Chapter

Motor Recovery in Different Types of Brachial Plexus Injury Surgeries

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Abstract

Brachial plexus injuries (BPI) affect mostly the young population. The management of these injuries is complex and there are many surgical options for treatment. To evaluate the patient motor component, the British Medical Research Council motor grading scale (BMRC), range-of-motion (ROM), disability of the arm, shoulder, and hand questionnaire (DASH), and push and pull dynamometer are the main clinical assessment tools that provide information about the clinical status regarding motor function. The purpose of this chapter is to show the motor recovery on interventions that are available as surgical alternatives for the management of BPI, through a systematic review of the literature.

Keywords: brachial plexus injury, peripheral nerve surgery, clinical outcome, motor recovery, systematic review

1. Introduction

Brachial plexus injuries (BPI) are highly disabling [1]. The functional restoration of these injuries tends to focus on motor recovery, this being reported in 94% of the articles published on brachial plexus surgery, displacing the evaluation of other fundamental aspects such as sensory, pain, quality of life, functional impact, and psychosocial context [2, 3]. However, motor recovery is directly related to improvement in quality of life [4]. Motor recovery can be evaluated in various ways, using clinimetric scales and assessment tools to measure strength such as the British Medical Research Council motor grading scale (BMRC) [5], active/passive range-of-motion (ROM) [6], and tools that allow us to quantitatively measure strength (push-and-pull dynamometer) [7]. Being the BMRC the most standardized, reliable, and valid measurement tool for evaluating muscle strength in patients with BPI [8]. Brachial plexus surgery has different objectives, where relative to motor recovery elbow flexion and shoulder abduction and stability are prioritized due to the greater chance for success [9]. However, we recognize the importance of considering other functions of the upper limb such as the motor functions of the hand, and some authors even mention the importance of restoring elbow extension [10].

2. Surgical techniques on brachial plexus surgery

The management of BPI is complex and there is more than one way of approaching it surgically. The alternatives for treatment include surgical neurolysis, end-to-end sutures, nerve grafting, nerve transfers, muscle/tendon transfers, and a combination of them (multiple interventions) [7]. Surgical success depends on several factors such as the patient's age, patterns of injury, severity of injury, timing of surgery, surgical technique, quality of the donor nerves, and length of nerve grafts, among others [11, 12]. Prospective, randomized controlled clinical trials that compared all the surgical repair strategies for BPI and their clinical outcomes have not been performed. Therefore, some considerations continue to generate uncertainty in surgical decision-making. For this reason, we consider it appropriate to evaluate if the current perception of effectiveness in terms of motor recovery of all surgical techniques is correct and guide the development of new studies on the subject.

The surgical treatment of BPI is based on a combination of evidence-based practice, feasibility, and the personal experience of the surgeon [12]. Prominent surgeons around the world have proposed different treatment algorithms that are likely based on multiple factors that include things such as patient populations, body mass index, insurance status, socioeconomic status, mechanisms of injury, injury patterns, location, and severity, among other relevant factors [13, 14].

2.1 Surgical Neurolysis

Surgical neurolysis is a technique that began to be used in the World War by exploration of the wound and wide debridement of the affected nerve [15]. The purpose of surgical neurolysis is to decompress the affected nerve structures. Neurolysis consists of making multiple longitudinal cuts along the epineurium and dissecting the connective tissue that surrounds the injured nerve structures, lysing the adhesions formed in the compartment [16].

In 1996, Clarke et al. [17] reported a study without a control group where they determined that neurolysis did not represent significant clinical changes compared to spontaneous recovery. It was a transcendent study because it ended up defining neurolysis as an ineffective technique for the management of BPI, this argument added to the popularization of nerve transfer and nerve graft, led to the abandonment of surgical neurolysis and decreasing the number of clinical studies carried out on this technique. However, Morgan R. et al. (2020) recently reported the results of a study using surgical neurolysis for 21 adult patients with post-traumatic BPI, observing that some patients achieved a BMRC rating score > 3 in elbow flexion after surgery [18]. The mechanism of symptomatology in the patients included in the study of Morgan R. is probably explained by the connective tissue that surrounds the nerve structures, generating a compressive phenomenon that causes strangulation of the nerve [19, 20]. Therefore, we can assume that surgical neurolysis can be effective in some specific cases. The results shown by this study and the results showed by Morgan R. support the need to reevaluate neurolysis alone as a surgical technique for the functional restorations of patients with BPI, through a well-controlled study, where it seems to be useful for those patients with post-traumatic compressive neuropathy.

