

Rehabilitation Interventions and Post Surgical Recovery Outcomes in Patients with Brachial Plexus Injury: A Narrative Review

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ABSTRACT

Brachial plexus injury (BPI) represents a multifaceted neurological disorder that can lead to substantial loss of motor and sensory function in the upper extremity. Despite notable progress in reconstructive surgical methods—such as nerve repair, grafting, and transfer—the outcomes following these procedures still show considerable variability, and full functional recovery is often not attained. We aimed to integrate and critically evaluate current evidence concerning the impact and efficacy of rehabilitation approaches in enhancing postoperative recovery outcomes among individuals affected by brachial plexus injury. The fundamental principles of rehabilitation are highlighted throughout the various stages of the postoperative period. During the initial postoperative phase, rehabilitation mainly concentrates on safeguarding joint structures, minimizing strain on repaired neural tissues, managing pain and edema, and maintaining the structural and functional integrity of the musculoskeletal system. Conversely, the subsequent phases of rehabilitation focus on promoting the activation of reinnervated muscles, implementing progressive strengthening programs, enhancing motor retraining, and reintegrating regained functions into daily living activities. Collectively, the current body of evidence suggests that rehabilitation serves as a crucial and ongoing component in promoting functional restoration, mitigating secondary complications, and enhancing the overall quality of life among individuals undergoing brachial plexus surgery.

KEYWORDS

Brachial plexus injury; Rehabilitation; Postoperative recovery; Post surgical care

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INTRODUCTION

Traumatic brachial plexus injuries (TBPI) represent one of the most severe and disabling forms of peripheral nerve damage affecting the upper limb¹. Over the past five decades, the incidence of brachial plexus injuries (BPI) has shown a marked rise, largely attributed to technological progress in transportation systems—particularly within the motor vehicle sector—throughout the 20th and 21st centuries². Various etiological factors can contribute to brachial plexus damage,

including obstetric complications, severe traumatic events such as falls, direct or blunt impacts, high-velocity motor vehicle accidents, penetrating injuries, excessive traction forces, and compressive mechanisms³. Motorcycle accidents account for the majority of closed brachial plexus injuries, representing approximately 67% of reported cases, while automobile collisions constitute the second most frequent cause, with a prevalence of about 14%⁴. The annual incidence of brachial plexus injury (BPI) within the general population is estimated to range between 0.17 and 1.6 cases per 100,000 individuals per year. Traumatic forms of BPI are observed predominantly among young male patients⁵.

Such injuries can result in significant motor and sensory impairments, functional disabilities, and psychological disturbances such as depression. Moreover, brachial plexus injuries impose notable socioeconomic burdens, as affected individuals frequently face early retirement and reduced workforce participation^{6, 7}. Furthermore, adult patients frequently experience psychological challenges, including anxiety and depression, in addition to facing difficulties in resuming occupational activities, which collectively contribute to a diminished quality of life. Therefore, timely surgical intervention is strongly recommended to optimize functional restoration of the affected limb⁸. Precise early identification of the injury type—specifically distinguishing between preganglionic and postganglionic lesions—is essential for determining the suitability and potential effectiveness of early surgical intervention aimed at restoring functional outcomes⁹.

The primary objective of surgical intervention is to optimize functional outcomes by reestablishing upper limb mobility. Contemporary surgical approaches encompass a range of advanced procedures, including nerve and tendon transfers, joint fusion, nerve grafting, neurolysis, and direct nerve repair. Findings from self-reported outcome studies indicate that reconstructive surgery does not consistently achieve complete restoration of upper limb function, full return to occupational activity, effective pain reduction, or notable improvements in perceived quality of life^{6, 10}. Optimal restoration of arm function following a brachial plexus injury can be achieved through the implementation of specialized, intensive rehabilitation programs¹¹.

