Brachial Plexus Injury Repair: Optimizing Surgical Management in Low- to Middle-Income Countries

Amit Thapa[1]

[1] Department of Neurosurgery, Kathmandu Medical College Teaching Hospital (KMCTH), Sinamangal, Kathmandu, Nepal

Address for correspondence Amit Thapa, MBBS, MS, MCh, Department of Neurosurgery, Kathmandu Medical College Teaching Hospital (KMCTH), Sinamangal, Kathmandu 44600, Nepal (e-mail: dramitthapa@yahoo.com).

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Abstract

Introduction Repair of brachial plexus injury (BPI) remains a neglected art in low- to middle-income countries (LMICs) where the more pertinent public health issues get priority and the facilities to manage such conditions are limited. We share our experience and provide recommendations to assist the existing and new facilities in providing the best care and spreading awareness.

Methods Over the period of 15 years, we have been managing patients with BPIs across age groups. Patients who could be followed for at least 1 year were included in the study. Etiological factors, neurological findings, procedure performed, and the outcome variables like improvement in power in the modified rankin scale (MRS) scale, sensory improvement, and functional capacity were studied.

Results A cohort of 172 patients with BPIs (87.8% male, mean age 27.9 years) was analyzed. The most common etiology was road traffic accidents, predominantly involving motorbikes (81%). Surgical delay decreased from 67.5% to 10% by 2024, with a mean delay of 4 months. Surgical intervention outcomes were significantly influenced by early repair, with direct neurorrhaphy for peripheral nerve injuries achieving the best results (93.8%). Neurotization yielded a 79.6% good recovery rate in incomplete BPI. DREZotomy [Dorsal Root Entry Zone lesioning (or destruction/section)] was performed in five patients with persistent pain, resulting in pain relief for all but one. No fatalities occurred, though four superficial infections were reported.

Conclusion BPI repair procedures provide gratifying results. Challenges in LMICs are unique but can be addressed with persistent, comprehensive efforts with collaborations across various platforms and organizations.

Keywords
- brachial plexus injury
- low- to middle-income countries
- optimizing surgical management
- repair
- surgery

Introduction

Brachial plexus injuries (BPIs), despite their low incidence,[1] remain a significant cause of disability, predominantly affecting young adults and neonates, often leading to severe long-term consequences. The impact on quality of life is profound, with substantial personal, familial, and societal costs.[2] Open lacerations and gunshot wounds, though less common in civilian populations, can result in significant BPI.[3] BPIs represent a neglected burden in low- and middle-income countries (LMICs), where limited recognition as a public health priority and inadequate resources lead to suboptimal management, often relying on expectant care. As a result, patients typically seek surgical intervention late, after months or years of ineffective conservative treatments.[4]

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To address this critical gap, we initiated a systematic program to comprehensively assess the needs and expectations of BPI patients and their families. We hereby share our experiences and provide recommendations to improve the outcome of BPIs in LMICs and ultimately enhance the quality of life for individuals suffering from these debilitating injuries.

Methods

The author has been performing surgical management of BPIs in Nepal since May 2010. This study included patients followed for at least 1 year. Clinical evaluations were documented using a customized chart (based on the Merle d'Aubigné system; ►**Fig. 1**) and classified by injury completeness, location (proximal/distal to the root), and distal involvement. Motor and sensory recovery were assessed using the Medical Research Council grading system. MRI was performed to exclude cervical spinal cord injuries and identify pre- and postganglionic lesions. Electromyography and nerve conduction velocity (NCV) studies were conducted 3 weeks postinjury and repeated during follow-up if satisfactory clinical improvement was not seen.

