53 Expected Outcomes of Surgical Treatment in Obstetrical Brachial Plexus Injuries

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Introduction

Increased experience in surgical intervention for brachial plexus birth injuries (BPBI) has improved understanding of outcomes and allowed surgeons to abandon techniques with inferior results in favor of more successful alternatives. Historically, operative management of BPBI consisted of brachial plexus exploration, neuroma resection, and direct nerve approximation [1–3]; however, given the poor results of primary repair and the advent of microsurgical techniques, alternative surgical strategies have been developed, including neuroma excision and nerve grafting, neurolysis, and nerve transfers. Neuroma excision and nerve grafting are considered the mainstay of surgical treatment and are often performed concomitantly with neurolysis. Neurolysis is a frequent adjunct to other techniques, but its use as a stand-alone treatment is controversial. More recently, nerve transfers using intraplexal donor nerves from the lower plexus when available have increased in popularity with good results. Extraplexal donor nerves are considered when intraplexal donors are not available, as in global brachial plexus injuries. The current literature indicates the outcomes of brachial plexus nerve grafting, neurolysis, and nerve transfers are superior to nonoperative treatment in infants with absent or delayed spontaneous nerve recovery or in infants with global injuries [4, 5]. Regardless of surgical technique, however, surgery usually does not "normalize" upper extremity strength and function, and secondary reconstructive surgeries and ongoing physical therapy are commonly needed. Currently, the surgeon's biggest challenges are determining the optimal surgical strategy and timing for an individual infant's unique injury to optimize function, limit musculoskeletal sequelae, and minimize the need for further interventions.

Studies of outcomes of brachial plexus surgery in infants are limited by (1) heterogeneity of injury patterns, surgical indications, timing of surgery, and operative techniques within the same study, (2) selection bias introduced by surgeon preference in surgical indications and technique, (3) lack of long-term follow-up, (4) inconsistent outcome measures between studies, (5) limited understanding of the role of rehabilitation and adjunctive treatments, and (6) a focus on clinician-derived measures of motor function and less attention devoted to patient-reported outcomes. Moreover, there are few studies comparing the outcomes of the most common surgical techniques. Long-term, multicenter prospective studies addressing these methodological deficiencies are needed to provide further insight and improve care of infants with BPBI.

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A. Y. Shin, N. Pulos (eds.), *Operative Brachial Plexus Surgery*,
https://doi.org/10.1007/978-3-030-69517-0_53

This chapter summarizes the available evidence regarding outcomes of the most commonly performed surgical techniques: nerve grafting, neurolysis, and nerve transfers.

Outcomes of Nerve Grafting

Since Narakas [6, 7] and Gilbert [8] began reporting outcomes of neuroma resection with nerve grafting in the early 1980s, this technique has become the mainstay of surgical treatment. Sural nerve autograft is the most commonly reported graft source, and although alternatives to autograft have been proposed (including nerve allograft, synthetic conduit tubes, vein graft, and human amniotic membrane), few have been evaluated in human or infant subjects [9].

Understanding of surgical outcomes of neuroma resection and nerve grafting comes principally from heterogeneous, retrospective cohort studies that include a variety of surgical indications and techniques, including brachial plexus exploration, neurolysis, neurorrhaphy, nerve grafting, nerve transfer, and various combinations thereof [10–13]. These studies report reliable recovery of deltoid and biceps function [4, 10, 14–16] with less predictable recovery of shoulder external rotation (SER) [10, 11, 14, 17–19]. In infants with global palsies, for whom the reconstructive priority is recovery of hand function followed by elbow and shoulder function, results are more variable. Infants undergoing these procedures commonly recover some hand motor function, but there is no clear consensus that they recover meaningful hand use [20–25].

