

# Timing of surgery as outcome predictor in brachial plexus injury: a systematic review and meta-analysis

## Contacts:

Luis Rafael  
Moscote-Salazar  
[rafaelmoscote21@gmail.com](mailto:rafaelmoscote21@gmail.com)

N.D.J.L. Villamil<sup>1</sup>, W.A. Flórez-Perdomo<sup>2</sup>, M. Acosta<sup>3</sup>, M.I. Camargo<sup>1</sup>, D.P. A. Pérez<sup>1</sup>, A. Agrawal<sup>4</sup>,  
L.R. Moscote-Salazar<sup>2</sup>

<sup>1</sup>Faculty of Medicine, University of Cartagena; Bolívar, Colombia;

<sup>2</sup>AV Healthcare Innovators, LLC; Madison, Wisconsin, United States;

<sup>3</sup>Renaissance Health System; Edinburg, Texas, United States;

<sup>4</sup>Department of Neurosurgery, All India Institute of Medical Sciences; Saket Nagar, India

**Objectives.** To evaluate the evidence of timing of surgery in Brachial plexus injury and neurological outcome.

**Data sources.** The search included PubMed (until November 2022); Scopus (until March 2023); Central Cochrane Registry of Controlled Trials (The Cochrane Library) (until March 2023); MEDLINE (Ovid) until 2023; November EMBASE (Ovid); CINAHL (until March 2023).

**Study selection.** All articles that reported assessment timing of surgery in Brachial Plexus Injury (BPI), poor neurological and functional outcome.

**Data extraction.** Study type, publication year, number of patients, level of lesion, preoperative assessment, delayed of operation, operative management, follow up. We performed a meta-analysis for each variable which there was important data to estimate the importance of surgical time in the management of BPI.

**Data synthesis.** 21 studies were included in the studies, which included collected data on 878 patients from retrospective and prospective observational studies. The analysis combined odds ratios, showing an overall effect of 3.1 (95 % confidence intervals 2.2–4.3), indicating that early surgery significantly improves neurological outcomes. The low heterogeneity suggests overall consistency across studies. Although studies such as Goubier et al. (2011) and Socolovsky et al. (2011) showed stronger effects, the results indicate that surgery timing plays a crucial role in neurological recovery, with early interventions being more favorable.

**Conclusion.** There is a solid foundation to support that early surgical intervention in patients with brachial plexus lesions is a more beneficial treatment than late stage interventions.

**Keywords:** brachial plexus, treatment outcome, surgical procedures, operative, brachial plexus neuropathies, neurologic manifestations

**For citation:** Villamil N.D.J.L., Flórez-Perdomo W.A., Acosta M. et al. Timing of surgery as outcome predictor in brachial plexus injury: a systematic review and meta-analysis. *Neyrokhirurgiya = Russian Journal of Neurosurgery* 2026;28(2):88–97.

DOI: <https://doi.org/10.63769/1683-3295-2026-28-2-88-97>

## Сроки хирургического вмешательства как фактор, определяющий исход при травме плечевого сплетения: систематический обзор и метаанализ

N.D.J.L. Villamil<sup>1</sup>, W.A. Flórez-Perdomo<sup>2</sup>, M. Acosta<sup>3</sup>, M.I. Camargo<sup>1</sup>, D.P.A. Pérez<sup>1</sup>, A. Agrawal<sup>4</sup>, L.R. Moscote-Salazar<sup>2</sup>

<sup>1</sup>Faculty of Medicine, University of Cartagena; Боливар, Колумбия;

<sup>2</sup>AV Healthcare Innovators, LLC; Мадисон, штат Висконсин, США;

<sup>3</sup>Renaissance Health System; Эдинбург, штат Техас, США;

<sup>4</sup>Department of Neurosurgery, All India Institute of Medical Sciences; Сакет Нагар, Индия

**Контакты:** Luis Rafael Moscote-Salazar [rafaelmoscote21@gmail.com](mailto:rafaelmoscote21@gmail.com)

**Цель.** Изучить влияние сроков проведения операции при повреждении плечевого сплетения на неврологические исходы.

**Источники данных.** Был проведен поиск в следующих базах данных: PubMed (до ноября 2022 г.); Scopus (до марта 2023 г.); Central Cochrane Registry of Controlled Trials (The Cochrane Library) (до марта 2023 г.); MEDLINE (Ovid) и EMBASE (Ovid) (до ноября 2023 г.); CINAHL (до марта 2023 г.).

**Отбор публикаций.** Были отобраны все публикации, включавшие информацию о сроках проведения операции по поводу повреждения плечевого сплетения, неврологических и функциональных исходах.

**Извлечение данных.** Для определения влияния сроков проведения операции на исходы повреждений плечевого сплетения мы выполнили метаанализ следующих переменных: тип исследования, год публикации, число пациентов, уровень повреждения, предоперационное обследование, отсрочка операции, ведение периоперационного периода, сроки наблюдения.

**Синтез данных.** В метаанализ было включено 21 ретроспективное и проспективное наблюдательное исследование. Всего проанализированы данные 878 пациентов. Было рассчитано отношение шансов: величина эффекта составила 3.1 [95 % доверительный интервал 2,2–4,3]. Таким образом, раннее проведение операции значительно улучшает неврологические исходы. Низкая гетерогенность данных показывает общую согласованность исследований. Несмотря на то что некоторые исследования, такие как J.N. Goubier и соавт. [2011] и M. Socolovsky и соавт. [2011], показали более сильные эффекты, результаты анализа указывают на то, что сроки проведения операции играют ключевую роль в неврологическом восстановлении.

**Заключение.** Опубликованные данные указывают на то, что раннее хирургическое вмешательство у пациентов с повреждениями плечевого сплетения более эффективно, чем отсроченные операции.

