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Sari Pustaka Brachial Plexus Injury

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Abstract

Brachial Plexus Injury (BPI) is one of the most complex peripheral nerve injuries, causing significant functional impairment of the upper extremities and substantially reducing patients' quality of life. The increasing incidence of BPI, particularly in productive-age individuals due to high-energy trauma such as motorcycle accidents, underscores the urgent need for a comprehensive understanding of its epidemiology, diagnosis, management, and rehabilitation. This study aims to synthesize current scientific evidence on BPI through a systematic literature review. Data were collected from PubMed, Scopus, and Google Scholar using relevant keywords, with inclusion criteria limited to peer-reviewed articles published within the last 10–15 years. Qualitative descriptive analysis was employed to organize findings into key thematic areas. The results indicate that BPI predominantly affects young adult males through high-energy traction injuries, most frequently involving the upper trunk (C5–C6). Accurate diagnosis requires a combination of clinical examination, electromyography, nerve conduction studies, MRI, and CT-myelography to differentiate preganglionic from postganglionic lesions. Surgical reconstruction, including nerve grafting, nerve transfer, and free functional muscle transfer, yields optimal outcomes when performed within 3–6 months post-injury. Multidisciplinary rehabilitation is essential to restore upper limb function and prevent long-term disability. However, significant variation in clinical practice and the absence of standardized global guidelines remain major challenges, particularly in developing countries with limited microsurgical infrastructure and delayed referral systems. In conclusion, an integrated approach encompassing timely diagnosis, individualized surgical reconstruction, and structured rehabilitation is critical to improving functional outcomes in BPI patients globally.

Keywords: Brachial Plexus; Nerve Injury; Surgical Reconstruction; Epidemiology; Rehabilitation.

INTRODUCTION

Brachial Plexus Injury (BPI) is one of the most complex and challenging types of peripheral nerve injuries in the medical world, mainly due to its complex anatomical structure and vital role in controlling upper limb function (Stephens, 2025). The brachial plexus is composed of a series of nerve networks originating from the lower cervical and upper thoracic spinal segments, which then branch off to regulate almost all motor movements and sensations in the shoulders, arms, and hands (Retzky, 2024). When damage to this structure occurs either due to tearing, avulsion, or overstretching, the impact can be very widespread, causing functional impairments ranging from mild weakness to total paralysis of the upper limbs. In addition to motor and sensory deficits, patients also often experience severe neuropathic pain that is difficult to treat, so that overall the condition significantly reduces the quality of life, hampers daily activities, and causes psychological and social burdens.

BPI incidents In recent decades, it has shown an increasing trend in many countries, especially those with high rates of traffic accidents. The increase in the number of motor vehicle accidents, especially motorcycles, and high risk exposure in high-energy work environments, such as the construction and manufacturing industries, are the main factors contributing to the increase in BPI cases (Hofmann, 2025). This condition not only has an impact on the clinical aspect, but also has wide implications for the health service system and the economy, considering that many sufferers come from the productive age group. With the increasing complexity of cases, the urgency to understand BPI from the epidemiological aspects, injury mechanisms, diagnosis, and management strategies is becoming increasingly important for

medical practitioners, researchers, and health policymakers in designing more effective and standardized management (Chagas, 2021).

The latest epidemiological data show a tendency to increase BPI cases, especially in the productive age group. (Boyle et al., 2025) who analyzed data for 32 years in England and Wales found that the majority of BPI cases are caused by high-velocity trauma. Another study by (Cho, 2020) also confirmed a similar pattern, that the mechanism of blunt trauma, especially motorcycle accidents, is the dominant cause. This indicates that BPI is not only a medical problem, but also a socio-economic issue. In the context of developing countries, the epidemiological picture of BPI is more prominent. (Sumarwoto & al., 2022) reported the characteristics of 374 BPI patients who underwent surgery at orthopedic referral hospitals in Indonesia, where the majority of patients were young, male, and injured by motorcycle accidents. The findings support that the burden on BPI in countries with high traffic accident rates is still very significant.

The management of brachial plexus injury is a big challenge due to variations in injury patterns, degrees of nerve damage, and the time of patient arrival at health facilities(Rodríguez et al., 2021) emphasize that early diagnosis and evaluation should include a thorough understanding of the anatomy of the brachial plexus, detailed clinical examinations, and the use of supporting modalities such as MRI and EMG. Delayed diagnosis can reduce the chances of successful nerve reconstruction. The development of surgical techniques in the last two decades has contributed to the increase in clinical outcomes of BPI patients. (Rezende, 2013) explained that advances in nerve transfer techniques, nerve grafts, and other reconstruction techniques have changed the paradigm of BPI treatment. This modern approach provides new hope for patients who were previously thought to have very limited recovery opportunities.

