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Brachial Plexus Birth Injury: Trends in Early Surgical Intervention over the Last Three Decades

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Background: Early surgical management of brachial plexus birth injury has advanced owing to targeted surgical techniques and increases in specialty-centers and multi-institutional collaboration. This study seeks to determine trends in the early surgical management of BPBI over the last 30 years.

Methods: A systematic review was performed through MEDLINE (PubMed) identifying studies limited to the early surgical management of BPBI from 1990 to current. Patients treated after 1 year of age (ie, tendon transfers and secondary reconstructive efforts) were excluded. Diagnostic tests, age of intervention, surgical treatment modalities, and outcome scoring systems were extrapolated and compared so as to determine trends in management over time.

Results: Seventeen studies met criteria, summating a total of 883 patients. The most commonly reported physical examination classifications were the Mallet and AMS scoring systems. Most patients underwent neuroma excision and sural nerve autografting (n = 618, 70%) when compared with primary nerve transfers (148, 16.8%), primary nerve transfer with autografting combinations (59, 6.7%), or neurolysis alone (58, 6.6%). There was no significant change in the proportion of patients treated with sural nerve grafting, combination graft and transfer procedures, or isolated neurolysis over time. However, there has been a significant increase in the proportion of patients treated with primary nerve transfer procedures ($\tau_b = 0.668$, $P < 0.01$) over time.

Conclusion: Although neuroma excision and sural nerve autografting has been the historic gold-standard treatment for brachial plexus birth injury, peripheral nerve transfers have become increasingly utilized for surgical management. *(Plast Reconstr Surg Glob Open 2022;10:e4346; doi: 10.1097/GOX.0000000000004346; Published online 23 May 2022.)*

INTRODUCTION

Brachial plexus birth injury (BPBI) is a neurologic insult that occurs secondary to traction of the brachial plexus during the perinatal period. The incidence of BPBI is reported between 0.38 and 5.1 per 1000 live births, which has steadily decreased over the last few decades secondary to identification and prevention of risk factors and corresponding advances in obstetric care.[1,2] Perinatal risk factors for BPBI have been well described, with shoulder dystocia secondary to newborn macrosomia (birthweight >4.5 kg) known to be the most common. Other risk factors that have been described include forceps or vacuum-assisted delivery, maternal diabetes, previous deliveries resulting in BPBI, breech presentation, multiparous pregnancy, difficult presentation, and prolonged labor.[3–5] Evidence-based prevention of these injuries remains elusive, underscoring the importance of optimal treatment of the sequelae.

There has been considerable debate over the optimal physical examination classification system, diagnostic studies, and treatment modalities that are best suited to diagnose and treat these patients. These disagreements have led to discrepancies when comparing patient outcomes and thus created adversity in guiding clinical decision-making.[6] Ultimately, treatment for patients with BPBI aims to restore function in the affected limb, with priorities of intervention being, in order, optimizing hand function, elbow flexion, and shoulder external rotation and abduction.[7,8] The spectrum of current surgical intervention includes neurolysis, neuroma resection and grafting,

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or primary nerve transfer. Autologous sural nerve grafting following neuroma resection remains the gold standard and the most common reconstruction technique utilized for postganglionic BPBIs.[9]

Despite advances in our understanding of the pathophysiology of these injuries as well as refinement in surgical techniques, a lack of consensus in superiority remains. With evolving targeted surgical techniques and an increase in specialty-centers and multi-institutional collaboration with these injuries, this study aimed to provide an analysis of the trends in diagnostic evaluation and surgical techniques utilized in BPBIs over the last 30 years. We hypothesized that there has been decreased utilization of advanced imaging and electrodiagnostic studies, decreased use of neurolysis in isolation, and an increase in nerve transfer procedures.

MATERIALS AND METHODS

A literature search was performed through MEDLINE (PubMed) for English-language case series involving the surgical treatment of BPBI in January of 2021. Search terms included "brachial plexus birth injury" and "obstetric brachial plexus." Independent abstracts were reviewed by two of the authors (M.W. and M.T.). Adult brachial plexus articles and review articles were excluded. There was a minimum 1-year follow up requirement and patients treated after 1 year of age (ie, tendon transfers and secondary reconstructive efforts) were excluded. Full article review was performed among remaining articles by all authors (Fig. 1). Diagnostic tests, age of intervention, surgical treatment modalities, and outcome scoring systems were extrapolated and compared so as to determine trends in management over the last 30 years. The summative data were categorized per decade of publication for subsequent statistical analysis. In Pearson chi-square test, P-values less than 0.05 were considered to represent a significant difference in categorical variables. A Kendall tau-b correlation was performed to determine trends in the percentage of patients treated with the different surgical modalities over time. All analysis was performed in SPSS, version 25 (IBM Corp., Armonk, N.Y.).