**Ключевые слова:** плечевое сплетение, исход лечения, хирургическое вмешательство, операция, нейропатии плечевого сплетения, неврологические проявления

**Для цитирования:** Villamil N.D.J.L., Flórez-Perdomo W.A., Acosta M. и др. Сроки хирургического вмешательства как фактор, определяющий исход при травме плечевого сплетения: систематический обзор и метаанализ. *Нейрохирургия* 2026;28(2):88–97. [На англ.]

DOI: <https://doi.org/10.63769/1683-3295-2026-28-2-88-97>

## INTRODUCTION

Brachial plexus injuries (BPI) represent a significant clinical challenge due to their potential to cause profound motor and sensory deficits, severely impacting an individual's quality of life, with an estimated incidence of 1.75 per 100,000 individuals annually [1]. These injuries often result from trauma, such as vehicular accidents or sports-related incidents, and surgical intervention is frequently required to restore function. Neurotization, a surgical technique involving the transfer of a donor nerve to a denervated nerve to restore function, is commonly employed in BPI treatment. The optimal timing of surgery for BPI remains a topic of considerable debate among clinicians and researchers. Early surgical intervention is hypothesized to facilitate better neural recovery by preventing irreversible muscle atrophy and fibrosis, whereas delayed surgery might be considered in cases where spontaneous recovery is anticipated.

The literature on BPI includes a range of studies exploring different aspects of surgical timing and outcomes. For instance, Songcharoen et al. (1996) and Samii et al. (1997) focused on neurotization techniques for restoring elbow flexion and musculocutaneous nerve function, highlighting the potential benefits of early surgical intervention [2, 3]. Conversely, studies such as those by Dubuisson and Kline (2002) and Matsuyama et al. (2002) provide a broader perspective on BPI management, encompassing various surgical timings and techniques [4, 5]. Despite numerous studies addressing the timing of surgical intervention for BPI, there remains a lack of consensus on the optimal window for surgery to achieve the best neurological outcomes. Previous research has demonstrated varied results, with some studies, such as

Teboul et al. (2004) and Dong et al. (2010), showing favorable outcomes with early surgery, while others, like Gao et al. (2013) and Xiao et al. (2014), suggest that the timing may not be as critical [6–9]. These inconsistencies underscore the need for a comprehensive analysis of the existing evidence.

The present systematic review and meta-analysis aim to consolidate current evidence on this critical issue, evaluating the impact of early versus delayed surgery on neurological and functional outcomes in patients with BPI. By synthesizing data from randomized controlled trials (RCTs), quasi-randomized controlled studies, and observational studies, this review seeks to provide a comprehensive analysis that can inform clinical practice and guide future research. The goal is to establish a clearer understanding of how surgical timing influences recovery, thereby optimizing treatment strategies for individuals suffering from BPI.

## METHODS

The scheme to follow will be in accordance with the recommendations of the meta-analysis and the systematic reviews of the PRISMA declaration for the presentation of the systematic reviews of randomized clinical trials and observational studies meta-analysis and the Cochrane Manual of systematic reviews and meta-analysis.

### Literature search strategy

A search for RCT, not RCT, prospective and retrospective cohort studies will be carried out through PubMed (until November 2022); Scopus (until March 2023); Central Cochrane Registry of Controlled Trials (The Cochrane Library) (until March 2023); MEDLINE (Ovid) until 2023;

November EMBASE (Ovid); CINAHL (until March 2023); in addition to the reference list of included studies and other relevant data in addition to potentially eligible studies.

The terms (“peripheral nervous injury”) OR (“Brachial plexus injury” OR “non-Obstetric nervous injury” OR “non Neonatal brachial plexus injury”) AND (“prognosis” OR “motor function” OR “MRC scale”) AND (“randomized clinical trials” OR “clinical trials” OR “observational study”) NOT “animals”. The strategy will include subject headings (MeSH) and text words connected with Booleans term.

#### Inclusion criteria

The studies to be included are screened separately using the following inclusion criteria:

Randomized controlled trials, quasi-randomized controlled studies, and prospective and retrospective observational studies assess the timing of surgery in BPI and poor neurological and functional outcomes.

#### Exclusion criteria

In this systematic review and meta-analysis, the following studies were excluded: 1. Studies carried out in the pediatric population. 2. Studies that included obstetric or neonatal injury. 3. Case reports and/or case series of 10 patients or less.

#### Data collection process

Two review authors (L.R.M.S and W.F.P) extracted data from included studies using a piloted data extracted tool, if any discrepancy appeared was resolved by discussion. Two authors (L.R.M.S and W.F.P) independently download full text articles, with discrepancies resolved through discussion. The references of relevant studies were cross-checked for additional studies not identified by electronic search.

#### Data extraction

The following data is extracted from the articles: First, Study characteristics; Second, patient characteristics (number of patients, demographics, and clinical characteristic); Third, Eligibility, based on the mentioned study selection criteria. The doubts were clarified by consensus.

#### Study risk of bias assessment

The risk of bias assessment was performed using the ROBINS-I tool, which evaluates the following 7 domains: D1: “Bias due to confounding”; D2: “Bias in selection of participants”; D3: “Bias in classification of interventions”; D4: “Bias due to deviations from intended intervention”; D5: “Bias due to missing data”; D6: “Bias in measurement of outcomes”; D7: “Bias in selection of the reported results”, based on the presence or absence of some characteristic in “Low Risk”, “moderate

risk”, “serious Risk”, “critical Risk” and “no information” (Fig. 1).

Publication bias was assessed using funnel plots for asymmetry and Egger’s test. The results of these assessments are presented in Fig. 2.

#### Evaluation of the quality of the studies included

The quality of included studies was through Newcastle–Ottawa Quality Assessment Scale, studies with scores of 9, were considered of high methodological quality, 7 to 8 points score (Table 1) Those with scores in a range 6 were considered of Moderate Quality.