All open wounds were immediately explored. Clean-cut nerve injuries with easily identifiable ends were repaired via

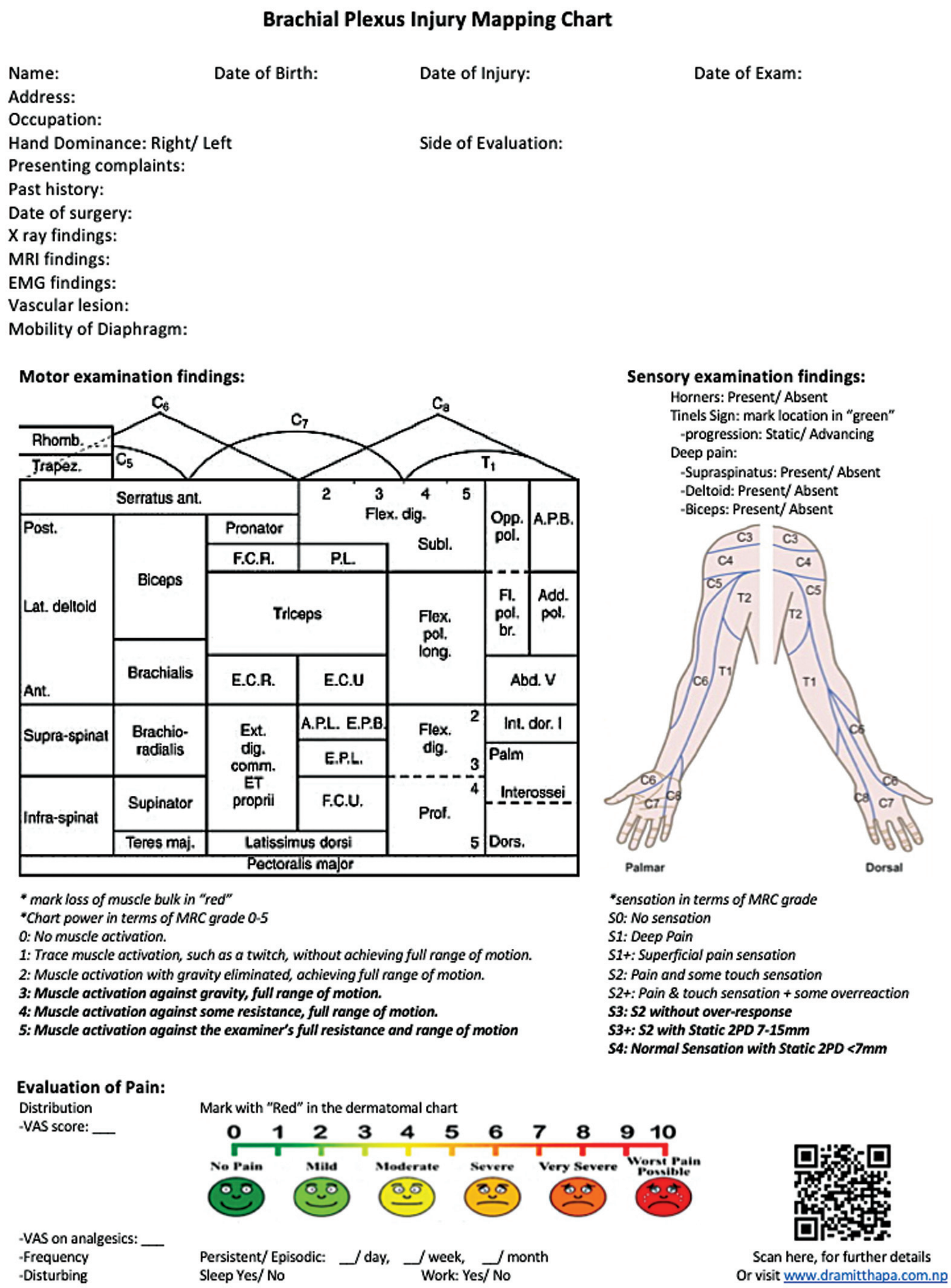

Fig. 1 Brachial plexus injury mapping chart.