2.2 End-to-end suture

End-to-end suture is a surgical technique that consists of directly confronting the free edges of the transected nerve structure by using a suture to conserve continuity. This alternative is useful in cases of neural transaction when it is possible to face the limits without causing tension (<1–2 cm) [21]. The material commonly used to repair the damage is a monofilament like interrupted nylon or polypropylene suture (6–0 to 8–0) [22]. It is imperative that the surgeon must perform the suture taking into consideration the anatomical alignment of the nerve bundles [22]. Other possible applications according to Kim et al. for transected nerves when there is no nerve action potential and the procedure is to dissect sharply the proximal and distal stumps, with adequate cross-sections approach the nerve endings avoiding excessive tension in the suture site. In acute partial lacerations (72 hours) end to end improved functional outcomes in 73% over a population of 22 patients with 16 patients that achieve grade 3 function as a primary repair [22].

2.3 Nerve graft and nerve transfer

Nerve grafts and nerve transfer are other surgical alternatives that surgeons often use to treat BPI. A systematic review published by Garg et al. shows that the data strongly favors nerve transfer over traditional nerve grafting for the restoration of improved shoulder and elbow function in patients with complete traumatic upper BPI [23]. However, several articles show uncertain results. Hardcastle et al. published a systematic review where they compared nerve graft versus nerve transfer for the restoration of the shoulder abduction in traumatic brachial plexus palsy, observing that the proportion of functional recovery of shoulder function for nerve transfer was not statistically significant (OR 1.34, 95% CI: 0.27–6.72) compared with nerve transfer, establishing that nerve transfer and grafting are similarly effective in terms of shoulder abduction [24]. Other studies show controversial results in pediatric and adult populations [25, 26]. Therefore, the choice of the best treatment modality is still controversial. The evidence suggests that in upper trunk BPI in adults, the Oberlin procedure and other nerve transfer techniques are the more successful approaches to restoring elbow flexion and shoulder abduction compared with nerve grafting [27]. The decision between performing nerve graft versus nerve transfer is controversial in this context, a prospective, randomized; controlled trial would be necessary to evaluate the factors involved in clinical outcomes such as the pattern and location of injury.

2.4 Muscle and tendon transfer

The muscle/tendon transfer is more complex technique with higher morbidity, these types of techniques are usually indicated for patients with long-term evolution after injury (>6–12 months). The time interval between the injury and the surgical intervention is relevant because after 12–18 months of injury, the nerve regeneration is reduced [28]. Moreover, atrophy and fibrosis of muscles innervated by the affected nervous structure result in poor outcomes [29]. Therefore, muscle/tendon transfer should be considered for patients who have large evolution or patients without recovery after a primary intervention. Possibly the muscle/tendon transfers are the surgical techniques that have the best motor outcomes in severe injuries [30]. It is necessary to carry out new studies to evaluate whether this technique is adequate in patients with a recent injury (< 6 months), comparing its effectiveness and morbidity with other conventional techniques.

3. Materials and methods

3.1 Systematic review

This systematic review was carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (PROSPERO ID: CRD42022296184) [31]. The selection criteria, search, and data extraction are summarized in **Figure 1**. The main objective of this search is to establish the magnitude of changes in motor status after surgical intervention in adult patients with BPI according to the type of intervention. A focused question was developed by the Patient population, Intervention, Control, Outcome (PICO) method: Do adult patients with BPI (patient population) undergoing surgery (intervention) have motor recovery (outcome), according to the type of surgical intervention (comparison)?

3.1.1 Eligibility criteria

According to prospectively deposited eligibility criteria, we included any reports of adult patients with a diagnosis of post-traumatic BPI who underwent primary surgical intervention in studies that reported pre- and post-operative motor clinical