#### Extraction, manage and statistical analysis of data

The independent review was carried out for the selected articles and the data regarding moderate and good motor function recovery defined as MRC more than 3, timing of surgery categorized as Early surgery less than 6 months and delayed as more than 6 months. The corresponding Authors were contacted for missing data and any disagreements were resolved through consensus. The statistical analysis was performed through the Pooled Odds ratio (OR) with the Mantel-Haenszel methodology for reasons by using a randomized effect analysis model (Comprehensive Metanalysis Software version 3.3.070, 2014, New York, USA). Heterogeneity was assessed by I<sup>2</sup>, lower than 50 % value was being considered as Low heterogeneity, between 50,01 % to 60 % moderate Heterogeneity, 60,01 % to 70 % High heterogeneity and upper than 70 % considered as Very High heterogeneity of the included studies in the analysis.

## RESULTS

### Study selections

After completing the literature search using the strategy we described above, the results yielded a total of N articles of which N were potentially eligible taking into account the title and abstract or both. After reading the texts in full, 33 articles were considered eligible, 12 were excluded (Fig. 3) because they did not meet the inclusion criteria or answer the research question. Finally, 21 articles were included for the review.

### Study characteristics

All the studies that were included in the review were observational studies, 17 of them retrospective [2–6, 8–19] and 4 prospective [20–23]. The summary of the characteristics of all is described in Table 2.

### Systematic review

In the evaluation of nerve surgery outcomes, multiple studies have highlighted the critical role that timing plays in achieving favorable results. Songcharoen et al. reported a significant increase in poor outcomes when surgery was delayed beyond 9 months post-injury, with the percentage rising from 25 % to 62.5 % in these patients [2]. This trend

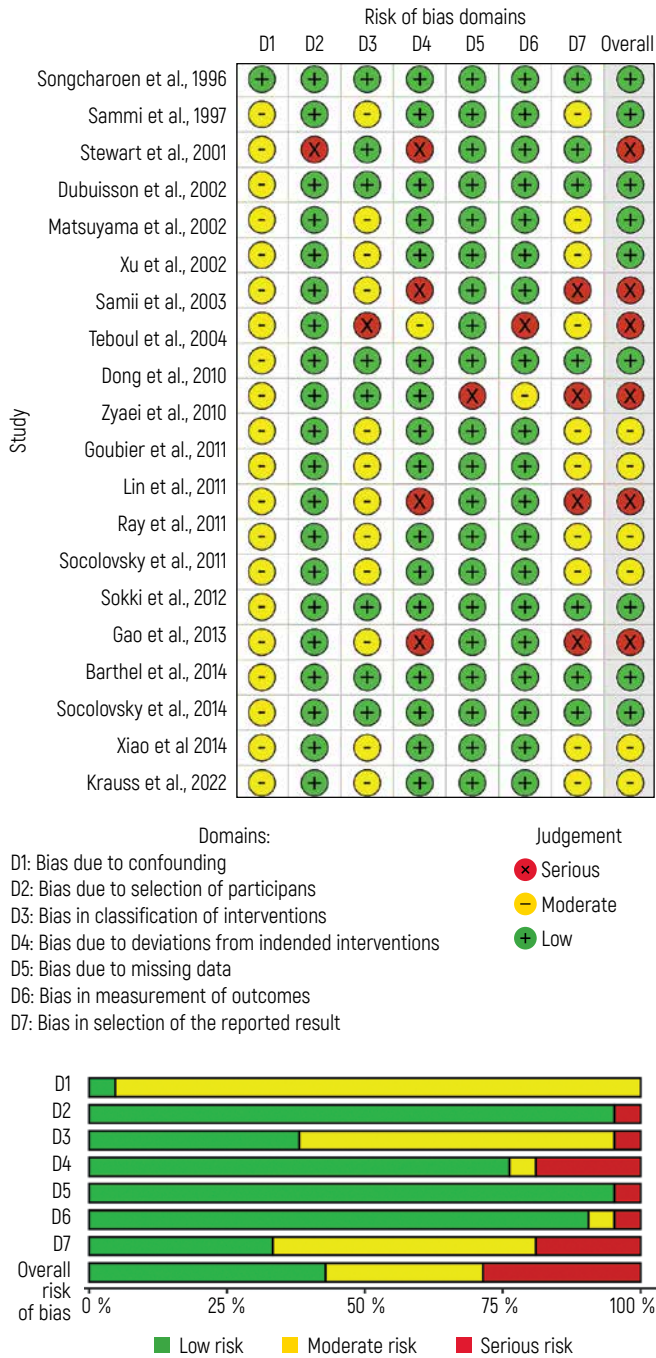


Fig. 1 | Рис. 1  
Risk of bias assessment using ROBINS-I. A number of studies evaluated and included in the analysis are recorded  
Оценка риска систематической ошибки с использованием системы ROBINS-I. Число рассмотренных и включенных в анализ исследований

is further supported by Sammi et al. (1997), who demonstrated that patients undergoing surgery within 7 months of the injury had significantly better outcomes compared to those treated later ( $p < 0.05$ ) [3]. The benefits of early surgical intervention are echoed by Stewart et al. (2001), who emphasized the importance of addressing nerve

deficits that fail to improve within two to four months of injury, recommending timely surgery to prevent long-term damage [10].

Dubuisson and Kline found that the median interval between trauma and surgery was 7 months, and reinnervation success rates varied depending on the timing of the intervention [4]. Reinnervation of the musculocutaneous nerve was observed in 86 % of patients operated on within 6 months, 65 % of those treated between 7 and 12 months, and only 50 % of patients who underwent surgery after 12 months. This reinforces the findings by Samii et al. (2003), who also observed a statistically significant improvement in outcomes for patients receiving surgery within the first 6 months post-injury compared to those who had delayed intervention ( $p < 0.05$ ) [3, 11].