Rehabilitation serves as a cornerstone in post-traumatic recovery, with early initiation generally recommended to prevent or mitigate secondary complications^{8, 11}. In terms of rehabilitation, the treatment process is typically prolonged, as functional improvements tend to occur gradually over an extended period. Minimal muscle activity may persist for several months following the initial injury, and noticeable functional improvements after surgical intervention are often observed only after three to four years of continuous rehabilitation. The duration of recovery is determined by several contributing factors, including the severity and complexity of the injury, as well as the promptness of diagnosis and subsequent therapeutic management⁸. Rehabilitation constitutes an essential component of the recovery process for both surgically and conservatively managed TBPI patients, highlighting the pivotal role of early multidisciplinary team interventions in optimizing functional outcomes^{12, 13}. The occupational and physiotherapists integrate a variety of person-centered therapeutic approaches within the rehabilitation process to maximize upper limb functional recovery¹³.

Rehabilitation plays a pivotal role in the management of TBPI. Evidence from multiple studies demonstrates that structured rehabilitation interventions contribute to enhanced motor and sensory recovery, improved quality of life, and greater independence in activities of daily living, as reflected in self-reported outcome measures. Consequently, implementing a comprehensive rehabilitation program grounded in a client-centered approach is essential following TBPI and subsequent reconstructive surgery to optimize upper limb functional outcomes¹⁴.

We aimed to provide a systematic synthesis of the existing literature evaluating the effectiveness of rehabilitation interventions in enhancing postoperative recovery outcomes among individuals with brachial plexus injuries.

METHODS

In this narrative review, we aimed to summarize published research on the effectiveness of rehabilitation interventions on post-surgical recovery outcomes in patients with brachial plexus injury. Relevant studies were retrieved from reputable databases, including Scopus, Web of

Science, Google Scholar, SID, and Magiran, using the keywords rehabilitation, brachial plexus injury, recovery and surgery. After the search process, irrelevant studies, low-quality articles, and abstracts were excluded.

Finally, the eligible articles were reviewed, and the findings were descriptively reported and summarized.

Anatomy and pathophysiology of brachial plexus injury

- Anatomy

The brachial plexus is composed of several distinct structural components, namely the roots, trunks, divisions, and cords.

- Roots

In the majority of cases, the roots of the brachial plexus arise from the anterior rami of the lower four cervical spinal nerves (C5–C8) together with the first thoracic spinal nerve (T1). Nevertheless, certain anatomical variations may be observed, such as the incorporation of anterior rami extending from C4 to C5, termed the prefixed brachial plexus, and those originating from T2 to T1, referred to as the postfixed brachial plexus¹⁵.

- Trunks

The roots converge to constitute three primary trunks—upper, middle, and lower. The upper trunk is generated through the fusion of the fifth (C5) and sixth (C6) cervical spinal nerves. The middle trunk represents a direct continuation of the seventh cervical spinal nerve (C7), while the lower trunk is formed through the union of the eighth cervical (C8) and first thoracic (T1) spinal nerves¹⁶.

- Divisions of the trunks

Each trunk segregates into anterior and posterior divisions, which subsequently contribute to the innervation of the anterior and posterior regions of the upper limb. The divisions subsequently unite to form the cords of the brachial plexus. Three distinct cords—posterior, lateral, and medial—are established through the convergence of the respective dorsal and/or ventral divisions. The

posterior cord is constituted by the convergence of the three posterior divisions derived from each of the trunks, corresponding to the spinal nerve roots C5 through C8 and T1. The lateral cord arises from the anterior divisions of the upper and middle trunks (C5–C7), while the medial cord continues from the anterior division of the lower trunk (C8–T1)¹⁶.

Pathophysiology

A brachial plexus injury commonly results in unilateral paralysis of the upper limb. Associated injuries are observed in approximately 54% of cases, with common concomitant conditions including bone fractures, vascular damage, and head trauma^{17, 18}. Motorcycle accidents represent high-energy impact traumas that may result in brachial plexus injury, particularly when the upper limbs or cervical region are involved. Brachial plexus injury most often occurs as a result of high-force traction that pulls the shoulder and upper arm away from the torso or neck. Sudden, forceful shoulder movements may result in clavicular impingement, which in turn can compromise the brachial plexus and the adjacent subclavian vascular structures^{19, 20}. For example, in motorcycle crashes, the impact may drive the head and neck toward the ground while the upper limbs are simultaneously forced in the opposite direction. This mechanism induces marked shoulder hyper abduction and widening of the scapulohumeral angle, placing the C5–T1 nerve roots at risk of high-velocity traction and avulsion. This mechanism predominantly results in nerve root avulsion lesions, reported in approximately 70%–80% of motorcycle-related brachial plexus injuries^{21, 22}.