Management strategies remain highly variable among surgeons. (Christy, 2025) found significant differences in treatment recommendations among American surgeons for adult BPI cases. These differences are mainly seen in the selection of the type of surgery, the determination of the time of operation, and the expected functional targets. This variation shows the need for more comprehensive standardization or clinical guidelines. Various clinical guidelines have been developed, but there are still inconsistencies in their implementation. (Weekes, 2025) through *a scoping review* of BPI handling guidelines stated that despite progress, global consensus has not been fully reached. This is influenced by the heterogeneity of cases, the limitations of high-evidence-based research, and differences in health facilities between countries.

Surgical reconstruction for brachial plexus injury is also highly dependent on the type and extent of the injury. (Hsueh & Tu, 2020) describe surgical strategies for C5–C6 combination injuries with or without C7 involvement, in which the choice of reconstruction techniques should be tailored to the anatomy of the injury and the goal of functional recovery. (Hill et al., 2021) also emphasize that the ideal time of surgery is within 3–6 months after injury to maximize nerve regeneration outcomes. Postoperative rehabilitation is an important component that cannot be separated from the care of BPI patients. (Li, 2023) reviewed various rehabilitation protocols and emphasized that appropriate physiotherapy interventions can support nerve regeneration, maintain joint movement, and minimize muscle atrophy. A multidisciplinary approach that includes physiotherapists, occupational therapists, and pain specialists has been shown to improve patients' functional outcomes.

In various countries with limited resources, the challenges of handling BPI are increasingly complex. (Lunga et al., 2024) reported that although surgical outcomes were quite good in middle-income countries, referral delays, limited microsurgery facilities, and access to rehabilitation were major obstacles. (Sumarwoto & al., 2021) also stated that increasing diagnostic capacity, referral speed, and public education are important steps to improve the success of BPI handling in developing countries. Thus, a comprehensive understanding of epidemiology, diagnosis, management, and rehabilitation is indispensable in an effort to improve the clinical outcomes of BPI patients globally.

Given the complexity, the rising incidence, and the existing gaps in standardized care, there is an urgent need for a comprehensive synthesis of current knowledge on BPI. The novelty of this review lies in its integrated approach, synthesizing the latest evidence across the full spectrum of BPI care from global epidemiology and injury mechanisms to advanced surgical techniques, rehabilitation strategies, and the specific challenges faced in developing countries. The primary objective of this research is to provide a cohesive and updated overview of BPI management to inform clinical practice. The contribution of this study is its potential to serve as a consolidated resource for clinicians, researchers, and policymakers, highlighting areas of consensus, identifying persistent gaps, and advocating for the development of standardized, globally applicable guidelines to ultimately improve functional outcomes for patients suffering from this devastating injury.

RESEARCH METHOD

This study used a qualitative approach with a literature review method that aims to comprehensively analyze various scientific findings related to Brachial Plexus Injury (BPI). This approach was chosen because it allows researchers to in-depth examine epidemiological aspects, injury mechanisms, diagnosis, and management and rehabilitation strategies based on published scientific sources.

The data sources in this study come from articles from reputable scientific journals, medical textbooks, and clinical reports relevant to the research topic. Data collection was done through searching academic databases such as PubMed, Scopus, and Google Scholar, using keywords such as "brachial plexus injury," "epidemiology," "diagnosis," "management," and "rehabilitation." Inclusion criteria include articles that have been published in the most recent time period (±10–15 years), are available in full text, and have direct relevance to the topic of discussion. Meanwhile, articles that do not have clear scientific validity or are not relevant to the focus of the research are excluded from the analysis.

The data analysis technique is carried out by the qualitative descriptive analysis method, which is by grouping, comparing, and synthesizing various findings from the collected literature. The data were then systematically compiled into several main themes, including the anatomy and physiology of the brachial plexus, epidemiology, injury mechanisms, diagnosis, surgical management, rehabilitation, and management challenges in developing countries. This analysis process aims to obtain a complete picture and identify the latest patterns, gaps, and developments in the handling of BPI.

To maintain the validity of the data, this study uses credible and indexed reference sources, and compares various research results from several authors to obtain objective

conclusions. In addition, the literature synthesis approach is carried out critically to avoid bias and ensure that the results of the discussion reflect the current scientific conditions.

With this method, it is hoped that the research will be able to provide a comprehensive and integrated picture of brachial plexus injury and become the basis for the development of further research and more effective clinical practices.