Table 1 Operative plan

Classification	Site and age of injury	Target movement	Target recipient	Probable donor
C5–6 injury	Early postganglionic injury	Shoulder stabilization/abduction/rotation and elbow flexion	Lateral cord or upper trunk (or anterior division)	C5 viable root
			Posterior cord or upper trunk (or posterior division)	C6 viable root
	Preganglionic or late postganglionic injury	Shoulder stabilization abduction/external rotation	Suprascapular nerve	Spinal accessory nerve branch
		Shoulder abduction/internal rotation	Axillary nerve (anterior division)	• Long or lateral head of triceps branch of the radial nerve • Thoracodorsal nerve
		Elbow flexion	Musculocutaneous nerve	• Median nerve ± ulnar nerve fascicles • Median pectoral nerve
C567 injury	Early postganglionic injury	Triceps/wrist extension	Lateral cord or upper trunk	C5 viable root
			Posterior cord	C6 viable root
			Middle trunk/posterior cord	C7 viable root/C7 posterior division
	Preganglionic injury or late postganglionic injury	Shoulder stabilization abduction/external rotation	Suprascapular nerve	Spinal accessory nerve branch
		Shoulder abduction/internal rotation	Axillary nerve (anterior division)	Intercostal nerves
		Elbow flexion	Musculocutaneous nerve	Median nerve ± ulnar nerve fascicles
		Elbow extension	Long head of triceps branch of radial nerve	• Median pectoral nerve • Intercostal nerve • Median nerve
C8 T1 preserved shoulder, elbow, and wrist motion, but complete palsy of fingers	Young patient/early injury	Finger movements	Lower trunk/medial cord	Ipsilateral or C/L C7
	Late cases	Finger movements	Median/ulnar nerve	Brachial nerve
			Posterior interosseous nerve	Nerve to brachial/supinators (C6 root)
Total C5T1 palsy		Shoulder stabilization abduction/external rotation	Suprascapular nerve	Spinal accessory nerve branch
		Elbow flexion, shoulder abduction/internal rotation, elbow extension, wrist extension	Lateral/posterior cord	C/L C7
		Elbow flexion	Musculocutaneous nerve	2–4 intercostal nerve
		Elbow extension	Radial nerve	5–6 intercostal nerve

end-to-end anastomosis. Contaminated wounds were debrided, and nerve ends were tagged for repair after 3 to 4 weeks. Closed wounds were assessed for neuropraxia or axonotmesis and closely monitored every 3 weeks for up to 3 months before considering surgical intervention in the absence of clinical or electrophysiological recovery. If recovery plateaued or preganglionic injury was present, surgery was performed as early as 3 weeks postinjury. Surgical interventions, like neurolysis, nerve repair, nerve graft, nerve transfer or neurotization or DREZotomy or functional free muscle/tendon transfer, were offered according to the operative plan depicted in ►**Table 1**. Due to the non-availability of glue, coaptation was performed with 8–0 nylon suture (►**Fig. 2**). Neural repair was offered up to 1 year after trauma, and up to 18 months for obstetric palsy. Postsurgery, patients were followed clinically and electrophysiologically for recovery. If recovery was inadequate after 6 months, second-look or booster surgeries were considered. Etiological factors, neurological findings, surgical procedures, and outcome measures [including Medical Research Council (MRC) Scale for Muscle Strength grade improvement, pain, sensory recovery, and functional capacity] were assessed. A good recovery was defined as MRC grade 3 or higher, and Tinel's sign progression indicated nerve regeneration.

Besides providing services, the author started interacting with other specialties, presenting his data and discussing problems in management during various national and regional meetings. Public lectures and online talks help spread the message of services to the masses and the health providers.

Categorical variables were summarized as counts and percentages, and continuous variables as means with standard deviations or medians with interquartile ranges, based on distribution. Comparisons were made using Fisher's exact test for categorical variables, and either Student's *t*-test or Mann–Whitney U test for continuous variables, depending on distribution. Statistical significance was set at $p < 0.05$, and analysis was performed using SPSS version 28.