The brachial plexus injury observed in neonates during childbirth is predominantly attributed to traction mechanisms. In cases of shoulder dystocia, excessive traction on the fetal neck widens the angle between the shoulders and cervical spine. Compression injuries are uncommon and typically arise secondary to clavicular fractures, hematomas, or pseudo aneurysms. Brachial plexus injuries may result from traction forces applied by obstetricians during attempts to alleviate shoulder dystocia. Numerous studies document both transient and persistent brachial plexus injuries—including nerve root avulsions—occurring during uncomplicated vaginal deliveries as well as cesarean sections^{23, 24}.

Surgical Treatment

Several types of surgical interventions have been documented to enhance postoperative functional outcomes. The selection of the most suitable approach is determined by the nature of the lesion. The surgical procedures can be categorized as follows.

- Neurolysis

In cases where the nerve remains anatomically continuous, performing neurolysis can be beneficial²⁵. The preservation of the interfascicular microarchitecture and the integrity of the neural sheath is essential for optimal nerve function and postoperative recovery. Due to the potential risk of vascular injury, interfascicular neurolysis is generally avoided; instead, an anterior epineurectomy is undertaken to remove the associated fibrotic tissue. The application of direct nerve stimulation both pre- and post-neurolysis allows for the assessment of enhanced neural conductivity. Determining the clinical efficacy of neurolysis is challenging, as functional recovery may result from several contributing factors other than the procedure itself^{2, 26}.

- Nerve Grafting

Nerve grafting represents the primary approach for well-defined transection injuries when the proximal stump is intact and no axial disruption is present. The surgical outcome is affected by multiple factors, including the length of the nerve graft, the degree of scar formation at the injury site, the number of graft segments utilized, the condition of the proximal stump available for repair, and the extent of the nerve gap requiring reconstruction. Following surgery, the nerve's responsiveness should be confirmed through somatosensory evoked potentials (SEPs), and the conduction of the stimulated spinal roots must be assessed. However, the reliability of C5 evaluation using SSEPs remains a subject of debate^{2, 27}.

- Neurotization

In cases of complete brachial plexus trauma, shoulder stabilization achieved through arthrodesis enables the surgeon to harvest all viable nerve grafts necessary for subsequent reconstructive procedures.

Conversely, in cases of upper brachial plexus injury accompanied by shoulder instability and pain, arthrodesis may serve as a definitive management option. Several critical parameters should be carefully considered when planning shoulder arthrodesis. First, adequate thoracoscapsular function is a prerequisite. Second, preservation of peripheral hand mobility is crucial, as shoulder arthrodesis provides no clinical benefit to a paralyzed hand. Integrity of the acromioclavicular, sternoclavicular, and scapulothoracic joints is essential, as any impairment in these articulations may compromise the success of arthrodesis^{2, 28}.

- Arthrodesis

Shoulder arthrodesis, also referred to as shoulder fusion, is a surgical procedure in which the humeral head is fused to the glenoid to achieve joint stability. In the early 20th century, this surgical approach was commonly employed for various indications, including osteoarthritis, rheumatoid arthritis, irreparable rotator cuff tears, severely comminuted proximal humeral fractures, tuberculous destruction of the glenohumeral joint, and recurrent shoulder dislocations²⁹. In recent decades, the indications for shoulder arthrodesis have progressively declined, primarily owing to the advances in shoulder arthroplasty, which has demonstrated more favorable clinical outcomes³⁰. Currently, shoulder arthrodesis is considered a salvage and reconstructive option for adult patients with brachial plexus palsy secondary to traumatic injury.²⁹

- Functioning Free Muscle Transplantation (FFMT)

Free functional muscle transfer (FFMT) involves transplantation of a muscle segment with microvascular anastomosis to restore perfusion, followed by microneural coaptation to the recipient motor nerves to achieve reinnervation. In numerous instances, delayed surgical intervention or complete brachial plexus avulsion significantly reduces the likelihood of achieving favorable functional outcomes. Despite advances in reconstructive nerve surgery, the functional restoration of shoulder and elbow motion through nerve transfer or grafting, as well as the recovery of hand function, often remains unsatisfactory. Therefore, FFMT is recommended for chronic cases, particularly those presenting

beyond 9 to 12 months after injury^{28, 31}.