Upper and Middle Trunk BPBI

Two recent studies evaluated the outcomes of neuroma resection and nerve grafting in a cohort treated with a uniform surgical technique and consistent surgical indications. Lin et al. [17] evaluated 92 infants at a minimum of 4 years of follow-up. Infants with upper and middle trunk injuries experienced significant improvement in 7 of the 15 motions measured by the Active Movement Scale (AMS) (Fig. 53.1), including shoulder abduction, flexion, and external rotation, elbow flexion, and forearm supination. At final follow-up, >60% of infants demonstrated functionally useful motor function (defined as AMS score ≥ 6) for shoulder abduction and flexion, elbow flexion and extension, forearm pronation and supination, and wrist flexion and extension. Infants with global injury significantly improved in 13 of the 15 AMS motions (all except shoulder internal rotation and pronation), and the majority (>50%) demonstrated functionally useful shoulder adduction and internal rotation, elbow flexion and extension, wrist flexion, finger flexion, and thumb flexion. They concluded that neuroma resection and nerve grafting resulted in significant improvements in AMS scores and in the proportion of patients demonstrating functional motor use. Manske et al. [14] reported the outcomes of this procedure in 43 infants at a mean age of 7 months with a minimum of 18 months' follow-up. Using the Active Movement Scale, 91% of infants recovered antigravity elbow flexion, and 67% recovered antigravity shoulder abduction. Fewer infants recovered SER (19%) and wrist extension (37%). The mean duration until antigravity strength was observed was >12 months for all evaluated motions. Secondary reconstructive procedures were common, including tendon transfers for SER (49% of children), biceps rerouting (21%), and tendon transfer for wrist extension (21%).

The Active Movement Scale	
Observation	*Muscle Grade*
Gravity eliminated	
No contraction	0
Contraction, no motion	1
Motion ≤ 1/2 range	2
Motion > 1/2 range	3
Full motion	4
Against gravity	
Motion ≤ 1/2 range	5
Motion > 1/2 range	6
Full motion	7

Fig. 53.1 Active movement scale. (With permission from Curtis et al. [26])

Despite the postoperative improvements in upper limb function following neuroma resection and nerve grafting compared to preoperative function, impairments commonly persist, and secondary reconstructive surgeries are often necessary. Up to 70% of children may undergo multiple secondary procedures, including tendon transfers for SER, biceps rerouting, tendon transfer for wrist extension, and forearm or humerus osteotomies [14]. One-third of patients may require assistance with activities of daily living, with the extent of persistent impairment correlating with the extent and severity of injury [21]. Impairments due to a BPBI, however, may not limit participation and health-related quality of life. Children with BPBI participate in sports at the same rate as unaffected children without increase in rate of injury [27] and report peer relationships similar to an age-matched population [28].

Global BPBI

Several studies have specifically evaluated recovery of hand function in infants with global BPBI [14, 21–23, 25, 29], most commonly using the modified Raimondi scale, which rates hand motor function from 0 (no function) to 6 (normal function) (Fig. 53.2). Most indicate that hand motor recovery is commonly observed, but may not result in meaningful hand use (Raimondi score ≥ 3). Pondaag and Malessy [23] reported that 69% of infants who underwent brachial plexus reconstruction at approximately 4.4 months old had Raimondi scores of 3 or greater. Similarly, Terzis et al. reported Raimondi scores of 4 or better in 16 BPBI infants with poor hand function preoperatively who underwent neuroma resection and nerve grafting in the first 3 months of life [24]. In contrast, Kirjavainen et al. reported a mean Raimondi score of 2.2 (range: 0–5) in 25 infants with global BPBI who underwent a wide variety of procedures, compared to mean scores of 4.6 in infants with upper trunk palsies and 4.3 in infants with upper and middle trunk palsies [21]. Kirjavainen also reported abnormal sensation using Semmes-Weinstein monofilament testing in 76% of infants with global injuries who underwent nerve grafting, half of whom lacked protective sensation or worse. Additionally, 40% of these children demonstrated abnormal stereognosis using the Moberg-Dellon pickup test, with 16% unable to identify any of the six items tested [21]. Lower plexus avulsion injuries were associated with a lower Raimondi score.