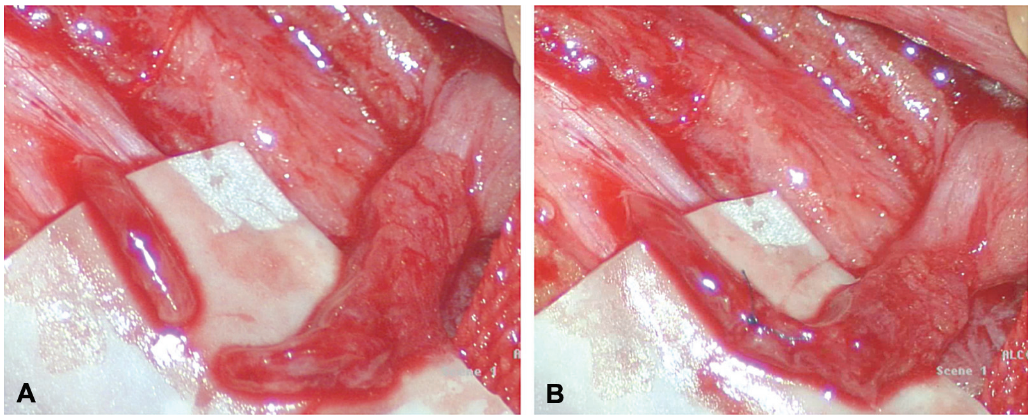

Fig. 2 Direct coaptation without graft: (**A**) Aligning the ends, and (**B**) tension-free repair.

Results

A cohort of 172 patients with BPIs who underwent surgical intervention and were followed for at least 1 year was analyzed. The cohort consisted of 151 males (87.8%) with ages ranging from 2.4 months to 65 years (mean 27.9 ± 10.1 years). The most common etiologies were road traffic injuries (81%), predominantly involving motorbikes (100%), followed by falls (10%), other trauma (9%), and obstetric palsy (2.3%).

Right-hand involvement was noted in 116 cases (67.4%). A majority (91.9%) of injuries were closed, while 8.1% were open wounds. Injury types included 49 preganglionic (28.5%), 74 postganglionic (43%), 30 mixed (19.2%), and 16 peripheral nerve injuries (9.3%). About 63 patients (36.6%) had complete BPI.

In the early years of service, 67.5% of patients (26/80) presented too late for surgical intervention. However, by 2024, delayed presentation decreased significantly to 10%. The mean delay in surgical intervention was 4 months postinjury. Of the cases treated, 16 patients underwent direct repair, 20 received neurolysis alone (with neurolysis serving as a supplementary procedure in 52 cases), and 143 patients underwent neurotization, with 88 of these utilizing autologous cable grafts, such as sural nerve, ipsilateral medial cutaneous nerve of the forearm, or superficial radial nerve.

The results indicated that age (good vs. poor outcome: 27.6 vs. 27 years) and injury location (preganglionic, postganglionic, or mixed) were not significantly associated with outcomes ($p = 0.83$ and $p = 1.000$, respectively). However, outcomes were significantly influenced by injury type and repair delay. Peripheral nerve injuries demonstrated the best outcomes, followed by incomplete and complete BPIs ($p = 0.05$; ►**Table 2**). Early surgical intervention (within 4 months) was associated with improved recovery ($p < 0.026$).

Direct neurorrhaphy for peripheral nerve injuries yielded a 93.8% good outcome, neurotization in incomplete BPIs resulted in 79.6%, and 60.3% in complete BPIs. For preganglionic and postganglionic injuries, good outcomes were observed in 69.4% and 62.2%, respectively, while mixed injuries had the lowest recovery rate at 57.6% (►**Table 2**). In a cohort of 88 patients receiving grafts, 58.3% achieved good recovery.

Among surgical techniques, direct repair produced the highest rate of favorable outcomes (93.8%, $p = 0.49$), followed by neurolysis (69.4%, $p = 0.008$) and neurotization (60.8%, $p = 0.05$). The highest rates of good recovery were seen with individual donors like the spinal accessory nerve and double Oberlein (78%), followed by the triceps branch of the radial nerve (Somsak's technique; 70%), C5 and C6 nerve roots (61%), intercostal nerves (52%), and contralateral C7 (40%). The best outcomes for recipient nerves were noted for the suprascapular and musculocutaneous nerves (78%), followed by the axillary (75%), radial (66%), and upper/middle trunk nerves (51%; ►**Figs. 3** and **4**). Due to the delayed presentation of most patients, distal neurotization was prioritized over proximal exploration and repair.