> **Takeaways**
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> **Question:** Has the type of early surgical intervention for brachial plexus birth injury changed over the last 30 years?
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> **Findings:** Over the last 30 years, the gold-standard neuroma resection and sural autografting has remained the most common procedure. There was a significant increase in the proportion of patients treated with nerve transfer procedures.
>
> **Meaning:** There has been a growing interest in the use of primary nerve transfers, and determining outcomes of nerve transfer versus grafting remains controversial.

RESULTS

The literature search resulted in 17 studies between 1988 and 2019 meeting the specific criteria, summating a total of 883 patients (Table 1).[10–26] The United States and Canada were the most published countries on BPBI. The average age of surgical intervention was 6.7 months. There was a significant increase in the number of studied patients and overall publications over the 30-year period: from 117 patients in the first decade to 463 in the final decade ($P < 0.05$). Rates of preoperative imaging

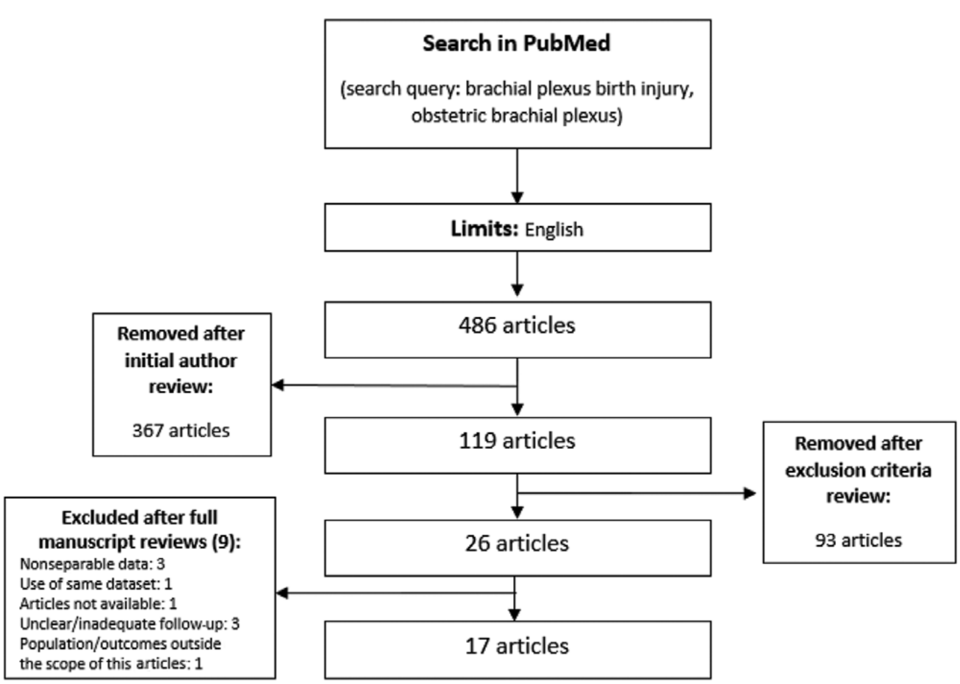

Fig. 1. Flow diagram of study selection and stages of exclusion.

Table 1. The List of Individual Studies That Met Inclusion and Exclusion Criteria