Hand 0	Total palsy
Hand 1	No sensibility; possible tropic disturbance Some finger flexion (useless); useless thumb; no lateral pinch
Hand 2	Protective sensibility Some active useful finger flexion; no extension of wrist or fingers Weak lateral pinch with thumb; supinated forearm
Hand 3	Protective sensibility (some discrimination) Active extension of wrist with passive flexion of fingers (tenodesis) Lateral pinch with thumb; pronated forearm
Hand 4	Protective sensibility (some discrimination) Active useful flexion of wrist and fingers; intrinsic balance Mobile active thumb with some oppoition-adduction Pronated foream (no active supination)
Hand 5	Discriminative sensibility Active complete wrist and finger flexion Active extension of wrist but weak or absent finger extension Good intrinsic (median and ulmar)
Hand 6	Active pronosupination (even partial) As in hand 5 but with active extension of fingers and quite normal pronosupination

Fig. 53.2 Modified Raimondi scale. (With permission from Terzis and Kokkalis [24])

Outcomes of Neurolysis

Neurolysis is often performed in conjunction with nerve grafting, and evaluation of outcomes is often included in retrospective reviews of a variety of procedures as described above. Neurolysis as a stand-alone treatment for BPBI is controversial. Andrisevic et al. [30] reviewed 17 infants treated with isolated neurolysis of the upper trunk neuroma-in-continuity for whom intraoperative nerve conduction studies demonstrated >50% conduction across the neuroma. The authors reported significant postoperative improvement in shoulder abduction, flexion, external rotation, and internal rotation; elbow flexion; forearm supination; and wrist extension. Among children with 2 years of follow-up, the majority recovered “useful function,” defined as AMS score ≥ 6, for elbow flexion (14/16), shoulder abduction (11/16) and shoulder flexion (11/15), but not external rotation (5/15). The authors concluded that infants with >50% conduction across the neuroma-in-continuity benefit from neurolysis, as an alternative to neuroma excision and nerve grafting [31]. However, the lack of a control group makes it difficult to prove that this recovery was due to the neurolysis and would not have occurred without surgery. Similarly, Chin et al. [32] described the outcomes of brachial plexus exploration and isolated neurolysis in 32 infants with favorable intraoperative EMG findings (absence of spontaneous insertional activity and normal compound motor action potential (CMAP) morphology) and also reported good recovery of shoulder abduction and elbow flexion but limited recovery of SER.

Other studies have reported less encouraging results from isolated neurolysis [17, 32–34]. Lin et al. [17] compared the outcomes of 92 infants who underwent neuroma resection and reconstruction with sural nerve grafting to 16 infants who underwent neurolysis alone. Among those who had neurolysis alone, significant postoperative increases in AMS scores were seen only for forearm supination in infants with upper and middle trunk palsies. In infants with global injury, significant improvement was observed in elbow flexion, supination, finger extension, and thumb extension. In comparison, infants with all types of BPBI who underwent grafting experienced significant improvement in nearly all motions measured by the AMS. Additionally, a greater proportion of infants who underwent nerve grafting showed functional recovery (AMS score ≥ 6) compared to those undergoing neurolysis alone. The authors concluded that, while nerve resection and grafting results in functional AMS scores, the inferior outcomes seen with neurolysis alone support abandoning neurolysis as a stand-alone treatment. König et al. [33] performed intraoperative nerve conduction studies in ten infants undergoing brachial plexus exploration for BPBI and performed an isolated neurolysis for the five infants who demonstrated conduction across the neuroma and neuroma resection and nerve grafting for the remainder. The outcomes of neurolysis alone were “disappointing” compared to those of resection and grafting.

Lastly, several studies [32, 34, 35] evaluated the ability of intraoperative electrodiagnostic studies to predict lesion severity, but none identified clinically useful criteria to differentiate avulsion, neurotmesis, and axonotmesis from normal nerves to guide intraoperative decision-making.

