely important, little is gleaned with regard to prognostication from this initial examination. The exception may be the presence of Horner's syndrome in the context of a panplexopathy. The presence of Horner's syndrome is indicative of a preganglionic, non-recoverable lesion and an indication for surgery [3]. Aside from this finding, there are no reliable indicators of non-recoverable lesions. Hence, time must be allowed to observe for spontaneous recovery. Though the optimal time period is not universally agreed upon, the most commonly used time period is 3 months. Gilbert demonstrated that motor outcomes at 5 years of age were poor in those children who failed to spontaneously recover biceps function by 3 months of age [23, 27, 28].

Thus, this is the rationale for evaluation at 3 months, with those children not demonstrating spontaneous recovery of biceps function being unlikely to recover and thus likely to benefit from operative intervention.

However, further detailed analysis revealed flaws in this system. Michelow and colleagues demonstrated that if absent biceps function at 3 months is utilized as the sole criterion for prediction of recovery, the prediction is incorrect in 12% of patients. When multiple movements were assessed at 3 months and combined into an overall score, the percentage of incorrect predictions dropped to only 5% [7]. One of the issues with assessment at 3 months of age is that some patients will go on to develop biceps contraction at 6 months, though the significance of this finding is uncertain [39, 44]. Waters has shown that patients developing biceps function after 5 months of age have improved outcomes with operative management compared to nonoperative management [8, 18]. Thus, the significance of delayed recovery of biceps function is unclear. Other tests such as the towel test and cookie test have been suggested to be helpful in predicting those patients likely to benefit from surgery [9, 13, 38]. In the towel test, a towel is placed over the infant's face and the infant is observed for the ability to remove the towel with the affected arm [9]. In the cookie test, a small cookie is placed in the infant's hand and the humerus is held at the infant's side. The infant is then observed for the ability to generate enough elbow flexion to bring the cookie into his/her mouth [13]. This remains a specific challenge to the peripheral nerve surgeon as there is no consensus as to what method of evaluation should be used. The ideal evaluation would be highly specific and sensitive and able to be predictive at a young age.

In adults, one of the mainstays of evaluation of the peripheral nervous system is the electrodiagnostic study including nerve conduction studies and electromyography (EMG), but these studies are fraught with difficulties in neonates. EMG studies are often difficult to interpret and are often discordant with clinical findings. When a paralyzed biceps is encountered clinically, one would expect an EMG to show a loss of motor unit potentials (MUPs) and the presence of denervation activity. However, frequently, in the setting of a paralyzed biceps in infants, motor unit potentials are present and denervation activity is absent [36]. A number of reasons have been suggested for these confusing findings. Malessy and colleagues have suggested five reasons that there may be the presence of motor unit potentials despite no observed biceps activity: (1) inadequacy of the clinical examination, (2) overestimation of the number of motor unit potentials, (3) luxury innervation, (4) central motor disorders, and (5) abnormal nerve branching [11]. Examining an infant is limited by the inability of the infant to voluntarily participate in the examination. For this reason, it may be that Medical Research Council (MRC) grade 1 or 2 movement may be missed. The estimate of the number of motor unit potentials (MUPs) may be overestimated due to the difference in the size of motor fibers in infants versus adults. Because fibers are smaller in infants, a significantly larger number of fibers are recorded for the same EMG needle uptake area compared to adults. Luxury innervation refers to the idea that muscles have more than one neuromuscular synapse early in development. During normal development, pruning occurs so that only one neuromuscular synapse remains. However, there is disagreement

about when this pruning occurs. If this pruning occurs after birth, it may be that the presence of a brachial plexus lesion affects this pruning process. It has previously been shown that in infants with NBPP, intraoperative stimulation of C7 yields elbow flexion and shoulder abduction, suggesting luxury innervation of the biceps by C7 [10, 40]. This luxury innervation is not pruned due to the lack of competition from C5 and C6 as a result of the brachial plexus injury. This may result in identifying MUPs in the biceps from C7 rather than C5 or C6. Many motor pathways depend on afferent input for normal formation. However, in NBPP, not only is the motor pathway lost but the afferent sensory pathway is also lost. This may result in abnormal formation of central motor pathways such that even if axonal regeneration occurs to the biceps, the motor pathways may not form correctly to allow movement [30, 51]. Finally, abnormal branching of regenerating axons may occur. Because of abnormal branching and misdirection, axonal regeneration can terminate in other muscles resulting in co-contraction of various muscles. This co-contraction due to abnormal branching may result in detection of MUPs despite lack of activation of the biceps.