Re-exploration and distal neurotization with side-to-end supercharge transfer was done in three patients (1.7%) with mixed-type injuries who did not have satisfactory recovery over the follow-up period of 6 months.

Five patients had persistent pain after BPIs, of which three underwent nerve repair. They were offered the DREZotomy procedure, following which all became pain-free except for one, who, after initial recovery, had a recurrence of pain after 6 weeks.

There was no mortality in the series, but four patients had surgical site infections, which were all superficial, and none had to be re-explored.

Discussion

Comparison of Injury Profiles and Reporting Disparities in Brachial Plexus Injuries: Southeast Asia versus Western Data

Western data do not accurately reflect the injury profile observed in our region, which is often underreported. Most existing literature comes from Western societies, where motorcycle use is less prevalent compared with Southeast Asia.[1,3,5,6] In contrast, our findings align more closely with data from North Malaysia [Motor Vehicle Accident (MVA) 91.6%, motorbike 100%], India (MVA 90%, motorbike 90%), and Thailand (MVA 91%, motorbike 82%).[5] The next most common cause of injury in our series is falls from height, a prevalent injury mechanism in rural, hilly regions of Nepal,

Table 2 Factors affecting outcome in repair of brachial plexus injury

		Good outcome (MRC $\geq$3)	Poor outcome (MRC $<$3)	Percentage of good recovery	*p*-Value
Age (years)		27.6	27.0	–	0.83
Type of injury	Peripheral	15	1	93.8%	0.05
	Incomplete BPI	74	19	79.6%	
	Complete BPI	38	25	60.3%	
Location of injury[a]	Preganglionic	34	15	69.4%	1.000
	Postganglionic	46	28	62.2%	
	Mixed injuries	19	14	57.6%	
Type of repair	Direct repair	15	1	93.8%	0.49
	Neurolysis	50	22	69.4%	0.008
	Neurotization	87	56	60.8%	0.05

Abbreviation: BPI, brachial plexus injury.
[a]Excludes peripheral nerve injuries.