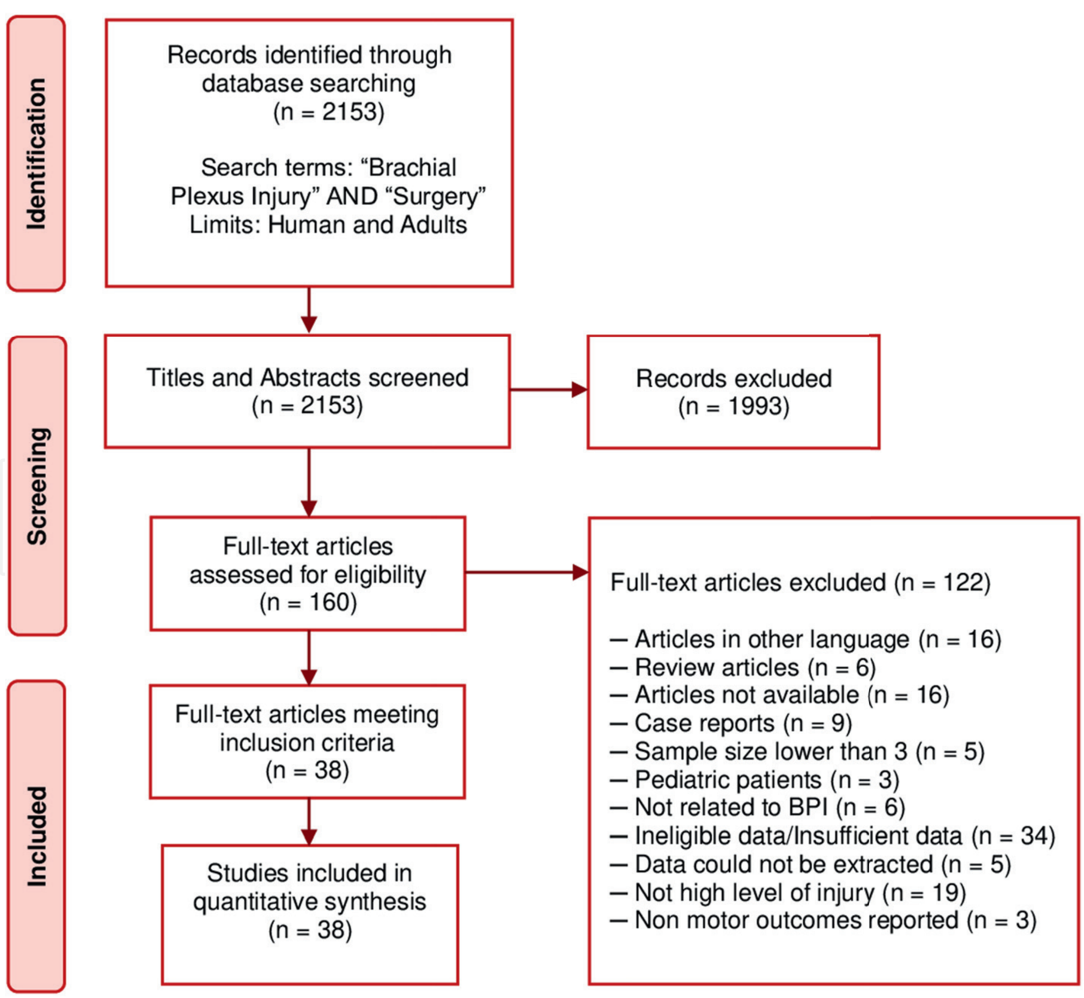

Figure 1.
Flow diagram according to PRISMA guidelines. Brachial plexus injury.

assessment. Conversely, we excluded pediatric populations (obstetric brachial plexus palsy), BPI with the intermediate or low location of injury (distal arm, elbow, forearm, wrist, and hand), case reports, publications with a population of n < 3, basic science research, article reviews, and publications written in other languages than English.

3.1.2 Search strategy

Studies were identified using the advanced search in PubMed with the Mesh terms "Brachial Plexus Injury" as the main topic and "Surgery" as a subtopic. We added "Humans" and "Adults" to avoid animal models and obstetric brachial plexus palsies (pediatric populations). For the "title" and "abstract" fields, 2153 total articles published between 1968 and 2021 were found. No constraints on study design, year of publication, or publication status were imposed. From the 2153 unique records identified by this search, screening for relevance by title and abstract resulted in 1993 articles being excluded. Of the remaining 160 articles selected for full-text evaluation, a total of 122 were excluded (**Figure 1**).

3.1.3 Data extraction

The final dataset consisted of 38 studies (**Table 1**) and was analyzed to extract specific parameters to be used for all subsequent analyses. During the first and second phases of the systematic review, the titles and abstracts were screened by two reviewers. If a clinic outcome was not mentioned in the abstracts, articles were excluded (A.S.A and G.J.A.I). During the last phase, full-text articles were evaluated by another author (C.R.J.D) and checked by two different reviewers (A.S.A and G.J.A.I). Disagreement between observers regarding the inclusion of publications was resolved through a consensus between different observers. The data extraction was focused on collecting data regarding the location of the injury, demographic (mean age and proportion of males), procedural (mean follow-up and interval injury-surgery), and motor status (pre- and postoperative).