With all of the incumbent challenges of EMG and nerve conduction studies in neonates, we are left to ask whether or not there is any value to obtaining such studies. There does still appear to be some value to obtaining these studies, and we still do routinely obtain them. Electrodiagnostic studies can be poor at detecting nerve root avulsions. We have previously shown that the sensitivity for nerve root avulsions is only 27.8%. However, electrodiagnostic studies do appear to be useful in detecting ruptures. The sensitivity of electrodiagnostic studies for intraoperatively confirmed ruptures was 92.8%. This pattern is the opposite pattern compared to computed tomographic (CT) myelography which showed increased sensitivity for avulsions and lower sensitivity for ruptures. Thus, the two studies complement each other [24]. Electrodiagnostic studies do potentially provide useful information, though their interpretation and optimal timing remain challenges in the evaluation of NBPP.

In addition to the clinical examination and electrodiagnostic studies, a variety of imaging modalities are available to aid in the evaluation of the patient with NBPP. However, each modality comes with its own set of challenges, and no consensus exists for the appropriate set of diagnostic imaging for these patients. Historically, CT myelography is likely the most commonly employed imaging modality in these patients. We have shown previously that CT myelography has only a 58.3% sensitivity for nerve ruptures but a 72.2% sensitivity for avulsions [24]. While this adds valuable information, CT myelography is certainly not highly sensitive. Debate also exists as to what criteria should be used to diagnose an avulsion. The two most debated criteria are pseudomeningocele alone versus pseudomeningocele with absent rootlets. Studies vary in the reported value of each of these diagnostic criteria. Tse et al. reported a sensitivity of 73% when pseudomeningocele alone was used versus 68% when pseudomeningocele with absent rootlets was used. While not highly sensitive, CT myelography is highly specific with reported specificity of 96% whether pseudomeningocele alone or with absent rootlets was used [21]. A previous report from Chow and colleagues had shown that utilizing

pseudomeningocele with absent rootlets for diagnosis improved the specificity from 85% to 98% [12]. One possible explanation for why Tse and colleagues did not find a similar increase is that their cohort of patients had a high proportion of Narakas grade 3 and 4 injuries and thus included more injuries to C8 and T1 where avulsions are more likely to occur. In their study, 18 of 19 pseudomeningoceles identified contained absent rootlets. If they had had a more mixed population relative to injury severity and level, they may have observed a similar increase in specificity as Chow observed [21]. Regardless, the optimal diagnostic criteria remain debated and sensitivity remains a challenge. Additionally, CT myelography brings with it challenges inherent to the procedure including the invasive nature of the procedure, instillation of intrathecal contrast and associated risks, and exposure to ionizing radiation.

More recently, high-resolution magnetic resonance (MR) imaging and MR myelography have been used in place of and compared to CT myelography. MR myelography has been shown to have a similar sensitivity and specificity for nerve root avulsions compared to CT myelography, 68% and 96%, respectively [21]. In another study of high-resolution MR imaging, the sensitivity and specificity for nerve root avulsions were 75% and 82%, respectively [48]. Some of the same issues are present as with CT myelography, however, including defining the diagnostic criteria to be used for avulsions and imaging of the more distal nerves for evidence of rupture. High-resolution MR imaging/MR myelography does offer some advantages, including the noninvasive nature of the study, the lack of intrathecal contrast administration, and the lack of exposure to ionizing radiation. With a similar sensitivity and specificity compared to CT myelography and the several aforementioned advantages, we have replaced CT myelography with high-resolution MR imaging in the evaluation of patients with NBPP.

One challenge of both CT and MR myelography is visualization of the extraforaminal nerve roots and trunks in order to evaluate for evidence of rupture. Ultrasound can help overcome this challenge. Ultrasound is particularly useful in evaluating the upper and middle trunks and less so the lower trunk. The sensitivity in identification of neuromas in our study was 84% for both the upper and middle trunks and 68% for the lower trunk. Ultrasound can also be used to provide some information about how proximal the injury is based on evaluation of the serratus anterior and rhomboid muscles. Atrophy in these muscles detected on ultrasound suggests a proximal injury, making the presence of a viable proximal stump for nerve grafting less likely and making us favor nerve transfer instead [25]. Ultrasound has little ability to evaluate the preganglionic segments of nerve roots, making evaluation for avulsion difficult with this imaging modality.