Lastly, Socolovsky's study on nerve grafting further underscored the importance of early intervention. He found that 66.7 % of the 30 long grafts performed within 6 months yielded good outcomes, with an overall good outcome rate of 48.9 %. Collectively, these studies stress the importance of early surgical intervention, particularly within the first 6 months after injury, to maximize the chances of nerve reinnervation and functional recovery [16].

#### Data analysis

An improvement of good outcomes was evident in patients who were treated in 6 months or less compared to the control group (OR 3.1, 95 % confidence intervals 2.2–4.3;  $p < 0.001$ ) (Fig. 4), while studies reporting later surgeries showed less benefit, with some interventions failing to reach statistical significance. Key studies, such as those by Songcharoen et al. and Socolovsky et al., displayed significantly higher OR, reinforcing the advantage of early surgery.

The heterogeneity analysis revealed an  $I^2$  of 0.000 %, indicating no significant heterogeneity among the studies, suggesting that the results are consistent and robust. Moreover, the funnel plot showed no evidence of publication bias ( $p = 0.67750$ ), further supporting the reliability of these findings (Fig. 2).

#### DISCUSSION

The findings from this systematic review and meta-analysis offer valuable insights into the role of surgical timing in managing BPI. Our analysis indicates that early surgical intervention, defined as surgery performed within six months of injury, is associated with significantly improved motor function recovery compared to delayed surgery. This supports the hypothesis that early intervention can capitalize on the window of neural plasticity and prevent secondary muscle degeneration and fibrosis, thereby enhancing the potential for functional recovery.

Several factors may contribute to the observed benefits of early surgery. Firstly, the timing of intervention is crucial for the reinnervation of muscles before they undergo irreversible atrophy. Secondly, early surgery may mitigate

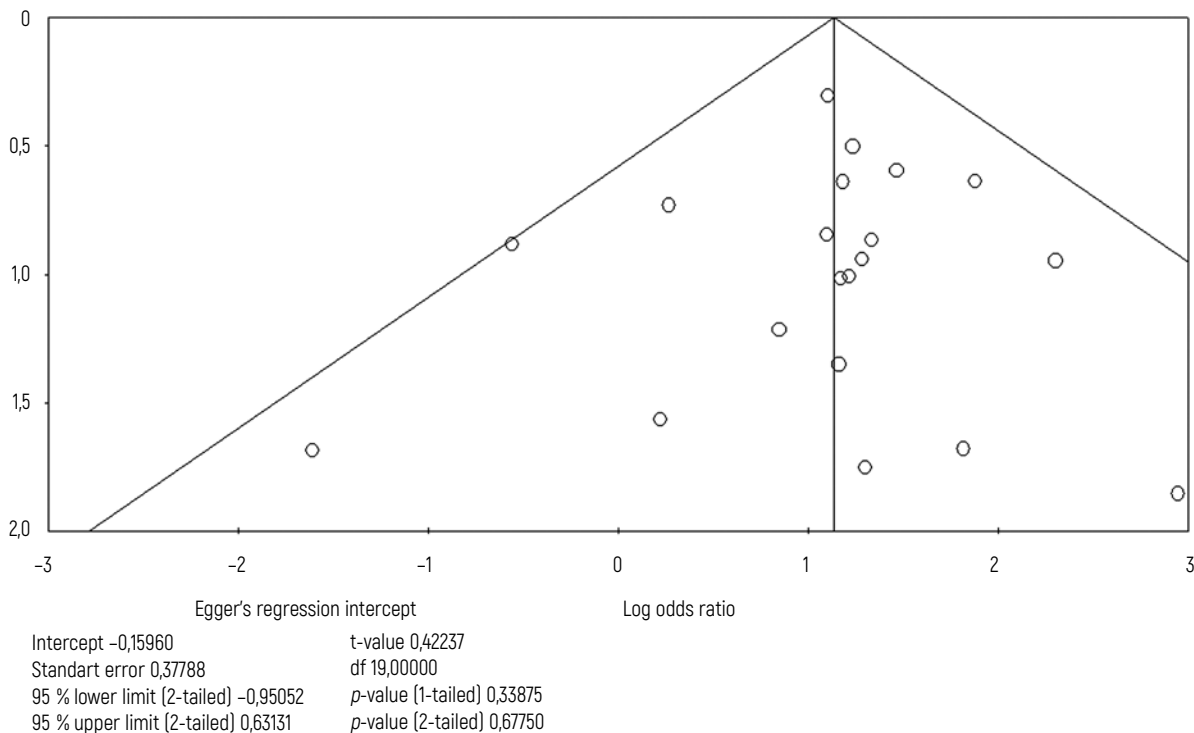


Fig. 2 | Рис. 2

Egger's regression intercept  
Пересечение регрессионной кривой Egger

fibrotic scar tissue formation, which can impede nerve regeneration. These findings align with the principles of neurobiology, suggesting that prompt surgical repair facilitates more effective nerve regeneration and functional recovery [2, 3].

This review incorporates a diverse array of studies, including works by Songcharoen et al. (1996), Samii et al. (1997), and Gao et al. (2013), among others, each contributing to the overall understanding of surgical timing. The included studies consistently show that early intervention results in better outcomes, particularly in terms of motor function recovery. For instance, Songcharoen et al. demonstrated that early spinal accessory neurotization significantly improved elbow flexion, while Gao et al. highlighted the benefits of early intercostal nerve transfer for triceps function [2, 3, 8].

However, the review also highlights considerable heterogeneity among the included studies, which underscores the complexity of this clinical issue. Variations in study design, patient populations, and definitions of “early” and “delayed” surgery contribute to this heterogeneity. Despite these variations, the overall trend favors early surgical intervention. Future research should aim to standardize definitions and methodologies to reduce heterogeneity and enhance the comparability of studies.