Study (Author & Year)	Sample size (n)	Type of surgery	Type of Study*
Altaf F (2012) [32]	13	SN; MI	CS
Azab A (2017) [33]	13	MTT	CS
Baltzer H (2016) [34]	29	NG; NT	PS
Baltzer H (2016) [35]	51	NT	RS
Bertelli J (2016) [36]	13	NG	RS
Cambon A (2012) [37]	7	MTT	CS
Cambon A (2018) [38]	11	NT	RS
Coene L (1992) [39]	57	MI	RS
Cho A (2015) [40]	19	NT	RS
Dolan R (2011) [1]	21	NT	PS
Dubuisson A (2002) [41]	134	EE; SN; NT	RS
Elkwood A (2011) [42]	8	MTT	CS
Friedman A (1990) [43]	3	NG	CS

Study (Author & Year)	Sample size (n)	Type of surgery	Type of Study*
Frueh F (2016) [44]	6	NT	CS
Gao K (2013) [45]	22	NT	RS
Garcia A (2014) [46]	6	NT	CS
Gousheh J (1995) [21]	217	EE; NG; SN	RS
Gutkowska O (2017) [47]	33	SN	CS
Haninec P (2012) [48]	21	EE	CS
Jerome J (2012) [49]	15	NT	PS
Kachrama. C (2017) [50]	15	MTT	RS
Kim D (2003) [22]	42	EE; NG; SN	RS
Khalifa H (2012) [51]	24	NG; NT	RS
Laubscher M (2015) [52]	27	EE	RS
Lee Y (2008) [53]	6	NG	CS
Li G (2019) [11]	465	EE; MTT; NG; SN; NT	RS
Malessy M (1998) [54]	25	NT	CS
Maldonado A (2017) [55]	65	MTT:MI	RS
Moor B (2010) [56]	12	NG	PS
Nicoson M (2016) [57]	13	MTT	RS
Roganovic Z (2004) [58]	131	NG	RS
Roganovic Z (2005) [59]	81	NG	RS
Roganovic Z (2007) [60]	9	NG	RS
Sallam A (2017) [61]	52	NG; NT	RS
Soldado F (2016) [28]	8	NT	RS
Stewart M (2001) [62]	59	NG; SN	RS
Stockinger T (2008) [63]	6	NT	RS
Wolfe S (2014) [64]	10	NG	RS

**The studies included were non-controlled, non-randomized before and after studies (quasi-experimental studies). SN: Surgical neurolysis. EE: End-to-end suture. NG: Nerve graft. NT: Nerve transfer. MTT: Muscle/tendon transfer. MI: Multiple interventions (different surgical approaches performed on the same patient). CS: Case series. RS: Retrospective study. PS: Prospective study.*

Table 1.
Studies included.

3.1.4 Quality assessment

All articles included in this work were graded independently by two reviewers (A.S.A and G.J.A.I) and subsequently reviewed by the same authors in a consensus meeting using the Newcastle Ottawa Quality assessment tool [65, 66], for assessing the quality of the included studies and was adapted for the evaluation of motor recovery in BPI. The following characteristics were considered for the evaluation: representativeness of the study, mechanism of injury, injury location, surgical technique description, preoperative motor status, postoperative motor outcome, motor evaluation according to BMRC, follow-up, mortality/morbidity. Three subjective qualitative categories were used to define quality, no concerns (NC), unclear (U), and many concerns (MC). Disagreements were resolved by consensus.

3.1.5 Outcomes

Motor recovery was collected using the British Medical Research Council (BMRC) motor rating scale, considering the results reported in the included studies before and after the intervention using this tool. Brachial plexus surgery focuses on elbow flexion recovery and shoulder abduction, depending on the characteristics of the injury. Therefore, the data from the evaluation of two muscle structures were collected mainly, the biceps brachii and the deltoid, wherein those cases in which both outcomes were reported, elbow flexion was prioritized to define the outcome of the patient. Effective motor recovery was established in any patient who showed a BMRC ≥3 after the intervention. It was decided to defer the evaluation of ROM because it is intended to establish that surgical techniques have a more significant impact on the exclusive recovery of strength, regardless of joint stability. In order to increase the sample size of sub-groups, those articles that reported different types of surgical interventions (mixed studies), were divided into subgroups according to the type of surgical intervention performed (nerve transfer, nerve graft, muscle/tendon transfer, end-to-end suture, surgical neurolysis, and multiple interventions (different surgical techniques performed in the same patient)).