One of the main challenges in preoperative decision-making is identification of appropriate candidates for nerve surgery as early as possible. To that end, we attempted to identify peripartum and neonatal factors that were associated with persistent NBPP. We identified cephalic presentation, induction or augmentation of labor, birth weight > 9 lbs., and the presence of Horner's syndrome as increasing the likelihood of persistence. Cesarean delivery and Narakas grade 1 and 2 injuries

reduced the odds of persistence. Horner's syndrome is a constellation of clinical findings including ptosis, anhidrosis, and miosis due to injury to the sympathetic trunk. The Narakas scale is an injury grading scale where Narakas grade 1 is injury to the upper trunk only (C5, C6), grade 2 is injury to the upper and middle trunks (C5, C6, C7), grade 3 is pan-plexus injury without Horner's syndrome, and grade 4 is a pan-plexus injury with Horner's syndrome. The study was performed on a biased sample, however, due to the fact that the population of patients was that already referred for evaluation by a nerve surgeon [37]. Nonetheless, the design of this study was such that it was intended to address the main challenge in the preoperative evaluation of patients with NBPP which is early identification of those patients that will not recover who should undergo nerve surgery. While the physical examination, electrodiagnostic studies, imaging studies, and peripartum/neonatal history all have a role in the evaluation, we are still in need of a predictive algorithm that incorporates all of these methods of evaluation that can dichotomize these patients with high sensitivity and specificity. Future research should continue to address this challenge. Until such research addresses this challenge, we have developed our own algorithm for evaluation at the University of Michigan (Fig. 6.1).
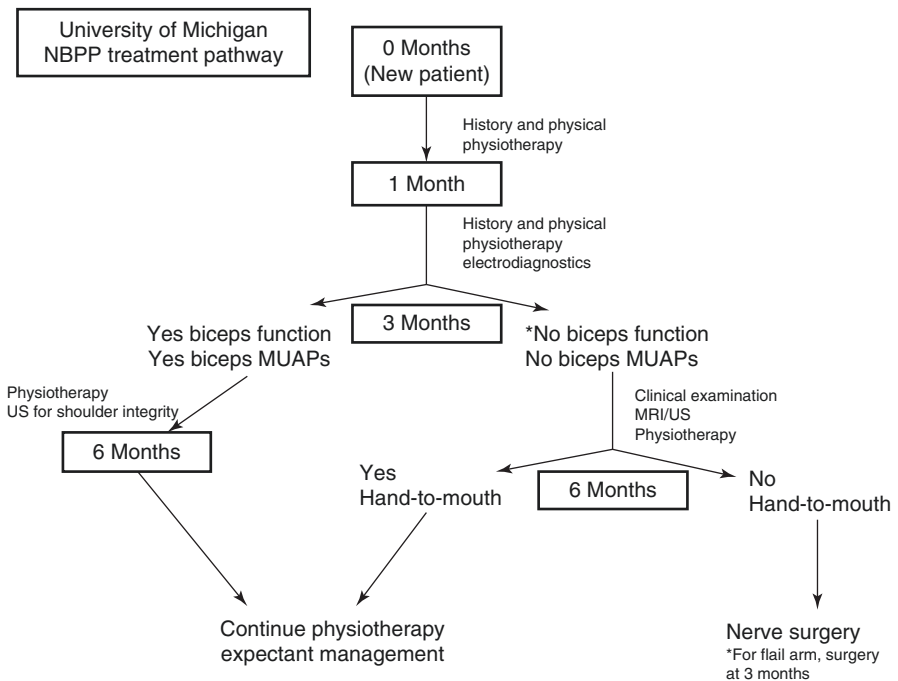

Fig. 6.1 Flowchart of the University of Michigan Neonatal Brachial Plexus Palsy (NBPP) pathway of presurgery decision-making. *US* Ultrasound, *MRI* Magnet Resonance Imaging, *MUAP* Motor Unit Action Potential

6.3   Challenges in Intraoperative Decision-Making

Once a decision is made to operate on a patient for persistent NBPP, a number of intraoperative challenges face the nerve surgeon. The main decision is what intervention to perform: neurolysis alone, nerve graft repair, or nerve transfer. For a number of reasons, this decision remains challenging. One main reason is the lack of comprehensive postoperative data that allow head-to-head comparison of interventions. This will be discussed in the next section. With the available data, how does the nerve surgeon make this decision?