The risk of bias assessment revealed that many studies had moderate to serious risks of bias, particularly

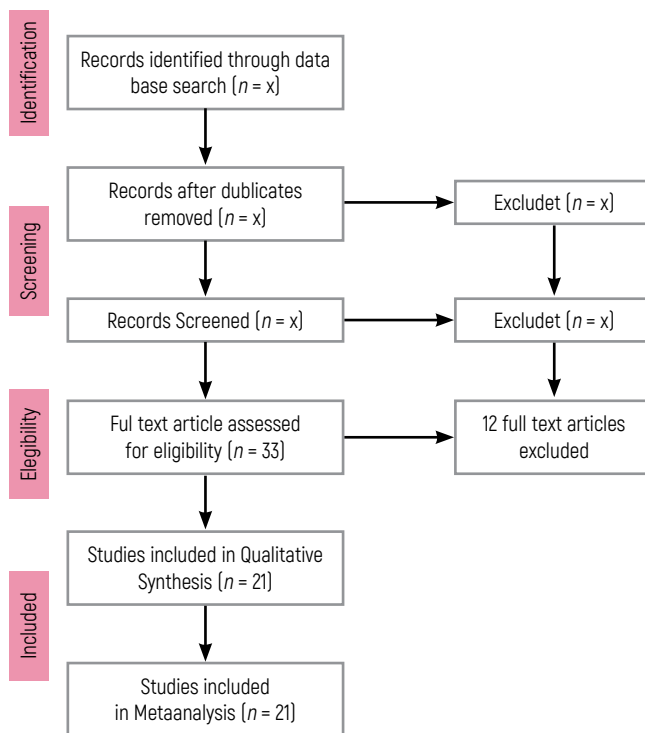


Fig. 3 | Рис. 3

Map of the item selection process, showing the number of records identified, included, and excluded

Схема отбора публикаций, показывающая количество идентифицированных, включенных и исключенных статей

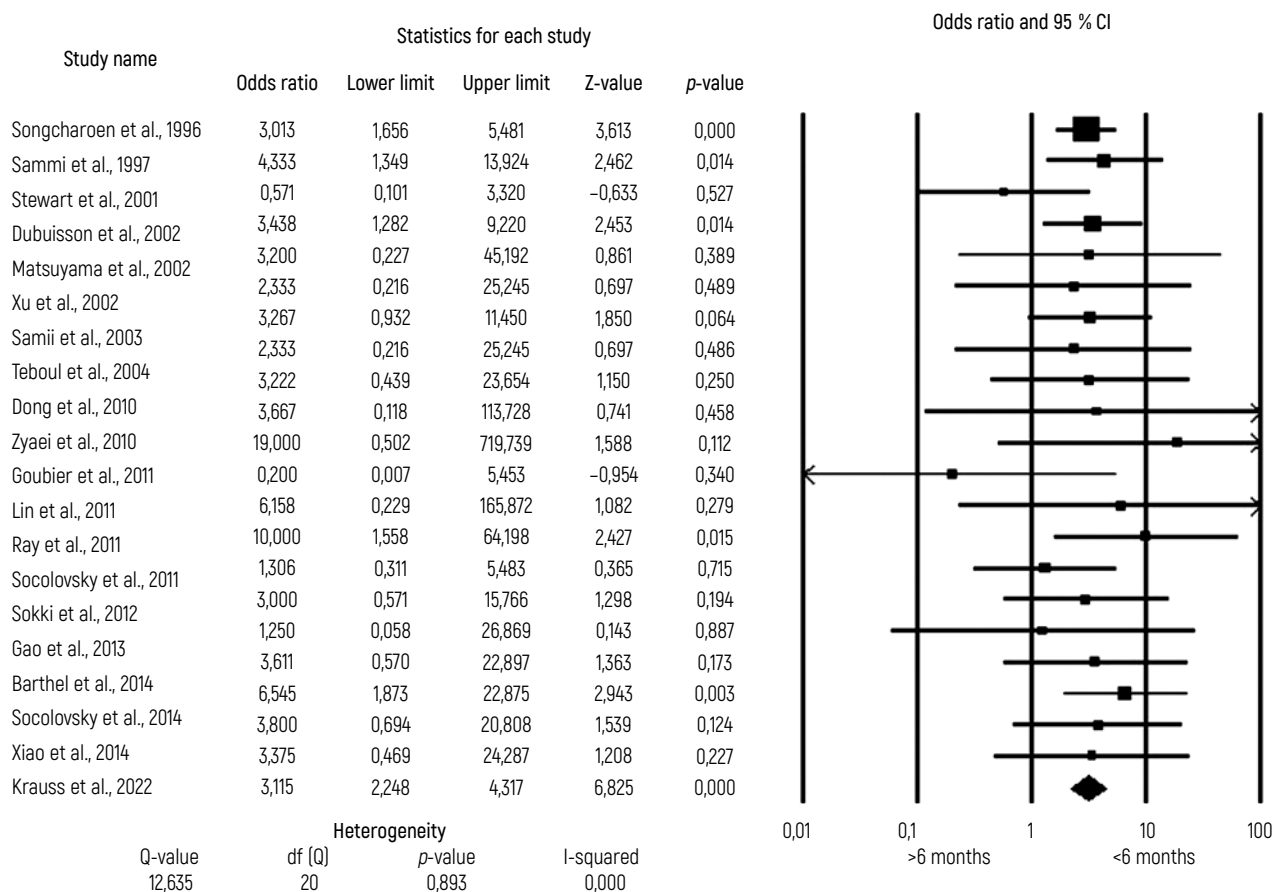


Fig. 4 | Рис. 4

Forest plot. The graph evaluates the odds ratios (OR) and their 95 % confidence intervals (CI). Heterogeneity statistics are presented: the Q value, degrees of freedom (df), p-value, and I-squared (I<sup>2</sup>), which measures the variability among the studies