Outcomes of Nerve Transfer

Extrapolating from experience in adult brachial plexus injuries, use of nerve transfers (neurotization) for the management of BPBI has become increasingly popular. These are particularly useful in the setting of isolated deficits, late presentation, failed nerve grafting, and multiple root avulsions [36, 37]. Intraplexal donors are used most commonly in isolated upper and middle trunk injuries, while extraplexal donors are useful in global plexus injuries and isolated upper trunk injuries.

Upper and Middle Trunk BPBI

Multiple nerve transfers are often performed concomitantly. One common combination of transfer for upper trunk injuries is the “triple nerve transfer”: (1) spinal accessory to suprascapular nerve for SER, (2) long or medial branch of triceps to axillary nerve for shoulder abduction, and (3) median or ulnar nerve fascicle to the biceps or brachialis branch of the musculocutaneous nerve for elbow flexion [38, 39].

Ladak et al. [40] presented the outcomes of triple nerve transfer in ten infants with isolated upper trunk injuries between 10 and 18 months of age. Mean AMS score for shoulder abduction, flexion, and external rotation, elbow flexion, and forearm supination all improved significantly between preoperative evaluation and exams performed at 1 and 2 years postoperatively. Mean scores at final follow-up demonstrated antigravity strength for shoulder abduction (AMS = 5.0), shoulder flexion (AMS = 5.4), elbow flexion (AMS = 6.2), and forearm supination (AMS = 5.9). While improved from preoperative exam, SER recovery was more limited (AMS = 4.3). McRae and Borschel [41] looked at the results of shoulder function following nerve transfers for pediatric brachial plexus injuries, including two infants with BPBI. Both of the infants with BPBI recovered functional shoulder abduction (AMS = 6), with less robust recovery of SER (AMS = 2, AMS = 3). To evaluate elbow flexion recovery, Little and colleagues [42] conducted a multicenter, retrospective review of 31 infants with BPBI who underwent either a single (median or ulnar) or double fascicle transfer to the biceps and/or brachialis branch of the musculocutaneous nerve. They found that 87% of infants recovered functional elbow flexion strength (defined as AMS score ≥6) and 21% had functional supination at a minimum 2 years' follow-up. It remains unclear if a double fascicular transfer results in superior elbow flexion and forearm supination recovery compared to single fascicle transfer. Alternative intraplexal nerve transfers to the musculocutaneous nerve, including the medial pectoral nerve [43, 44], have also been described with encouraging results.

O'Grady and colleagues [45] compared the outcomes of triple nerve transfer to nerve grafting for isolated upper trunk injuries in infants with similar preoperative AMS scores and age at time of surgery. Both groups demonstrated similar improvement in postoperative shoulder flexion, shoulder abduction, and elbow flexion, but the nerve transfer group had significantly better SER (AMS = 4.3 vs AMS = 2.9) and forearm supination (AMS = 5.6 vs AMS = 4.4) at 2-year follow-up. Nerve transfer was also associated with decreased operative time, shorter length of hospital stay, and lower costs.

Several studies compared the outcomes of spinal accessory nerve (SAN) to suprascapular nerve (SSN) transfer to nerve grafting for SER recovery and demonstrated similar findings in favor of the SAN to SSN transfer [18, 46–48]. Pondaag et al. [18] retrospectively evaluated SER recovery in 86 infants who underwent grafting of C5 to the SSN (n = 65) or transfer of the SAN to the SSN (n = 21). They identified no differences in postoperative SER AMS scores between the two techniques and reported that only 20% of the entire cohort recovered >20° of true SER. Similarly, Seruya et al. [47] evaluated the long-term outcomes of 74 infants with BPBI who underwent grafting (n = 28) or transfer of the SAN to the SSN (n = 46). Although there was no difference in postoperative AMS SER scores between the two techniques, there was a significantly higher rate of secondary reconstructive shoulder procedures in the grafting group compared with the transfer group. Interpretation of these studies is limited by baseline differences in AMS scores, injury severity, number of avulsion injuries, and age at the time of surgery. In a multicenter cohort of infants with similar injury severity, AMS scores, and age at surgery, Manske and colleagues [48] compared infants who underwent nerve grafting to the SSN (n = 59) or SAN to SSN transfer (n = 86) with a minimum follow-up of 18 months. The authors found that although there was no difference in mean postoperative AMS scores for SER (AMS = 3 in both groups), a greater proportion of infants who underwent nerve transfer achieved functional strength (AMS score ≥6) and the nerve transfer cohort had fewer secondary shoulder reconstruction procedures (hazards ratio 0.58 (95% CI 0.35–0.95)). Several approaches have been described for both the SAN to SSN transfer [49, 50] and triceps to axillary nerve [49, 51] transfer, but no comparative studies have demonstrated the optimal surgical strategy.