In adults, recoding nerve action potentials (NAPs) across a lesion in continuity can be helpful. When nerve action potentials are recorded across a lesion, it is often best to perform neurolysis alone, as nerve action potentials traveling across a lesion in continuity suggest a recovering nerve [43]. However, in neonates, nerve action potentials are not similarly useful. Intraoperative nerve action potentials in neonates are thought to provide overly optimistic data. One study included ten lesions in continuity and found positive NAPs across the lesion in five patients. Neurolysis alone was performed in these patients and none had a good recovery [33]. In an additional study, Pondaag and colleagues found that the specificity for a severe lesion of absent NAPs and compound muscle action potentials (CMAPs) across a lesion in continuity was high (>90%). However, the sensitivity was very low (<30%) [41]. Taken together, the available data suggest that intraoperative NAPs and CMAPs in neonates are not useful in guiding decisions. Thus, the surgeon is challenged with relying on preoperative assessment to determine who should undergo nerve reconstruction and that is fraught with the challenges previously described.

Thus, once a decision for surgery is made, the real decision is whether to graft or to transfer. There are very little data and very few studies directly comparing nerve grafts to nerve transfers for NBPP. Thus, determining the optimal intervention remains challenging. There are currently disagreements about the role of nerve transfers in the treatment of NBPP. The International Federation of Societies for Surgery of the Hand suggests that the role of nerve transfers in NBPP is unclear but that nerve transfers are a viable option for Erb's palsy but should not be first-line treatment for more severe injuries. The committee suggests that there should not be an overreliance on nerve transfers and there should remain an inclination toward brachial plexus exploration and nerve graft repair [52]. Further data, however, are needed to determine the optimal roles of both nerve transfer and nerve graft repair.

Erb's palsy with C5 and C6 injury is the most common pattern of injury in NBPP. While nerve graft repair is the traditional intervention, nerve transfers have been shown to be a viable option. Recovery of elbow flexion has been shown to be good following ulnar or median nerve fascicle transfer to the biceps or brachialis branch of the musculocutaneous nerve. In one study, 87% of patients undergoing these transfers obtained functional elbow flexion recovery. Outcomes were worse for supination recovery with only 21% recovering functional supination [34]. While there was no direct comparison to nerve graft repair, these outcomes suggest nerve transfer is a viable option.

Reinnervation of the suprascapular nerve is important for restoration of external rotation of the shoulder following C5/C6 injury in NBPP. Early experience reinnervating the suprascapular nerve was poor regardless of whether nerve graft repair or nerve transfer was used [35]. More recently, however, outcomes have been better. There have been mixed data comparing spinal accessory nerve transfer with C5 nerve graft repair. Spinal accessory nerve transfer is at least equivalent to C5 nerve graft repair, but some data suggest it may have better outcomes [47, 53]. Seruya and colleagues found that C5 nerve graft repair led to poorer shoulder function and also increased secondary shoulder surgery compared to spinal accessory to suprascapular nerve transfer [47]. The major challenge remains making a decision to graft or to transfer in the setting of a lack of data comparing the two interventions. Future studies will need to focus on comparing outcomes. Additionally, as we discuss in the next section, it will be important to compare outcomes more in depth than simply motor outcome.

A similar dilemma exists in the adult population of brachial plexus injury patients. What is the optimal repair strategy to maximize outcomes? For upper trunk injuries with loss of shoulder abduction, external rotation, and elbow flexion, there is little in the way of direct comparisons between nerve graft repair and nerve transfer. However, two recent meta-analyses help compare the two strategies, and both concluded that nerve transfer strategies are superior to nerve graft repair. These studies utilized the Medical Research Council (MRC) grading scale where M5 is normal strength, M4 is movement against active resistance, M3 is movement against gravity but no active resistance, M2 is movement with gravity eliminated, and M1 is flicker movement or contraction only. Garg and colleagues found that 83% of patients with nerve transfers achieved M4 or greater elbow flexion strength and 96% achieved M3 or greater. Comparatively, only 56% of patients with nerve graft repair achieved M4 or greater strength and 82% achieved M3 or greater. Shoulder outcomes were similarly better with nerve transfers. Seventy-four percent of dual nerve transfer patients achieved M4 or greater shoulder abduction strength versus 46% with nerve graft repair. Both shoulder abduction and external rotation were better in the nerve transfer group [26]. Ali and colleagues recently supported these findings. They found that nerve transfer techniques were superior to nerve graft repair for the restoration of elbow flexion and shoulder abduction. Specifically, with regard to elbow flexion, the Oberlin procedure (transfer of an ulnar fascicle to the biceps branch of the musculocutaneous nerve) was superior to all other strategies [4]. Thus, for upper trunk brachial plexus injuries, nerve transfer seems to be superior to nerve graft repair, but no direct comparative data are available. This data is not conclusive, however, and there certainly remains controversy. In fact, in a systematic review, we previously found that the data did not support the sole use of nerve transfers for upper brachial plexus injury. We recommended at that time that the standard should still include brachial plexus exploration with nerve graft repair when feasible [55]. Additional comparative studies are needed to better elucidate the optimal strategy.