Диаграмма Forest plot. На графике представлены отношения шансов и их 95 % доверительные интервалы (CI), а также статистические данные по гетерогенности: значение Q, степени свободы (df), значения p и I<sup>2</sup>, которые описывают вариабельность между исследованиями

Table 1 | Таблица 1

Newcastle-Ottawa Scale for quality assessment of studies included in this meta-analysis

Шкала Newcastle-Ottawa для оценки качества исследований, включенных в данный метаанализ

Study	Representativeness sample	Size Sample	Source of information	Demonstration that outcome was not present at study start	control variable confusion	Assessment outcome	Enough follow up period	Newcastle-Ottawa Scale Score
Songcharoen et al., 1996	★★	★	★	★	★	★★	★	9/9
Sammi et al., 1997	★	★	★	★	★	★	★	7/9
Stewart et al., 2001	★	★	★	★		★	★	5/9
Dubuisson, Kline, 2002	★★	★	★	★		★	★	5/9
Matsuyama et al., 2002	★★	★	★	★	★	★	★	8/9
Xu et al., 2002	★★	★	★	★	★	★	★	8/9
Samii et al., 2003	★	★		★		★	★	5/9
Teboul et al., 2004	★	★			★	★	★	5/9
Dong et al., 2010	★★	★	★	★	★	★	★	8/9

End of table 1  
Окончание табл. 1

Study	Representativeness sample	Size Sample	Source of information	Demonstration that outcome was not present at study start	control variable confusion	Assessment outcome	Enough follow up period	Newcastle-Ottawa Scale Score
Zyaei et al., 2010	★	★		★		★	★	5/9
Goubier et al., 2011	★★	★	★	★	★	★	★	8/9
Lin et al., 2011	★★	★	★		★	★	★	7/9
Ray et al., 2011	★	★		★		★	★	5/9
Socolovsky et al., 2011	★★	★	★		★	★	★	7/9
Sokki et al., 2012	★★	★	★		★	★	★	7/9
Gao et al., 2013	★★	★	★	★	★	★★	★	9/9
Ren et al., 2013	★	★		★		★	★	5/9
Barthel et al., 2014	★★	★	★	★	★	★	★	8/9
Socolovsky et al., 2014	★★	★	★	★	★	★	★	8/9
Xiao et al., 2014	★★	★	★		★	★	★	7/9
Krauss et al., 2022	★★	★	★		★	★	★	7/9

★ Indicates that it meets criteria in Newcastle-Ottawa Scale.

Table 2 | Таблица 2

Characteristics of all studies included in the review

Характеристики всех исследований, включенных в обзор

Study	Type	N	Level of lesion	Preoperative assessment	Delayed of operation	Operative management	Follow up
Songcharoen et al., 1996	Retrospective observational study	216	C5-T1	Cervical Myelography (CM) Electrodiagnostic testing no specified (EDT)	<6 months: 110 >6 months: 106	Nerve graft Nerve transferer	6 years
Sammi et al., 1997	Retrospective observational study	54	C5-C6	Electromyography (EM)	<6 months: 21 >6 months: 33	Neuro graft Nerve transferer	4 years
Stewart et al., 2001	Retrospective observational study	58	C5-T1	No reported	<6 months: 35 >6 months: 23	Neurolysis, neuro graft Nerve transferer	2 years
Dubuisson, Kline, 2002	Retrospective observational study	99	C5-T1	Cervical Myelography (CM) Electromyography (EM) Magnetic Resonance Imagen (MRI)	<6 months: 72 >6 months: 27	Neurolysis, neuro graft Nerve transferer	3 years
Matsuyama et al., 2002	Retrospective observational study	16	C5-T1	Cervical Myelography (CM) Electromyography (EM) Magnetic Resonance Imagen (MRI) Nerve conduction test (NCT)	<6 months: 9 >6 months: 7	Neurolysis, nerve graft Nerve transferer	5 years
Xu et al., 2002	Prospective observational study	15	C5-T1	Electromyography (EM)	<6 months: 9 >6 months: 5	Neurolysis	No reported

End of table 2  
 Окончание табл. 2

Study	Type	N	Level of lesion	Preoperative assessment	Delayed of operation	Operative management	Follow up
Samii et al., 2003	Retrospective observational study	44	C5-T1	No reported	<6 months: 20 >6 months: 24	Nerve graft Nerve transferer	7.5 years
Teboul et al., 2004	Retrospective observational study	32	C5-C7	No reported	<6 months: 9 >6 months: 5	Nerve graft Nerve transferer	5 years
Dong et al., 2010	Retrospective observational study	40	C5-T1	Electromyography (EM)	<6 months: 32 >6 months: 8	Nerve transferer	3.9 years
Zyaei et al., 2010	Prospective observational study	10	C5-C6	Electrodiagnostic testing no specificized (EDT) Magnetic Resonance Imagen (MRI)	<6 months: 5 >6 months: 5	Nerve transferer	1 year
Goubier et al., 2011	Retrospective observational study	11	C5-C6	Magnetic Resonance Imagen (MRI)	<6 months: 9 >6 months: 2	Nerve graft Nerve transferer	2 years
Lin et al., 2011	Retrospective observational study	11	C5-T1	Electromyography (EM)	<6 months: 6 >6 months: 4	Nerve graft Nerve transferer	4 years
Ray et al., 2011	Retrospective observational study	29	C4-C7	Electromyography (EM) Nerve conduction test (NCT)	<6 months: 19 >6 months: 10	Nerve graft Nerve transferer	1.5 Years
Socolovsky et al., 2011	Retrospective observational study	27	C5-T1	Magnetic Resonance Imagen (MRI) Electromyography (EM)	<6 months: 15 >6 months: 12	Nerve graft	2 years
Sokki et al., 2012	Prospective observational study	30	No reported	Magnetic Resonance Imagen (MRI) Electromyography (EM)	<6 months: 15 >6 months: 15	Nerve graft Nerve transferer	1 years
Gao et al., 2013	Retrospective observational study	25	C5-T1	Electromyography (EM)	<6 months: 15 >6 months: 10	Nerve transferer	1.5 Years
Ren et al., 2013	Prospective observational study	11	C5-C6	Magnetic Resonance Imagen (MRI) Electromyography (EM)	<6 months: 6 >6 months: 5	Nerve transferer	3 years
Barthel et al., 2014	Retrospective observational study	29	C5-C7	No reported	<6 months: 15 >6 months: 14	Nerve graft Nerve transferer	7.5 years
Socolovsky et al., 2014	Retrospective observational study	58	C5-T1	Electromyography (EM) Magnetic Resonance Imagen (MRI) Nerve conduction test (NCT)	<6 months: 35 >6 months: 23	Nerve graft Nerve transferer	2 years
Xiao et al., 2014	Retrospective Observational study	32	C5-T1	Electromyography (EM)	<6 months: 23 >6 months: 9	Nerve transferer	8.4 years
Krauss et al., 2022	Retrospective observational study	31	C5-T1	Electromyography (EM) Magnetic Resonance Imagen (MRI) Nerve conduction test (NCT)	<6 months: 20 >6 months: 11	Nerve transferer	3 years