3.1.6 Data analysis

Statistical analyses were conducted using SPSS 25.0 for Windows software (SPSS, Inc., Chicago, IL). There are no complete clinical trials (controlled, randomized, and blinded) reported about each of the surgical techniques included in the analysis. For this reason, it was decided to include noncontrolled studies, where despite being studies that do not have a control group, they are valid for the analysis because the patients are being considered a self-control group, evaluating themselves before and after the surgical intervention. To calculate the effect size, contingency tables were created using two variables for motor outcome according to BMRC: motor recovery (≥M3), and absence of motor recovery (<M2), considering these variables for the group of patients before and after surgery. The effect size measure used was relative risk (RR). To define whether there was a statistically significant association between motor recovery and surgery, a 95% confidence interval (CI) was calculated for each effect size, this analysis was done for each article/subgroup and the results were graphed in a Forrest plot using the Review Manager Software from Cochrane (V.5.4.1) [67]. A p-value <0.05 was considered statistically significant.

3.2 Results

Table 1 provides a summary of the characteristics of the 38 articles that were included in the quantitative analysis. There were 34 retrospective studies (including 11 case series) and four prospective noncontrolled, nonrandomized studies. Regarding demographic and procedural factors these were the results: mean age 29.95 ± 5.27, percentage of males 88.1%, mean follow-up in months 33.31 ± 17.17, and mean interval injury-surgery in months 7.23 ± 4.5. Relative to the analysis of the quality of the publications, the following results were obtained are shown in **Figure 2**. Location of the injuries was represented to be mostly infraclavicular in 70.86% of the cases affecting

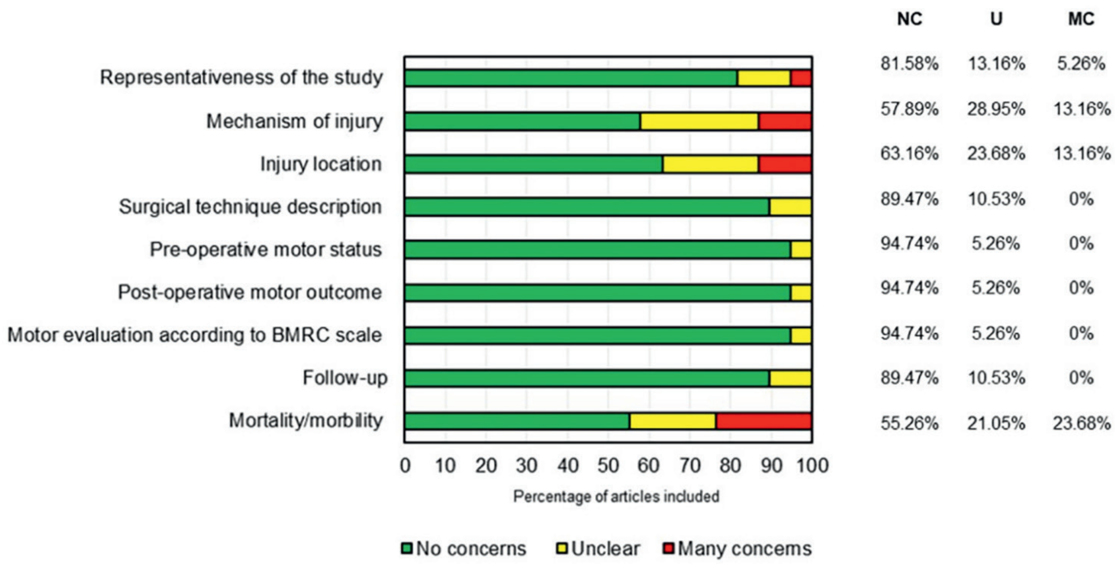

Figure 2.
Overall quality of included studies.