Restoration of hand function following lower trunk injuries is similarly challenging. In addition to nerve graft and nerve transfer techniques, an additional

consideration is the Doi procedure (double free muscle transfer) [20]. Ray and colleagues initially described a series of four patients with isolated lower trunk injuries in whom they performed transfer of the nerve to the brachialis to the anterior interosseous nerve, with good clinical outcomes [42]. Isolated lower trunk injuries, however, are relatively uncommon. With concomitant involvement of the upper brachial plexus, nerve transfer options become more limited. Dodakundi and colleagues initially reported success of the double free muscle transfer in total brachial plexus injury [19]. As an adjunctive intervention, wrist arthrodesis has been shown to improve both finger range of motion and overall hand function in patients with double free muscle transfer for pan-plexus injury [2]. Recently, Satbhai and colleagues reported an improvement in overall functional outcome and quality of life using the double free muscle transfer versus single free muscle transfer or nerve transfer for patients with pan-plexus injury [46]. However, it is not clear that hand function was significantly better. In addition, this study pertains to patients with pan-plexus injury and focuses on the overall function of the limb. In cases of isolated lower trunk injury, it is not clear what strategy, whether nerve graft, nerve transfer, free muscle transfer, or tendon transfer, yields the best results. Thus, determining the optimal reconstructive strategy remains challenging.

6.4 Challenges in Postoperative Evaluation

Postoperatively or, in the case of those neonates who are managed nonoperatively, throughout the natural history of the condition, we are tasked with evaluating these children in some way. This is particularly important in order to collect data to determine if operative intervention is helpful and in order to compare different types of intervention head to head. To this point, most evaluations have focused on motor outcomes and grading individual motor movements on scales such as the Medical Research Council (MRC), Active Movement Scale (AMS), and Louisiana State University motor grading scales. While a variety of outcome measures have been used, the five most common in the published literature include range of motion of the shoulder, range of motion of the elbow, the Mallet scale, MR imaging findings, and the MRC grading scale [45]. Very few evaluation instruments/metrics are specifically validated for use in the NBPP population. Validated evaluation instruments/metrics include the Active Movement Scale, Toronto Scale Score, Mallet Score, Assisting Hand Assessment, and Pediatric Outcomes Data Collection Instrument [16]. While gross motor function and evaluation of body structure and function are important, this may not capture the complete picture, as simply grading motor strength ignores other important factors such as sensation, arm preference, proprioception, functional use of the extremity, cognitive development, pain, quality of life, and language development [22]. Thus, it remains a specific challenge to determine how best to evaluate patients with NBPP. While a number of these domains of evaluation are specifically to the NBPP population, a similar problem exists when evaluating adults with brachial plexus injury following intervention. In this population, it also remains a specific challenge to go beyond purely

evaluating motor recovery and rather to also evaluate quality of life, functional use of the affected limb, and pain [22].

One challenge of the postoperative evaluation is determining the optimal duration of time to follow these patients. From age 5 onward, these patients generally have stable to improved hand and shoulder function. However, over the same time course, elbow function tends to slightly deteriorate. This is true whether or not nerve reconstruction was performed. Children who have poor shoulder external rotation benefit from shoulder surgery with significant improvement postoperatively [50]. Because of the continued decrease in elbow function and the significant benefit to shoulder external rotation following surgery for those patients in whom external rotation limitation is recognized, it is important to follow these patients throughout childhood and adolescence and into adulthood.