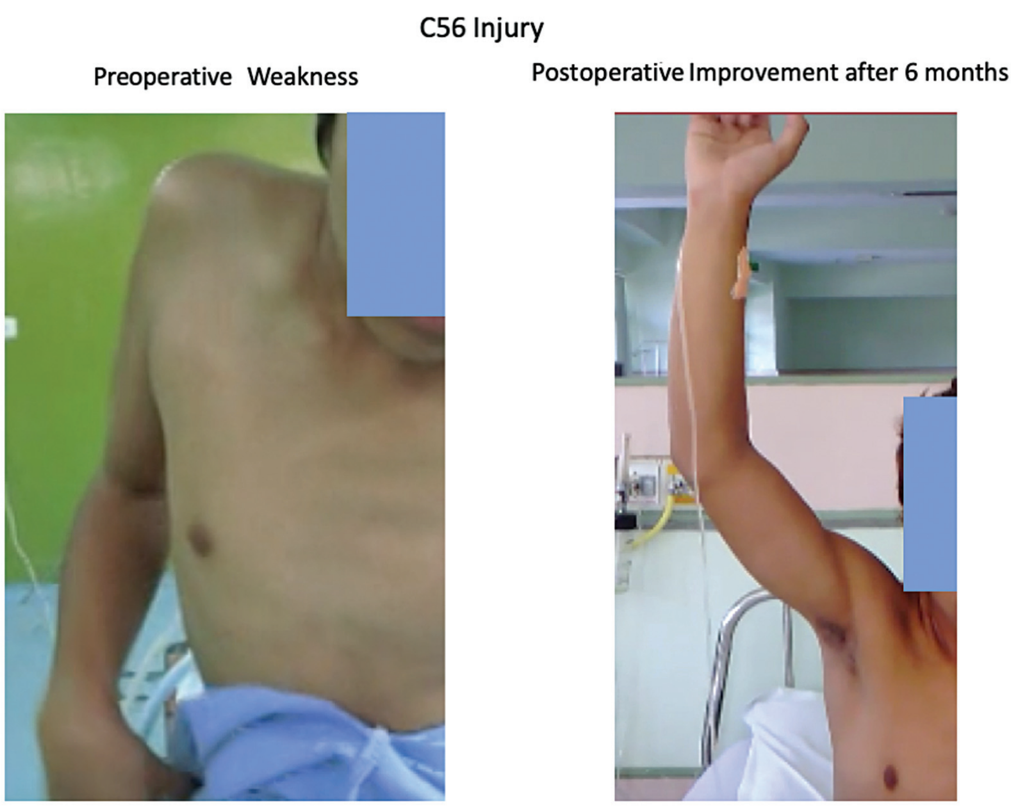

Fig. 3 Motor improvement after dual neurotization of suprascapular and axillary nerve.

where limited access to tertiary care often results in conservative management. Consequently, many BPIs in these areas remain underreported.[4] Additionally, there is a notable discrepancy in the proportion of open injuries; while our series reported 8% open wounds, Dubuisson and Kline found a significantly higher rate of 23% open wounds.[7]

Time is Function

Delayed surgical repair leads to muscle loss and diminished recovery, as neural regeneration takes time to bridge the gap.[8] Kobayashi et al, in a rat model, demonstrated that delaying nerve reconstruction beyond 1 month after transection resulted in significant impairment of muscle mass recovery and integrated motor function, preventing full recovery.[9] Our series demonstrated best results if operated within 4 months of injury; however, we did attempt repair in late cases where we opted for distal neurotization, which does not require any cable grafting.

Challenges of Setting Up Brachial Plexus Repair Services

When I started my neurosurgical practice in Nepal in 2010, BPIs were primarily managed conservatively, with few

Fig. 4 Functional improvement after triple neurotization of suprascapular, axillary nerve, and musculocutanous nerves following C56 injury.

attempts at surgical repair. Despite the pioneering efforts of Prof. Upendra Prasad Devkota, known as the Father of modern neurosurgery in Nepal, early surgical outcomes were suboptimal. A prevailing skepticism regarding the efficacy of brachial plexus repair led to limited patient referrals, and those who were referred often presented late, preventing timely surgical intervention.

The early years were marked by significant challenges. The absence of widespread access to electrophysiological studies meant that case selection relied heavily on clinical assessment. Additionally, ensuring the implementation of optimal surgical techniques and establishing effective long-term follow-up presented substantial logistical difficulties (►**Table 3**).

Complexity of Brachial Plexus Injuries: A Distinct Clinical Challenge

BPIs involve multiple nerves, minimal redundancy, and considerable anatomical variation, distinguishing them from peripheral nerve injuries in both complexity and repair strategies. While general guidelines can assist in treatment planning, the intricate anatomy of the brachial plexus necessitates highly specialized, individualized surgical interventions.

Optimal management of these injuries extends beyond the technical aspects of nerve repair. It requires a comprehensive understanding of the patient's functional needs and psychosocial context. Cultural and lifestyle factors significantly shape treatment priorities, emphasizing the critical role of a patient-centered approach in achieving the best possible outcomes.

Benefit of Surgical Repair

In clinical practice, surgical repair has been demonstrated to restore not only muscle strength but also overall limb function, leading to significant improvements in the quality of life.[10] A non-functional limb significantly impacts an individual's morale and can contribute to depression, affecting both the patient and their social environment. The

Table 3 Challenges in setting up a brachial plexus injury care center

1. **Conservative care belief**: Primary physicians and the lay public often believe that conservative management can improve outcomes for various injuries, despite limited evidence in some cases.
2. **Skepticism toward plexus injury repair**: Both senior and contemporary surgeons frequently consider repair of plexus injuries as ineffective or futile, contributing to limited surgical intervention.
3. **Lack of surgical referral**: There is a general absence of referrals for surgical repair, likely due to a combination of factors, such as perceived futility and misdiagnosis.
4. **Inadequate neurophysiological diagnostics**: The lack of neurophysiological diagnostic services hinders accurate identification of injury type, extent, and potential for spontaneous recovery.
5. **Limited surgical resources**: Inadequate operating rooms and time constraints make it challenging to conduct lengthy surgeries required for complex injury repairs.
6. **Cost barriers**: The high cost of necessary materials, such as glue and specialized sutures, prevents their widespread use in injury repair.
7. **Scarcity of trained physiotherapists**: The absence of qualified physiotherapists limits the rehabilitation options for individuals with complex injuries.