Author	Year Published	PubMed ID No.	Journal	Institution	Institutional Region	No. Patients
Boome and Kaye[10]	1988	3403599	*JBJS British*	Princess Margarget Rose Hospital, Edinburgh	Europe	22
Laurent et al[11]	1993	8331400	*Journal of Neurosurgery*	Texas Children's Hospital	United States	24
Sherburn et al[12]	1997	9486832	*Pediatric Neurosurgery*	St. Louis Children's Hospital	United States	18
Capek et al[13]	1998	9774011	*Plastic and Reconstructive Surgery*	Hospital for Sick Children, Toronto	Canada	43
Waters[14]	1999	10360693	*JBJS American*	Boston Children's Hospital	United States	6
Al-Qattan[15]	2000	11129172	*Plastic and Reconstructive Surgery*	King Khalid University Hospital	Asia	3
Xu[16]	2000	10993086	*Journal of Reconstructive Microsurgery*	Fujan Provincial Hospital	Asia	19
Haerle[17]	2004	15076607	*Journal of Pediatric Orthopedics*	Institut De La Main, Paris	Europe	73
Pondaag et al[18]	2005	16145533	*Neurosurgery*	Leiden University	Europe	86
Lin et al[19]	2009	19319058	*Plastic and Reconstructive Surgery*	Hospital for Sick Children, Toronto	Canada	108
Badr et al[20]	2009	19927081	*Neurosurgery*	Louisiana State University Health Sciences Center	United States	16
Tse et al[21]	2011	21617471	*Plastic and Reconstructive Surgery*	Hospital for Sick Children, Toronto	Canada	177
Chantaraseno et al[22]	2014	25509702	*Journal of the Medical Association of Thailand*	Rangsit University	Asia	22
El-Sayed[23]	2017	28596982	*Child Neurology Open*	King Saud University	Asia	9
O'Grady et al[24]	2017	28609352	*Plastic and Reconstructive Surgery*	University of Alberta andUniversity of Calgary	Canada	26
Al-Mohrej et al[25]	2018	29777271	*International Orthopedics*	King Faisal Specialist Hospital	Asia	125
Siqueria et al[26]	2019	30610478	*Childs Nervous System*	University of Sao Paulo Medical School	South America	104

remained stable over time with a trend toward decreasing, whereas rates of electrodiagnostic testing did not change (Table 2). The majority of authors utilized clinical criteria as indications for surgery. The most commonly used physical examination classification systems utilized to track postoperative outcomes were the Mallet and AMS scoring systems. However, there was no significant difference in utilization of the different reported outcome measure systems (Table 2; $P = 0.21$). Most patients underwent neuroma excision and sural nerve autografting (n = 618, 70%) compared with neurolysis alone (58, 6.6%), primary nerve transfers (148, 16.8%), and/or primary nerve transfer with autografting combinations (59, 6.7%). There was no significant change in the proportion of patients treated with neurolysis alone ($\tau_b = -0.251$, $P = 0.21$), sural nerve grafting ($\tau_b = 0.149$, $P = 0.42$), or combination graft and transfer procedures ($\tau_b = 0.073$, $P = 0.72$; Table 2) over time. However, there has been a significant increase in the proportion of patients treated with nerve transfer procedures ($\tau_b = 0.668$, $P < 0.01$; Fig. 2) over time.

DISCUSSION

Brachial plexus birth injuries remain problematic in the setting of the perinatal period. Although most newborns spontaneously recover, there remains a cohort of patients with lasting deficits requiring operative intervention for clinical improvement. Advances in surgical technique for optimizing outcomes have evolved in response to greater understanding of the pathophysiology of these injuries. However, there continues to be a lack of consensus in treatment superiority. Over the last 30 years, there has been a significant increase in the number of reported patients undergoing operative treatment. This reflects widespread agreement that early surgical intervention has proven clinical benefit. There has not been any significant change in the timing of surgical intervention nor change in the proportion of patients treated with neurolysis alone, sural nerve grafting, or combination graft and transfer procedures. However, there has been an increasing proportion of patients being treated with primary nerve transfer procedures. This may reflect an early shift away from historic neuroma excision and sural nerve autografting toward early nerve transfer procedures in the setting of brachial plexus birth injuries.

The average age at time of intervention was found to be between 6 and 7 months for all three decades, with no significant difference between them. No significant change was expected as the appropriate timing for microsurgical intervention remains controversial in patients who fail to spontaneously recover satisfactory function. It is generally accepted in the setting of brachial plexus injuries that the sooner the intervention, the better the functional outcomes.[27,28] The lack of active elbow flexion at 6 months incurs a poor prognosis for long-term shoulder and elbow function,[29] although many patients demonstrate some degree of recovery between 3 and 6 months of life.[14] Bauer and colleagues recently published the Treatment and Outcomes of Brachial Plexus Injury study, which was a prospective multicenter study aimed at identifying the optimal timing for nerve surgery.[9] After controlling for injury severity, there was no difference in functional outcomes between early (before 6 months of age) and late (after 6 months of age) surgical intervention in a series of 118 patients. Furthermore, they reported that clinical improvement was seen in 28 of 32 patients who underwent brachial plexus reconstruction after the age of 9 months. The authors concluded that without an indication for early surgery (panbrachial plexus lesion, root avulsions, Horner syndrome), allowing time for spontaneous recovery to occur before 6 months of age does not seem to affect the outcome following surgery.[9] Given these findings, patients should undergo operative treatment within the first year of life.