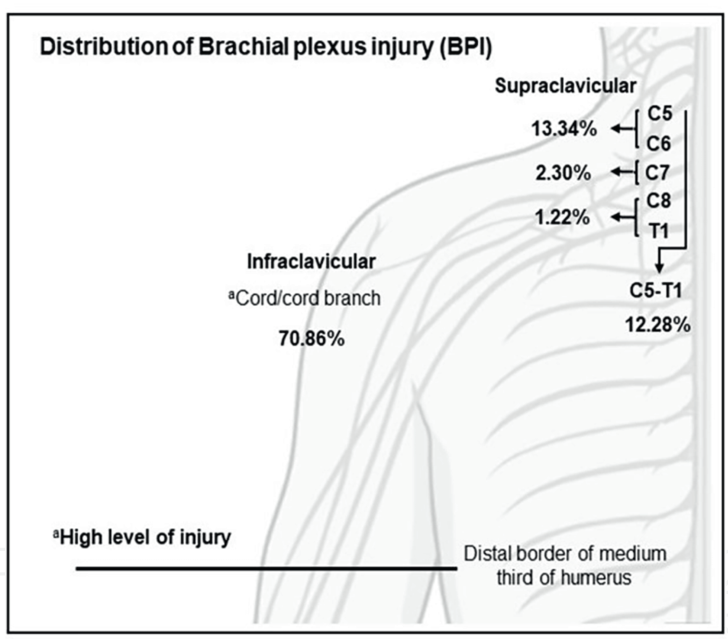

Figure 3.
Patterns of injury of the brachial plexus injuries included in the analysis.

cords or terminal branches of the brachial plexus at high level of injury (**Figure 3**). **Table 2** shows the demographic and procedural characteristics of the included studies according to the type of intervention.

3.2.1 Motor recovery

The priority in BPI motor recovery is commonly focused on restoring elbow flexion. According to the search for functional results in surgical management, the main therapeutic objective of the included studies was the re-establishment of elbow flexion of 31.58%, followed by shoulder abduction (28.95%), global motor recovery

Factor	Nerve Transfer Mean ± SD (n = 501)	Nerve Graft Mean ± SD (n = 566)	Muscle/tendon transfer Mean ± SD (n = 118)	End-to-end suture Mean ± SD (n = 216)	Surgical Neurolysis Mean ± SD (n = 251)	*Multiple interventions Mean ± SD (n = 97)
Age (yrs)	30.58 ± 5.76	30.33 ± 4.59	29.92 ± 3.87	27.41 ± 4.5	29.81 ± 9.2	31.6 ± 3.55
Number of males	85.91 ± 11.83	89.13 ± 12.71	89.19 ± 7.8	87.71 ± 7.12	89.75 ± 8.85	90 ± 10
Length of follow-up (mos)	34.36 ± 3.54	33.66 ± 15.75	33.56 ± 19.77	33.71 ± 19.09	36.54 ± 21.07	18.33 ± 17.38
Injury-to-surgery period (mos)	7.36 ± 4.18	6.98 ± 4.08	10.23 ± 7.77	4.43 ± 2.98	6.18 ± 1.84	6.6 ± 1.9

**Multiple interventions: Different surgical techniques performed in the same patient.*

Table 2.
Demographic and procedural factors from BPI surgical groups.