Table 4 Recommendations for improving outcomes in brachial plexus injury

Spreading awareness	• Disseminate information on available services through targeted communication. • Conduct Continuing Medical Education programs, public lectures, and media interviews. • Present at professional societies and conferences focused on BPI management. • Foster collaboration with allied specialties to optimize patient care.
Proper evaluation	• Perform thorough clinical and electrophysiological assessments to guide diagnosis and treatment. • Prioritize early identification of injuries for timely intervention. • Conduct comprehensive evaluations for associated injuries to avoid missed diagnoses.
Practical goals	• Understand and align treatment plans with patients' and families' expectations. • Prepare patients psychologically, enhancing cooperation with postoperative rehabilitation programs.
Optimum procedure	• Perform early and appropriate surgical repair to maximize recovery potential. • Consider joint movements and stability in planning surgical approaches. • Select optimal donor and recipient sites for nerve transfers. • Utilize appropriate suturing and nerve approximation techniques. • In late cases, consider neurotization using a donor distal, recipient proximal strategy for improved outcomes.
Dedicated physiotherapy and surveillance	• Motivate patients to adhere to intensive postoperative physiotherapy regimens. • Monitor recovery progress to identify delays or failures early. • Offer booster or second-stage surgical interventions when necessary to optimize functional recovery.

Abbreviation: BPI, brachial plexus injury.

psychological and social consequences extend beyond the physical impairment. When compared with conservative management, the Oberlein procedure for upper limb weakness has been shown to increase effectiveness by 0.79 Quality-Adjusted Life Years over a lifetime, with an estimated cost of $5,066.19.[11]

However, the outcome depends upon the completeness of injury, type of injury, timing of surgical intervention, the available donors, and the type of neural recipients.

What Has Worked in Low- and Middle-Income Countries?

A five-prong approach seems to have worked in our scenario (►**Table 4**).

Spreading Awareness

Effective management of BPIs starts with raising awareness among health care professionals and the public. This can be achieved through Continuing Medical Education (CME), public lectures, media interviews, and presentations at professional conferences. Collaborations with allied specialties like orthopedic surgeons, neurologists, and rehabilitation specialists are essential for improving multidisciplinary care and patient outcomes. To further this goal, we established the Reconstructive Neurosurgery Foundation (RNF) in Nepal, aiming to raise awareness about reconstructive neurosurgery, standardize practices and facilities, train health care professionals, and promote restoration and rehabilitation for neurological disorders, facilitating both functional and structural recovery.

This approach significantly improved patient outcomes in my later years of practice by allowing me to treat cases much earlier. Early intervention, combined with a more informed patient base and improved referral systems, played a key role in achieving better results.

Proper Evaluation

A thorough and systematic evaluation is critical to the effective management of BPIs. This includes a detailed clinical assessment (including key muscles to identify root injury, ►**Table 5**) followed by electrophysiological studies, which help determine the extent of nerve damage and the best course of treatment.[12] Early identification and classification of the injury is key to optimizing the timing and type of surgical

Table 5 Key muscle deficits to know about the root involvement

Root injury	Weakness of	Note
C5–6	Deltoid, supraspinatus, infraspinatus and biceps	Shoulder abduction and elbow flexion were affected
C5–7	+ FCR, triceps	Paralysis of FCR and triceps suggests involvement of C7 root
C5–8	+ weakness in FDP of ulnar digits and intrinsics innervated by the ulnar nerve	Flexors and intrinsics acting on the ulnar digits (ulnar nerve) receives primary innervation from C8, with supplementary input from C7
C8-T1	Paralysis in the FDP to the radial digits, FDS and the thenar muscles	Flexor and intrinsic hand muscles of the thumb and radial fingers (median nerve) receive significant contribution from T1
C7-T1	Complete paralysis of FDP + FDS to all digits	T1 consistently innervates the extensor pollicis longus

Abbreviations: FCR, flexor carpi radialis; FDP, flexor digitorum profundus; FDS, flexor digitorum superficialis.

intervention. Furthermore, a comprehensive evaluation of associated injuries—such as fractures, vascular damage, or shoulder instability—is essential to avoid overlooked pathologies and plan for a holistic treatment approach.