In the general population, approximately 90% of people have a right arm preference/dominance. In children with left upper extremity brachial plexus palsy, that percentage remains roughly the same, 93% in our previous study. However, when the right upper extremity is the affected limb, only 17% preferred the right limb. This is a significant deviation away from the population average [54]. This suggests neural plasticity is at work early in the development of these children. However, what is not clear is how dominant the unaffected extremity becomes. Is the affected extremity essentially a useless limb, or is there only a slight preference for the unaffected extremity? More importantly, do surgical interventions improve the functional use of the extremity and reduce the preference for the unaffected extremity? Finally, do nerve transfers that offer earlier, though some would argue less complete, recovery offer advantages over nerve graft repair due to the fact that recovery occurs when motor patterns are being established? These are the challenges in evaluation that remain to be answered.

It may not simply be weakness that leads to altered limb preference and reduced functionality. Proprioception plays a large role in the functional use of extremities. However, to this point, little focus has been given to evaluating proprioception following brachial plexus injury. We have previously assessed elbow position sense in adolescents with a history of NBPP. We found that position sense is impaired in the affected limb following NBPP [14]. Similarly, tactile spatial perception is reduced in the hand of the affected limb following NBPP [15]. It is unclear how much this affects daily use of the limb and overall limb preference. However, it may be an important component not assessed by purely focusing on gross motor function. Further assessments of proprioception and advanced sensory modalities are needed in future studies to determine their importance in daily activities and which interventions improve these modalities that contribute to complex functional use.

Delayed or altered use of the affected limb may also affect development in a more global fashion. Motor impairments in children have previously been reported to delay language [31]. The nature of the relationship between motor function and language is unclear. Decreased motor function may impair the ability of the child to explore the world around them, thus delaying language. We have previously shown a high rate of language delay in toddlers with a history of NBPP [17]. This finding has several important implications. First, it suggests that treating children with

NBPP is more complex than simply focusing on motor rehab. Recognizing the association of language delay and NBPP means that rehabilitation focused on language development should be part of the overall rehabilitation program. Furthermore, it suggests that assessment of language is an important component of the global assessment of these patients. A further understanding of exactly how language development and motor deficits, and more specifically NBPP, are linked may lead to a better understanding of interventions that may address this issue. For example, if delays in language development result from a decreased ability to explore the surroundings at a very young age, those interventions that favor early recovery, i.e., nerve transfers as opposed to nerve graft repair, may favor improved language development. This remains hypothetical, however, but points to the challenge of needing more complex evaluations to determine optimal interventions.

With language development being affected, one might hypothesize that behavioral issues may arise in children with a history of NBPP. This hypothesis turns out to be correct. Children with a history of NBPP show global developmental delays, difficulty with hand-eye coordination, and a higher incidence of emotional and behavioral problems. This was closely associated with the severity of initial injury [6]. One might assume that earlier or more complete recovery may be associated with a reduction in behavioral problems, but this has never been demonstrated. Thus, it remains a challenge to evaluate behavioral outcomes and to determine what factors are associated with reduced behavioral issues, including which interventions may help reduce these issues.

All of these challenges point to need for more global and comprehensive evaluation of patients with NBPP, both managed operatively and nonoperatively. Ultimately, what is important to these patients is having the highest quality of life possible. A number of factors have been identified as affecting the quality of life in these patients including social impact and peer acceptance, emotional adjustment, aesthetics and body image, functional limitations, finances, pain, and family dynamics [49]. The diversity of these factors points to the fact that assessment necessarily involves more than simply assessing motor function. It remains the challenge of the nerve surgeon taking care of patients with NBPP to develop the optimal assessment metrics and intervals and to compare interventions head to head using optimized global metrics, ultimately moving beyond simply the World Health Organization International Classification of Functioning, Disability, and Health Body Function and Structure domain and moving into evaluations in the Activity and Participation domain (http://www.who.int/classifications/icf/en/).

Conclusion

Neonatal brachial plexus palsy is a relatively common pathology. While most children will recover without surgical intervention, a number of challenges face the nerve surgeon throughout the preoperative, intraoperative, and postoperative care of these patients. Similar dilemmas regarding nerve graft repair versus nerve transfer face both the nerve surgeon treating NBPP and adult brachial plexus injury. Surgery for NBPP is in its relative infancy, which is the origin of most of these challenges. Further data are needed to help overcome these obstacles and

guide decision-making for these patients. While these challenges remain, it is an exciting field that holds promise for helping to improve function and quality of life for these patients through progressively improved decision-making algorithms and surgical intervention. With progress, however, new questions are likely to arise that will continue to challenge the nerve surgeon in optimizing care of these patients.

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