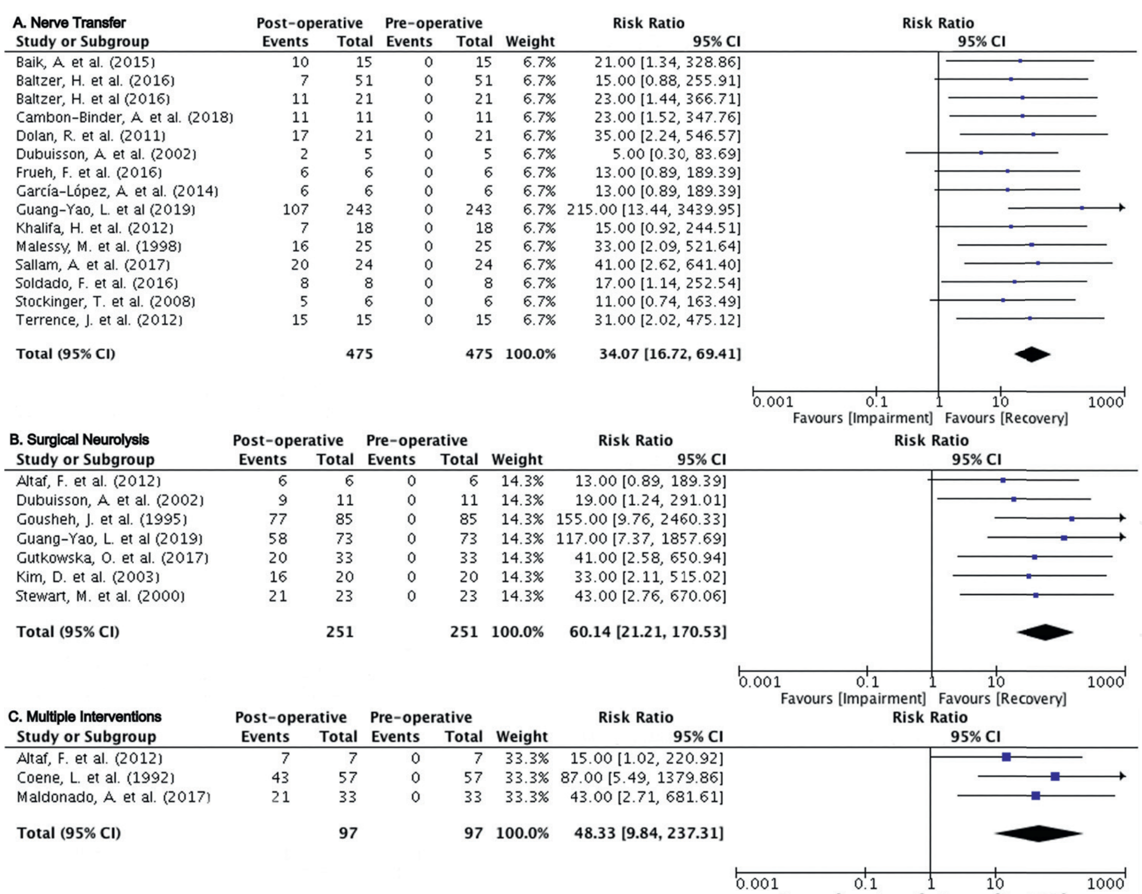

Figure 4.
Forrest plot of motor outcomes for patients with BPI after different types of surgical techniques. Proportions of patients reaching British Medical Research Council grade 3 (BMRC) or higher (≥M3) and corresponding 95 percent confidence intervals (CI); black diamonds represent the pooled proportions (PP) and corresponding 95 percent intervals, where those effect measures that are closer to zero represent the types of surgical intervention that most favors the motor recovery (≥M3) after the intervention. A. Nerve transfer PP (RR: 34.07 (CI: 16.72–69.41)). B. Surgical neurolysis PP (RR: 60.14 (CI: 21.21–170.53)). C. Multiple interventions PP (RR: 48.33 (CI: 9.84–170.53)).