Setting Practical Goals

Establishing clear, patient-centered goals is integral to the success of BPI management. Understanding the functional and psychosocial expectations of both patients and their families ensures that treatment plans are realistic and aligned with their needs. In upper BPIs, dual neurotization of the axillary and suprascapular nerves restores shoulder external rotation, crucial for tasks like tying buttons and eating (►**Fig. 4**). Moreover, preparing patients psychologically for the challenges ahead, including rehabilitation and potential functional limitations, is crucial to fostering a cooperative relationship and improving adherence to postoperative rehabilitation programs.

Optimum Surgical Procedure

Surgical repair for BPI requires timely and appropriately tailored interventions.[12] During the planning phase, consideration must be given to joint movements, stability, and the preservation of function. An individualized approach is necessary when selecting donor nerves for transfers, and careful consideration must be given to both donor and recipient nerve selection. If roots are available, it is preferable to do a classical reinnervation and reserve distal transfers for later use. The appropriate choice of suturing or approximation techniques (tensionless coaptation) is critical for successful nerve regeneration. In cases of uncertainty, it is preferable to explore and electrophysiologically assess the response after neurolysis, rather than delaying the decision.[10] In cases with late presentations, neurotization may be considered, using a distal donor nerve and a proximal recipient nerve strategy to optimize recovery.

Dedicated Physiotherapy and Surveillance

Postoperative physiotherapy is crucial for recovery, requiring patient motivation and strict adherence to rehabilitation protocols. The rehabilitation team plays a key role in delivering intensive, individualized physiotherapy to maximize recovery and prevent complications.[13] Continuous monitoring for signs of delayed or incomplete recovery is essential for timely intervention and treatment adjustment. In cases of insufficient progress, booster surgeries or second-stage procedures may be necessary to enhance functional outcomes. This is particularly important when only neurolysis was performed in the first surgery based on intraoperative NCV findings, or if the donor nerve was suboptimal. Supercharge nerve transfer, such as reverse end-to-side nerve transfer, has proven effective for Sunderland Grade II and III injuries, while Grade IV and V injuries benefit from nerve transfers, especially in late-presenting cases.[14]

Autonomic Dysfunction

Autonomic dysfunction is a significant complication of BPI, especially in cases involving the T1 nerve root, leading to conditions like Horner's syndrome (ptosis, miosis, anhidrosis) and other issues such as blood pressure instability, sweating abnormalities, and digestive disturbances. Management focuses on symptom relief through medications (anticholinergics, antidepressants, and cardiovascular drugs), lifestyle modifications (diet, stress management, exercise), and supportive therapies (physical and occupational therapy). Specialized treatments, such as sympathetic nerve blocks or sympathetic ganglionectomy, may be considered for persistent dysfunction.

What to Do in Late Case?

In patients with persistent neuropathic pain even after 1 year of avulsion, selectively destroying nociceptive neural structures in the posterior cervical spinal cord has proven effective. This can be achieved through microsurgical DREZotomy or by using laser, ultrasound, or radiofrequency lesioning techniques.

Limitations of the Study

This series did not include any gunshot injuries, which require a distinct management protocol and are associated with a guarded prognosis. With only three cases of obstetrical palsies, we were unable to draw significant conclusions. Some of the recommendations presented are based on the author's experience and should be replicated in multiple centers before being considered for broader guideline adaptation.

Conclusion

Timely and appropriate surgical management of BPIs can yield gratifying results even in LMICs, where unique challenges can be mitigated through persistent, comprehensive efforts and collaborations across medical institutions, professional societies, and organizations. Understanding patients' needs and preparing them psychologically for continuous rehabilitation and strengthening exercises is essential to achieving optimal outcomes.

Declaration of AI Use
During the preparation of this work, the author used online software for proofreading. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

Conflict of Interest
None declared.

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