in the domains of confounding and selection of participants. This necessitates caution in interpreting the findings and underscores the need for high-quality, well-designed RCTs to confirm these results. The quality assessment using the Newcastle–Ottawa Scale further indicates that while some studies are of high methodological quality, others fall into the moderate category, suggesting room for improvement in future research designs.

The clinical implications of these findings are significant. Early surgical consultation and intervention should be considered to maximize the potential for neurological recovery. However, clinical decision-making should remain individualized, taking into account the specific circumstances and recovery trajectories of each patient. The evidence suggests that a more proactive approach to surgical management can lead to better

functional outcomes, ultimately improving the quality of life for individuals with BPI.

## CONCLUSION

This systematic review and meta-analysis provide robust evidence supporting the benefits of early surgical intervention in patients with BPI. While acknowledging the limitations and heterogeneity of the included studies, the overall trend indicates that early surgery is a key predictor of improved neurological outcomes. Future research should focus on refining the timing and techniques of surgical intervention to optimize patient outcomes and further elucidate the mechanisms underlying successful nerve regeneration. By building on the current evidence base, clinicians can better tailor their approaches to managing BPI, ensuring that patients receive the most effective and timely care possible.

## Литература | Reference

1. Midha R. Epidemiology of brachial plexus injuries in a multitrauma population. *Neurosurgery* 1997;40(6):1182–8; discussion 1188–9. DOI: 10.1097/00006123-199706000-00014
2. Songcharoen P, Mahaisavariya B., Chotigavanich C. Spinal accessory neurotization for restoration of elbow flexion in avulsion injuries of the brachial plexus. *J Hand Surg* 1996;21(3):387–90. DOI: 10.1016/S0363-5023(96)80349-2
3. Samii M., Carvalho G.A., Nikkhah G., Penkert G. Surgical reconstruction of the musculocutaneous nerve in traumatic brachial plexus injuries. *J Neurosurg* 1997;87(6):881–6. DOI: 10.3171/jns.1997.87.6.0881
4. Dubuisson A.S., Kline D.G. Brachial plexus injury: a survey of 100 consecutive cases from a single service. *Neurosurgery* 2002;51(3):673–82; discussion 682–3.
5. Matsuyama T., Okuchi K., Akahane M. et al. Clinical analysis of 16 patients with brachial plexus injury. *Neurol Med Chir (Tokyo)* 2002;42(3):114–21; discussion 122. DOI: 10.2176/nmc.42.114
6. Teboul F, Kakkar R., Ameer N. et al. Transfer of fascicles from the ulnar nerve to the nerve to the biceps in the treatment of upper brachial plexus palsy. *J Bone Joint Surg Am* 2004;86(7):1485–90. DOI: 10.2106/00004623-200407000-00018
7. Huang X., You Z., Xiang Y. et al. Posterior division of ipsilateral C7 transfer to C5 for shoulder abduction limitation. *Front Neurol* 2023;14:1012977. DOI: 10.3389/fneur.2023.1012977
8. Gao K., Lao J., Zhao X., Gu Y. Outcome after transfer of intercostal nerves to the nerve of triceps long head in 25 adult patients with total brachial plexus root avulsion injury: Clinical article. *J Neurosurg* 2013;118(3):606–10. DOI: 10.3171/2012.10.JNS12637
9. Xiao C., Lao J., Wang T. Et al. Intercostal nerve transfer to neurotize the musculocutaneous nerve after traumatic brachial plexus avulsion: a comparison of two, three, and four nerve transfers. *J Reconstr Microsurg* 2014;30(5):297–304. DOI: 10.1055/s-0033-1361840
10. Stewart M.P., Birch R. Penetrating missile injuries of the brachial plexus. *J Bone Joint Surg Br* 2001;83(4):517–24. DOI: 10.1302/0301-620x.83b4.11583
11. Samii A., Carvalho G.A., Samii M. Brachial plexus injury: factors affecting functional outcome in spinal accessory nerve transfer for the restoration of elbow flexion. *J Neurosurg* 2003;98(2):307–12. DOI: 10.3171/jns.2003.98.2.0307
12. Dong Z., Zhang C.G., Gu Y.D. Surgical outcome of phrenic nerve transfer to the anterior division of the upper trunk in treating brachial plexus avulsion. *J Neurosurg* 2010;112(2):383–5. DOI: 10.3171/2009.4.JNS081064
13. Goubier J.N., Teboul F, Khalifa H. Reanimation of elbow extension with intercostal nerves transfers in total brachial plexus palsies. *Microsurgery* 2011;31(1):7–11. DOI: 10.1002/micr.20822
14. Lin H., Hou C., Chen A., Xu Z. Transfer of the phrenic nerve to the posterior division of the lower trunk to recover thumb and finger extension in brachial plexus palsy. *J Neurosurg* 2011;114(1):212–6. DOI: 10.3171/2010.7.JNS091748
15. Ray W.Z., Pet M.A., Yee A., Mackinnon SE. Double fascicular nerve transfer to the biceps and brachialis muscles after brachial plexus injury: clinical outcomes in a series of 29 cases. *J Neurosurg* 2011;114(6):1520–8. DOI: 10.3171/2011.1.JNS10810
16. Socolovsky M., Di Masi G., Battaglia D. Use of long autologous nerve grafts in brachial plexus reconstruction: factors that affect the outcome. *Acta Neurochir (Wien)* 2011;153(11):2231–40. DOI: 10.1007/s00701-011-1131-1
17. Barthel P.Y., Barbary S., Breton A. et al. Recovery of elbow flexion in post-traumatic C5-C6 and C5-C6-C7 palsy: retrospective dual-center study comparing single and double nerve transfer. *Chir Main* 2014;33(3):211–8. DOI: 10.1016/j.main.2014.02.002
18. Socolovsky M., Martins R.S., Di Masi G. et al. Influence of body mass index on the outcome of brachial plexus surgery: are there any differences between elbow and shoulder results? *Acta Neurochir (Wien)* 2014;156(12):2337–44. DOI: 10.1007/s00701-014-2256-9
19. Krauss E.M., Noland S.S., Hill E.J.R. et al. Outcome analysis of medial triceps motor nerve transfer to axillary nerve in isolated and brachial plexus-associated axillary nerve palsy. *Plast Reconstr Surg* 2022;149(6):1380–90. DOI: 10.1097/PRS.00000000000009148
20. Ren G.h., Li R.g., Xiang D.y., Yu B. Reconstruction of shoulder abduction by multiple nerve fascicle transfer through posterior approach. *Injury* 2013;44(4):492–7. DOI: 10.1016/j.injury.2012.10.024
21. Xu W.D., Gu Y.D., Xu J.G., Tan L.J. Full-length phrenic nerve transfer by means of video-assisted thoracic surgery in treating brachial plexus avulsion injury. *Plast Reconstr Surg* 2002;110(1):104–9; discussion 110–1.
22. Zyaei A., Saied A. Functional outcome of ulnar nerve fascicle transfer for restoration of elbow flexion in upper brachial plexus injury. *Eur J Orthop Surg Traumatol* 2010;20(4):293–7.
23. Sokki A.M., Bhat D.I., Devi B.I. Cortical reorganization following neurotization: a diffusion tensor imaging and functional magnetic resonance imaging study. *Neurosurgery* 2012;70(5):1305–11; discussion 1311. DOI: 10.1227/NEU.0b013e318241017d