Rehabilitation Strategies Post-Brachial Plexus Injury

Brachial Plexus Injury Rehabilitation Brachial plexus injury (BPI) management depends on lesion type, site, and severity, evaluated via CT myelography or MRI. Surgical intervention is optimal at 3–6 months post-injury, permitting traction-lesion recovery while avoiding iatrogenic injury; repair follows absent neural return. Preoperative neurotrophic rehabilitation is foundational²⁷, with postoperative therapy aiding neural recovery. Early intervention counters BPI-related upper limb atrophy regardless of surgery²⁷. Aims include nerve regeneration, intact muscle/joint preservation, and functional restoration to prevent atrophy, contractures, and motion loss³².

- Pain management

Psychotherapeutic follow-up by a clinician experienced in chronic pain management is strongly recommended³³. Certain patients report diminished pain severity following alcohol or cannabis use, alongside interventions, such as occupational therapy, acupuncture, physiotherapy, hypnosis, and transcutaneous electrical nerve stimulation (TENS)³⁴. TENS represents a specialized modality of low-frequency electrical stimulation formulated to alleviate pain. TENS seeks to induce neuromodulation grounded in Melzack and Wall's gate control theory of pain. It exhibits a remarkably low prevalence of side effects and complications³⁵. While TENS yields initial analgesic efficacy in 60%–65% of patients, these benefits typically diminish progressively, with merely 20%–30% sustaining clinically significant pain relief after one to two months of therapy.

Neuroprotective pharmacotherapy

Current research is actively investigating the therapeutic potential of locally or systemically administered agents to optimize peripheral nerve regeneration outcomes. These agents are designed to modulate key processes, including post-traumatic neuronal and glial apoptosis, Schwann cell proliferation, migration, and differentiation, as

well as growth cone dynamics and axonal trajectory alignment^{36, 37}.

- Orthotic management

Orthotic management serve to protect injured tissues by inhibiting aberrant movements that risk nerve-end retraction or suture/graft disruption, to avert or attenuate tendon-ligamentous contractures and deformations, and to support neuromuscular retraining via dynamic bracing paradigms^{38, 39}.

- Physical therapy

Physical therapy represents a pivotal rehabilitative approach that preserves muscle contractility amid denervation while promoting functional restoration upon reinnervation¹¹. Targeted physical activity has been demonstrated to potentiate intracellular regenerative processes and elicit afferent sensory input, thereby preserving appropriate cortical mapping of the impaired limb^{40, 41}.

- Electrical nerve stimulation

Electrical nerve stimulation is recommended for PNIs/BPIs necessitating surgical intervention to expedite the regeneration of injured nerve fibers⁴². Over several decades, preclinical investigations in animal models have elucidated the molecular underpinnings of peripheral nerve regeneration in response to direct electrical stimulation. Electrical stimulation modulates neuronal activity and triggers intracellular regenerative pathways, thereby promoting the biosynthesis of proteins essential for axonal elongation and collateral sprouting^{43, 44}.

- Occupational therapy

Extant research has established that repetitive, imitative drills lacking inherent purpose are substantially less effective than engagement in meaningful, goal-directed activities, a difference that is particularly pronounced in interventions targeting upper limb function^{45, 46}. Therefore, a mandatory rehabilitation component for PNIs/BPIs patients is doing targeted exercises to enhance the patient's ability to adapt to daily life. For example, consistent engagement in functional tasks, such as towel folding, bag lifting, knife-based cutting,

glass drinking, and utensil manipulation, expedited functional restoration among patients following brachial plexus injury surgery ⁴⁶.