There has not been any significant change in the proportion of patients treated with neurolysis alone. Although

Table 2. Reported Variables in Preoperative Diagnosis, Surgical Procedures Performed, and Outcome Scoring Systems Utilized

	1985–1999	2000–2009	2010–2019	*P*
Patients who received preoperative imaging	40%	33%	17%	0.80
Patients who received preoperative nerve conduction studies	40%	33%	33%	0.82
Average age for intervention (mo)	6.6	6.7	6.9	0.63
Total no. patients (n, % total; 885 total)	117 (13.2%)	305 (34.5%)	463 (52.3%)	
Surgical procedure				<0.05
Neurolysis alone (n, % group)	10 (8.5%)	28 (9.1%)	20 (4.3%)	
Neurolysis and nerve grafting (n, % group)	99 (84.6%)	247 (81.0%)	272 (58.7%)	
Nerve transfers alone (n, % group)	2 (1.7%)	21 (6.9%)	125 (27.0%)	
Combination graft and transfers (n, % group)	6 (5.1%)	9 (3.0%)	44 (10.0%)	
Average follow up (mo)	21	35	35	0.66
Outcome measure system				0.21
MRC	2	0	1	
Mallet	2	4	2	
AMS	1	1	3	
Other	0	2	0	

functional improvement has been reported with neurolysis alone, more recent studies have called into question its clinical utility. In 1996, Clarke and colleagues published outcomes for 16 infants with conducting neuroma-in-continuity who underwent microsurgical neurolysis of their lesions.[30] The authors reported that patients in the Erb's palsy group had significant improvement in shoulder movement, elbow flexion, supination and wrist extension, and clinically useful improvement in function was seen at the shoulder and elbow. Fifteen years later, Clarke directly compared functional outcomes in their cohort of patients with Erb's palsy or total palsy who underwent isolated neurolysis or neuroma resection and grafting.[19] They concluded that early improvements in function produced by neurolysis in Erb's palsy were not sustained over time and that neuroma-in-continuity resection and nerve grafting for both Erb's and total palsy produced significant improvements in AMS. Others have recently revisited neurolysis in isolation, arguing there are clinical situations in which it may provide adequate improvement in outcomes.[31] Proponents argue that infants who show signs of recovery intraoperatively with nerve stimulation or electrodiagnostic studies demonstrating greater than 50% nerve conduction preoperatively, neurolysis alone is sufficient.[32] However, there is no clear evidence that neurolysis alone affects the nature history of these injuries, as many children would have improved spontaneously without surgery. In addition to those above, Gilbert, Laurent, and Meyer have all reported suboptimal results with neurolysis alone.[8,11,33] Thus, neurolysis, as a complete surgical treatment for BPBI, appears to be falling out of favor despite the lack of significance in our findings.

There has not been any significant change in the proportion of patients treated with neuroma excision and sural nerve autografting. Interposition nerve grafting has been the mainstay of surgical treatment for these patients for decades.[8,14,34–38] This remains the gold-standard treatment today by the International Federation of Societies for Surgery of the Hand.[39] The drawbacks of resection and grafting include the significant distance of axonal regeneration, lack of utility in avulsion injuries, and inevitable injury to functioning nerves in dissociative or partial injury patterns. Due to these limitations, there has been a growing interest in nerve transfer procedures.