Lastly, Tora et al. [52] conducted a meta-analysis of nerve grafting versus nerve transfers to evaluate elbow flexion recovery and found comparable recovery of functional recovery in the nerve transfer and nerve graft groups (93% vs 96%, odds ratio = 1.15, 95% CI 0.19–7.08).

Global BPBI

In global BPBI, nerve transfers are used in conjunction with nerve grafting to provide an additional source of axonal inflow, especially in the setting of multiple nerve root avulsions. As in upper trunk injuries, the SAN is commonly transferred to the SSN for recovery of SER. Intercostal nerves are common donors to the musculocutaneous nerve for elbow flexion recovery [43, 53–55], and contralateral C7 nerve root transfer has been described for treatment of injuries with four or more root avulsions. Although these techniques are well-described in traumatic adult brachial plexus injuries, there is less information available regarding indications and outcomes for infants with birth injuries.

Luo et al. [54] evaluated the outcomes of transferring 3 or 4 intercostal nerves to the anterior division of the upper trunk or musculocutaneous nerve in 24 infants (16 global BPBI, 8 C5–C7 BPBI) and reported reliable recovery of elbow flexion using the Medical Research Council (MRC) scale; 92% of infants recovered ≥M3 elbow flexion and 71% recovered M4 strength. The authors found no difference in motor recovery between three and four intercostal nerve transfers, and transfer directly to the musculocutaneous nerve resulted in shorter reinnervation time (7.8 vs 9.3 months) compared to transfer to the upper trunk.

An alternative donor in brachial plexus injury with multiple avulsions is the contralateral C7 nerve root. Lin et al. [56] evaluated 9 infants with global BPBI with ≥ 4 root avulsions treated with contralateral C7 nerve transferred to the musculocutaneous and median nerve via a vascularized ulnar nerve graft. Seven of the nine infants recovered M3 or M4 elbow flexion strength, and five of nine recovered M3 or M4 wrist and finger flexion. The authors did not discuss donor side deficits or hand function on the affected side.

Contralateral C7 transfers were originally described with long cable grafts or vascularized ulnar nerve grafts, but more recent studies have used a retropharyngeal approach which decreases the amount of nerve graft needed.

Vu et al. [57] reported the outcomes of contralateral C7 transfer to the lower trunk using a retropharyngeal approach in five infants. At minimum 2-year follow-up, all children recovered sensation in the ulnar nerve distribution, but motor recovery did not often result in functional strength; one child recovered full wrist flexion strength (AMS = 7), while all other motions in all five patients were ≤3.

Conclusions

Nerve surgery for infants with BPBI has progressed since the initial description of primary nerve repairs. Newer techniques, including nerve grafting and nerve transfers, improve upper extremity function compared to nonoperative treatment in appropriately indicated patients, especially with regard to biceps and deltoid function. Despite these successes, persistent impairments and the need for additional operative and nonoperative treatment are common throughout childhood. Moreover, restoration of hand function in global injuries, recovery of SER, and mitigation of the musculoskeletal sequelae of BPBI remain challenging. Importantly, the effect of these interventions on patients' quality of life is not known. Methodologically rigorous studies are needed to advance understanding of surgical outcomes and improve care of infants with BPBI.

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