Core Principles of Postoperative Rehabilitation Following Brachial Plexus Surgery

Rehabilitation represents an essential element of the therapeutic continuum after brachial plexus surgery, serving as a key mediator in converting anatomical nerve reconstruction into meaningful functional restoration ⁴⁷. With ongoing refinements in early diagnostic approaches and surgical management of brachial plexus injuries, the need for comprehensive postoperative rehabilitation has been steadily increasing. Rehabilitation interventions provide measurable benefits across all phases of recovery—spanning the spontaneous recovery stage, the postoperative phase, and the sequela stage—by supporting functional restoration and adaptation throughout the continuum of care ⁴⁷. Medical rehabilitation plays a pivotal role in the management of peripheral and brachial plexus injuries, as it supports both spontaneous and postoperative nerve regeneration while promoting maximal and integrative functional recovery ¹¹. One of the fundamental principles of postoperative rehabilitation following brachial plexus surgery is the preservation and protection of the reconstructed neural structures ^{8, 48}. Accordingly, rehabilitation strategies must emphasize joint preservation, avoidance of excessive mechanical stress on reconstructed nerves, and the sustained maintenance of overall musculoskeletal integrity ^{11, 49}. Given the progressive nature of axonal regeneration and muscle reinnervation, rehabilitation approaches should be dynamically adapted to align with the corresponding biological phase of recovery ⁵⁰. The key goals of postoperative medical rehabilitation encompass alleviation of edema and pain, enhancement of neural regeneration, and prevention of excessive fibrosis at suture or anastomosis sites, as well as contractures and disuse muscle atrophy. Additional objectives include promoting compensatory movements through synergistic muscles with preserved innervation, providing psychological support, and fostering overall functional recovery. In the later stages, rehabilitation focuses on activation of reinnervated muscles, progressive strengthening, and reintegration of restored functions into daily

activities ^{51, 52}. In addition to peripheral mechanisms, neuroplastic adaptations within the central nervous system serve as a critical determinant in facilitating functional recovery ⁴⁹.

Determinants of Rehabilitation Outcomes

Psychosocial determinants can significantly affect the rehabilitation process following brachial plexus injury, especially within young, active male populations engaged in productive roles. Their elevated expectations regarding therapeutic effectiveness often hinder acceptance of potential permanent impairment and the prolonged duration necessary for neurological recovery. Consequently, while they tend to demonstrate strong motivation and compliance during the early phases of rehabilitation, they may later exhibit psychological withdrawal, denial, or emotional frustration as treatment progresses. Therefore, consistent monitoring of patients' adherence to therapeutic protocols during the later phases of recovery is imperative to minimize the likelihood of adverse behavioral responses and to facilitate timely psychosocial interventions, including psychotherapy, pharmacological management, and structured family support. At present, a standardized psychological rehabilitation framework for brachial plexus injury has not been established, and existing research addressing psychological recovery in this patient population remains scarce. Research examining the psychological dimensions of patients with brachial plexus injuries indicates that, during the initial stages of recovery, these individuals commonly adopt adaptive coping mechanisms and employ self-distraction techniques to manage negative emotional states ^{47, 53}.

CONCLUSION

Rehabilitation interventions represent a fundamental and integrative element in promoting optimal postoperative functional restoration and improving overall recovery trajectories in patients following surgical management of brachial plexus injuries. Despite notable progress in nerve reconstruction methodologies that has enhanced both the practicality and technical outcomes of surgical procedures, current evidence suggests that surgical intervention alone is insufficient to ensure

substantial or functionally significant recovery. Rather, the conversion of surgical achievement into long-term motor and sensory recovery largely relies on the adoption of systematic, phase-tailored, and outcome-driven rehabilitation protocols. Within this framework, rehabilitation functions not solely as a supplementary component to surgical intervention but as a pivotal determinant in facilitating functional recovery, minimizing secondary complications, and fostering long-term functional autonomy. Therefore, rehabilitation ought to be regarded as a fundamental and indispensable element of postoperative care, representing a core component of comprehensive recovery management rather than a merely adjunctive or supportive measure.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests.

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