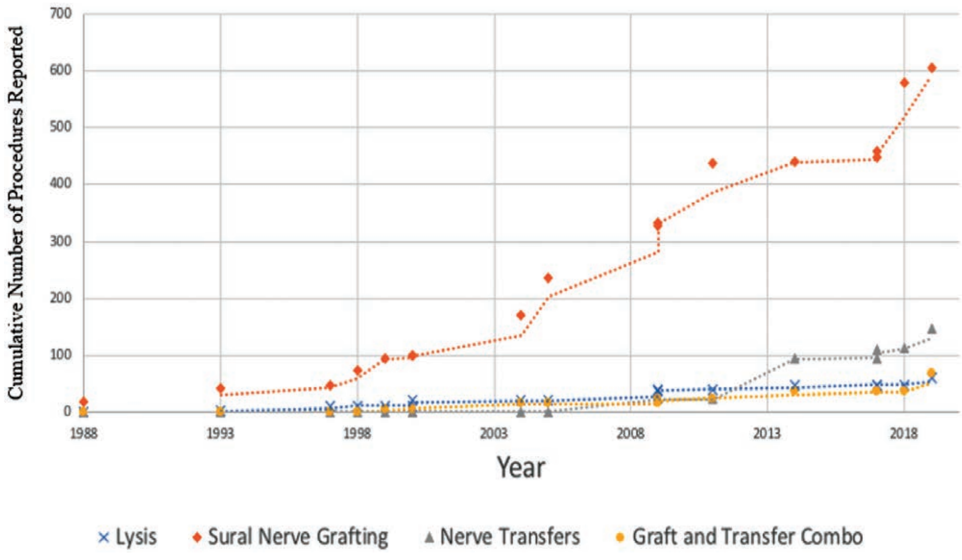

Fig. 2. Cumulative number of operative procedures reported over time.

There was a significant increase in the proportion of nerve transfer procedures over the last three decades. Candidates for nerve transfers include those with avulsion injuries as these cannot be treated with grafting. Nerve transfers are also favored in situations where dissociative recovery has occurred, where only some of the muscles innervated by a trunk have recovered sufficient function. As opposed to resecting and thereby disrupting the neural connection providing function of these muscles, an a la carte nerve transfer strategy can be employed to provide targeted reinnervation. The distal location of direct neurorrhaphy at a site closer to the target muscle allows a shorter regeneration time, faster recovery, and a longer window of time to allow spontaneous recovery before irreversible motor end plate demise.[40,41] Ladak et al reported on their results of 10 patients who underwent nerve transfers at 10–18 months of age.[42] They demonstrated progression of functional recovery between 6 and 24 months postoperatively with equivocal outcomes when compared with published results of nerve grafting. The authors argued that nerve transfer procedures therefore allow a greater amount of time for spontaneous recovery to take place without the risk of jeopardizing outcomes. Others have supported the utilization of nerve transfer procedures as well. Pondaag and colleagues directly compared sural nerve grafting with suprascapular nerve transfer for the restoration of shoulder external rotation with no appreciable difference in external rotation functional outcomes.[18] Multiple studies have validated these results,[21,43–45] interestingly, with some advocating for nerve transfer, as nerve grafting cohorts had significantly more secondary shoulder surgeries.[43] Restoration in shoulder flexion and abduction often has less reliable improvements after surgery; however, early results favor nerve transfers.[21,46] The seemingly equivalent or even improved outcomes in nerve transfer procedures likely explain the significant increase in the proportion of nerve transfer procedures over the last three decades.

Although there has been an increased interest in nerve transfer procedures as opposed to nerve grafting for BPBIs, no definite superiority has been reached. Precise indications for nerve transfers remain unclear, as there is a paucity of data in the current literature directly comparing nerve grafting with nerve transfer procedures in BPBI. The heterogeneity of lesions and the difficulty in conducting randomized controlled trials for BPBI limit most recommendations in the current literature to retrospective comparative studies and case series.[39]

Our findings in the present study are limited due to the weaknesses of a retrospective study. Limitations inherent to the utilization of other published work include reliability of the accuracy of documentation, potential for miscoding by practitioners, and lack of sufficient detail to make conclusions about the procedures described in the articles that met inclusion criteria. Furthermore, the generalizability of our results is limited by the quality of the evidence of the studies included, as well as the heterogeneity these studies in diagnostic criteria, inclusion and exclusion criteria, outcome measures, and durations of treatment and follow-up. Of note, this study excluded patients over the age of one in an attempt to limit publications focused on secondary reconstruction efforts. However, our understanding of the longevity of motor end plates has led to an increase in patients indicated for primary intervention beyond 12 months of age, such as the work by Ladak and Little.[42,47] The inclusion of these patients who underwent primary reconstruction efforts would have likely increased the power of this study.

In the time since surgical intervention for BPBIs was initially described, surgical advances in technique for optimizing outcomes has greatly evolved. Over the last 30 years, the gold-standard neuroma resection and sural autografting has remained the most common procedure. While the proportion of patients treated with neurolysis alone has not significantly changed, current evidence has nearly universally demonstrated that neurolysis has little benefit. There has been a growing interest in the use of primary nerve transfers and determining outcomes of nerve transfer versus grafting remains controversial. The heterogeneity of these lesions, varied treatment algorithms, and multiple assessment tools limit the number of high-quality studies in the field. Ongoing efforts that are led by interested hand and pediatric specialty societies to report multicenter results will continue to improve these limitations moving forward.

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