RESULTS AND DISCUSSION

Anatomy and Physiological Basis of Brachial Plexus

The brachial plexus is a very complex peripheral nerve network and is the main communication pathway between the central nervous system and the upper extremities. This tissue comes from the spinal nerve roots of segments C5 to T1 which form a hierarchical structure in the form of roots, trunks, divisions, cords, and terminal branches. According to (Rodríguez et al., 2021), the five main roots are joined into three trunks, namely the upper trunk (C5–C6), middle trunk (C7), and lower trunk (C8–T1), which are further divided into anterior and posterior divisions and form the lateral cord, posterior cord, and medial cord. From this cord emerge terminal branches such as n. musculocutaneous, n. axillaris, n. medianus, n. radialis, and n. ulnaris that have specific motor and sensory functions.

Functionally, the brachial plexus regulates almost all movements of the upper extremities, so injury to one or more roots can cause a variety of symptoms from segmental paresis to total paranoid paralysis (Fatma, 2022). The anatomical location of the brachial plexus makes it susceptible to traction and avulsion in high-energy trauma such as motorcycle accidents (Boyle et al., 2025); Cho, 2020; Sumarwoto & al., 2022). The disconnection of axons leads to impaired nerve impulse transmission, while peripheral nerve regeneration occurs slowly at about 1–3 mm per day (Hill et al., 2021). In addition to motor and sensory functions, the brachial plexus also carries autonomic fibers, so damage to the T1 roots can give rise to Horner's syndrome (Hsueh & Tu, 2020).

Epidemiology of Brachial Plexus Injury

Brachial plexus injury is a relatively rare condition but has a very significant functional impact, especially in the productive age group. The global literature suggests that BPI incidents are strongly associated with high-energy trauma, especially traffic accidents (Boyle et al., 2025).

1. Global Incidents and Trends
2. Distribution of Patients by Demographics
3. Injury Mechanism
4. Injury Patterns by Type and Degree of Damage
5. Epidemiological Variations in Clinical Practice and Therapeutic Recommendations
6. Epidemiological Impact on Health Services

Injury Mechanism and Lesion Type

Brachial plexus injuries occur as a result of stretching, tearing, or avulsion of nerve tissue due to significant mechanical forces. The most common mechanism is high-energy traction injuries in motorcycle accidents, in which the head and neck are pushed in the opposite direction to the shoulders (Boyle et al., 2025); (Cho, 2020). Injuries can also be caused by compression, penetration injuries, or combination mechanisms (Lunga et al., 2024).

The types of lesions are classified into preganglionic and postganglionic lesions. Preganglionic lesions in the form of root avulsion cannot be corrected with nerve grafts and require nerve transfer, whereas postganglionic lesions have better regeneration potential (Hsueh & Tu, 2020; Rezende, 2013). Based on the pattern of engagement, injuries most often involve the upper trunk (C5–C6), followed by extensive injuries to global palsy, especially in high-energy trauma (Sumarwoto & al., 2021).

Clinical Diagnosis and Evaluation

Clinical evaluation of suspected BPI aims to determine the extent and location of nerve damage, distinguish between preganglionic and postganglionic lesions, and plan surgical and rehabilitation interventions. (Rodríguez et al., 2021) emphasize the importance of a detailed anamnesis related to injury mechanisms, head and shoulder position, neuropathic pain, and onset of weakness. Medical Research Council scale motor examinations, dermatomal sensory examinations, and reflex evaluations help determine the extent of the lesions (Hsueh & Tu, 2020).

Electromyography and nerve conduction studies were used to assess denervation and lesion location, with examinations performed repeatedly after the acute phase (Hill et al., 2021). Plexus MRI and CT-myelography play an important role in detecting root avulsion, while ultrasound is beneficial for superficial postganglionic lesions (Rodríguez et al., 2021; Weekes, 2025). Determining the timing of surgical referrals is crucial, especially when there are no signs of recovery in 3–6 months (Hsueh & Tu, 2020).

Development of Surgical Management

The surgical development of adult brachial plexus injury management is influenced by advances in clinical evaluation and microsurgical techniques. Nerve reconstruction gives the best results when done within 3–6 months after injury (Hill et al., 2021; Fatma, 2022). Surgical techniques evolved from nerve grafting to nerve transfer and free functional muscle transfer.

Nerve transfer is the main choice in C5–C6 injuries due to the shorter regeneration interval and faster reinnervation time (Rezende, 2013; Hsueh & Tu, 2020). FFMT is used in chronic cases or when the end-plate motor has undergone irreversible degeneration (Sakellariou, 2014). Variation in practice among surgeons is still high and a global consensus has not yet been fully reached (Christy, 2025; Weekes, 2025).