## Authors' contributions | Вклад авторов

N.D.J.L. Villamil: conception and design, acquisition of data, critically revising the article, approved the final version of the manuscript on behalf of all authors, administrative/technical/material support, study supervision;

W.A. Flórez-Perdomo: conception and design, analysis and interpretation of data, drafting the article, reviewed submitted version of manuscript, approved the final version of the manuscript on behalf of all authors, administrative/technical/material support, study supervision;

M. Acosta: analysis and interpretation of data, drafting the article, study supervision;

M.I. Camargo: acquisition of data, critically revising the article, approved the final version of the manuscript on behalf of all authors, study supervision;

D.P.A. Pérez: acquisition of data, approved the final version of the manuscript on behalf of all authors, study supervision;

Amit Agrawal: conception and design, analysis and interpretation of data, drafting the article, critically revising the article, reviewed submitted version of manuscript, approved the final version of the manuscript on behalf of all authors, statistical analysis, study supervision;

L.R. Moscote-Salazar: conception and design, analysis and interpretation of data, drafting the article, critically revising the article, reviewed submitted version of manuscript, approved the final version of the manuscript on behalf of all authors, statistical analysis, administrative/technical/material support, study supervision.

N.D.J.L. Villamil: разработка концепции и дизайна, сбор данных, критический анализ статьи, утверждение окончательной версии рукописи, административная/техническая/материальная поддержка, руководство исследованием;

W.A. Flórez-Perdomo: разработка концепции и дизайна, анализ и интерпретация данных, подготовка статьи, рецензирование представленной версии рукописи, утверждение окончательной версии рукописи, административная/техническая/материальная поддержка, руководство исследованием;

M. Acosta: анализ и интерпретация данных, подготовка статьи, научное руководство исследованием;

M.I. Camargo: сбор данных, критический анализ статьи, утверждение окончательной версии рукописи, научное руководство исследованием;

D.P.A. Pérez: сбор данных, утверждение окончательной версии рукописи, научное руководство исследованием;

Amit Agrawal: разработка концепции и дизайна, анализ и интерпретация данных, написание статьи, критический пересмотр статьи, рецензирование представленной версии рукописи, утверждение окончательной версии рукописи, статистический анализ, научное руководство;

L.R. Moscote-Salazar: разработка концепции и дизайна, анализ и интерпретация данных, написание статьи, критический пересмотр статьи, рецензирование представленной версии рукописи, утверждение окончательной версии рукописи, статистический анализ, административная/техническая/материальная поддержка, руководство исследованием.

## Conflict of interest | Конфликт интересов

The authors report no conflict of interest concerning the materials or methods used in this study or findings specific.

Авторы заявляют об отсутствии конфликта интересов в отношении материалов, методов, использованных в данном исследовании, и конкретных результатов.

## Funding | Финансирование

The study was performed without external funding.

Исследование проведено без спонсорской поддержки.

Article submitted | Статья поступила: 13.04.2025.

Peer reviewed | Рецензия: 28.11.2025.

Accepted for publication | Принята к публикации: 02.04.2026.

Published online | Опубликована онлайн: 11.06.2026.