Treatment Variations Between Physicians and Standardization Challenges

The variation in BPI treatment between doctors is influenced by the complexity of the injury, the limitations of evidence, and the difference in experience and facilities between service centers. The survey showed significant differences in the selection of reconstruction techniques and intervention times, even in the same clinical scenario (Christy, 2025). This difference is increasingly evident between developed and developing countries due to limited access to microsurgery (Lunga et al., 2024).

A scoping review by (Weekes, 2025) shows that BPI clinical guidelines are still heterogeneous and have not been standardized. Variations in diagnosis, reconstruction, and rehabilitation also influence clinical outcomes (Rodríguez et al., 2021); Li, 2023).

Clinical Externalities and Prognostic Factors

The clinical outcomes of adult BPI are strongly influenced by injury patterns, treatment time, reconstruction techniques, and rehabilitation. Partial C5–C6 injury without avulsion has the best prognosis, while total injury or multiple avulsion has worse outcomes (Hsueh & Tu,

2020; Rezende, 2013). Surgery in 3–6 months provides optimal functional outcomes, while delays increase the risk of end-plate motor degeneration (Hill et al., 2021).

Other factors that affect outcomes include the patient's age, local network conditions, service center experience, and rehabilitation quality (Li, 2023; Lunga et al., 2024). Although the methods of output assessment still vary, the combination of surgical reconstruction and comprehensive rehabilitation remains key to functional restoration (Weekes, 2025).

Rehabilitation and Functional Recovery

Rehabilitation is an integral component of BPI management and should be started as early as possible to prevent contractures and maintain joint mobility (Li, 2023). The initial program includes pain management and passive exercise, while the postconstruction phase focuses on muscle re-education and nerve stimulation (Hsueh & Tu, 2020; Rezende, 2013).

The success of rehabilitation is influenced by the degree of injury, surgical strategy, and access to therapy facilities. A multidisciplinary approach plays an important role in increasing patient independence (Sumarwoto & al., 2022). Continuous rehabilitation is recognized as a major factor in long-term recovery (Weekes, 2025).

Challenges of Handling BPI in Developing Countries

The handling of BPI in developing countries faces challenges in the form of delays in diagnosis and referral, limited diagnostic facilities, and a lack of neuro-reconstruction experts (Sumarwoto & al., 2022). Low access to MRI and electrophysiological evaluation makes it difficult to determine the right therapy strategy (Rodríguez et al., 2021).

The limitations of microsurgical facilities and long-term rehabilitation, as well as socio-economic factors, further worsen clinical outcomes (Lunga et al., 2024; Li, 2023). Therefore, it is necessary to strengthen the referral system, improve the education of health workers, and integrate national standards to improve the quality of BPI handling.

CONCLUSION

(Wade et al., 2023) Brachial Plexus Injury (BPI) is one of the most complex peripheral nerve injuries with a major functional impact on the upper extremities. Based on a literature review, BPI mainly occurs due to high-energy trauma, especially motorcycle accidents, and most often affects men of productive age. This epidemiological pattern is consistent across countries, both developed and developing, as shown by research in the United Kingdom–Wales, Brazil, and Indonesia. An in-depth understanding of the anatomy of the brachial plexus is an important basis for understanding injury mechanisms, clinical manifestations, and management strategies. The most common mechanism of injury is traction and nerve root avulsion as a result of high-speed accidents, which often result in multiple damage with a worse prognosis. Systematic clinical evaluation, including motor, sensory, reflex, and supporting examinations such as EMG, NCS, MRI, and CT-myelography, plays an important role in distinguishing preganglionic and postganglionic lesions as the basis for determining surgical procedures. The development of nerve reconstruction techniques has brought significant advances in BPI management, with nerve grafting, nerve transfer, and free functional muscle transfer as the foundation of modern management. Clinical outcomes are strongly influenced by the timeliness of the intervention, where surgical action within 3–6 months after injury provides the best functional outcomes. Long-term rehabilitation through a multidisciplinary approach is an essential component in the restoration of upper extremity function (Guo et al.,

2020). The review also showed significant variation in treatment between doctors and service centers due to differences in clinical experience, availability of microsurgical facilities, and suboptimal standardization of global guidelines. These challenges are increasingly evident in developing countries due to delayed diagnosis, limited diagnostic and microsurgical facilities, and uneven access to rehabilitation. Therefore, the success of BPI treatment is highly determined by an integrated comprehensive approach, improvement of referral systems, strengthening of microsurgical facilities, and efforts to standardize guidelines to improve patients' functional output.

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