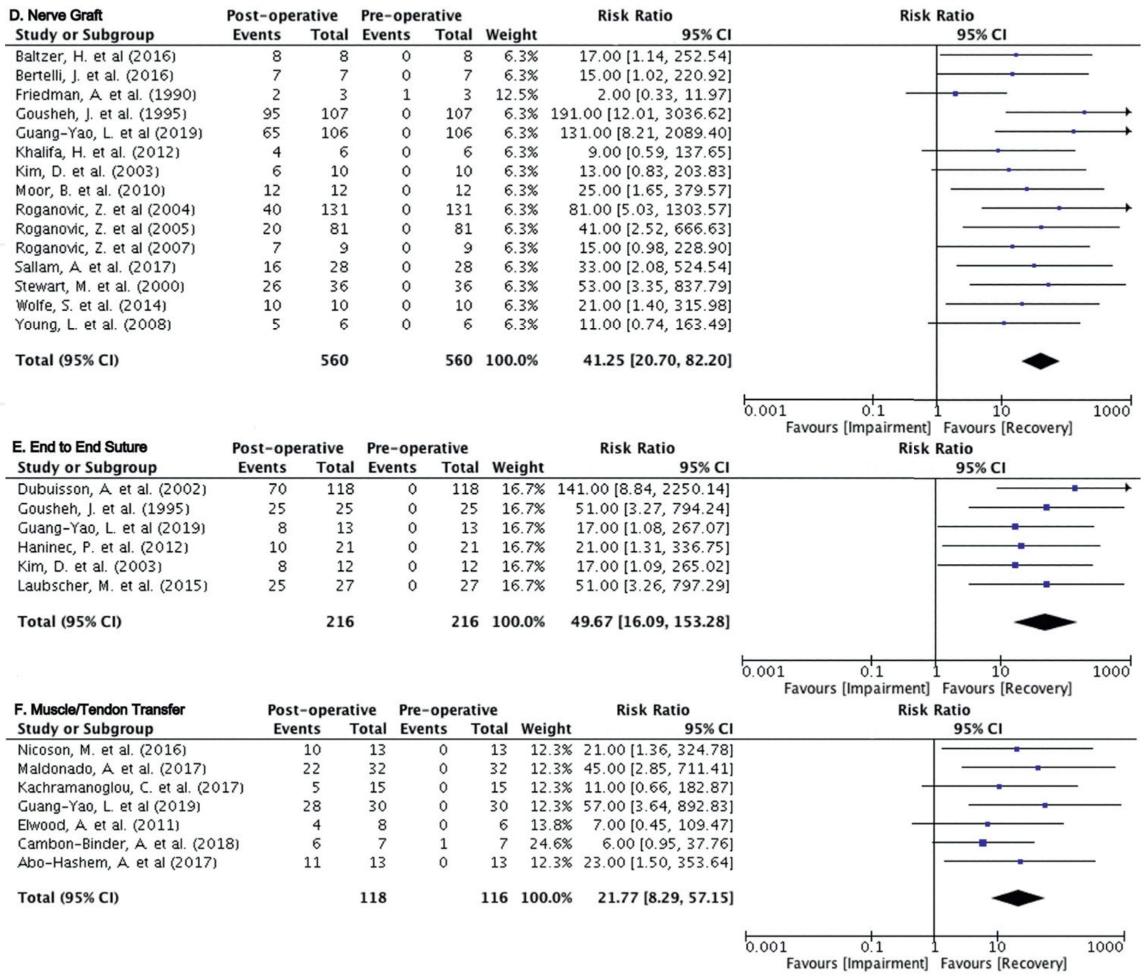

Figure 5.

Forrest plot of outcomes for patients with BPI after different types of surgical techniques. Proportions of patients reaching British Medical Research Council grade 3 (BMRC) or higher (≥M3) and corresponding 95 percent confidence intervals (CI); black diamonds represent the pooled proportions (PP) and corresponding 95 percent intervals, where those effect measures that are closer to zero represent the types of surgical intervention that most favors the motor recovery (≥M3) after the intervention. D. Nerve graft PP (RR: 41.25 (CI: 20.70–82.20)). E. End-to-end PP (RR: 49.67 (CI: 16.09–153.28)). F. Muscle/tendon transfer PP (RR: 21.77 (CI: 8.29–57.15)).

(23.68%), handgrip (15.79%), external rotation (2.63%), and elbow extension (2.63%). Regarding the outcome variable defined as motor recovery, this was defined as any patient who showed a recovery of strength after surgery ≥M3 according to BMRC. **Figures 4** and **5** shows the effect sizes (RR) and CI of the different articles and subgroups according to the type of surgical intervention. The results according to the type of surgery are the following: surgical neurolysis group (RR: 60.14 (CI: 21.21–170.53)), end-to-end suture (RR: 49.67 (CI: 16.09–153.28)), multiple interventions (RR: 48.33 (CI: 9.84–237.31)), nerve graft (RR: 41.25 (CI: 20.70–82.20)), nerve transfer (RR: 34.07 (CI: 16.72–69.41)) and muscle/tendon transfer (RR: 21.77 (CI: 8.29–57.15)).

4. Discussion

According to the information presented in this chapter, we conclude that all the surgical technics improve motor recovery in brachial plexus injuries. However, the clinical aspects, the time of lesion and the surgeon’s abilities and expertise are the keys to decision-making. Our experience in this field allows us to define that the surgical management of BPI should be carried out progressively, starting with simple interventions (surgical neurolysis and end-to-end suture) and making them increasingly complex according to the severity and location of the injury (nerve graft, nerve transfer, and muscle/tendon transfer).

The surgery should follow the next principles: surgical neurolysis should be performed in some patients with preservation of nerve continuity and conduction that presents compressive neuropathy. End-to-end suture is preferred if the defect is too large to be anastomosed without tension directly. In large defects, nerve grafts should be performed, with direct intraplexal repair. If necessary, utilize the sural nerve, radial nerve (superficial branch), or the medial cutaneous nerve. After 6–12 months postinjury, the nerve regenerative capacity is reduced, and thus, the muscle fibrosis and degeneration. For this reason, muscle/tendon transfer should be considered in order to use a healthy muscle and fresh nerve transfer.

The main limitation of this study is that no heterogeneity tests were performed to assess which of the different surgical techniques have a greater motor recovery. However, a meta-analysis requires other fundamental factors needed to be involved in the data synthesis (demographic, socioeconomic, surgical injury interval, severity, pattern of the lesion, location, and extent of the injury, among others). Unfortunately, this was not possible in this study because many of the articles on the subject were reported in a nonstandardized way omitting some data, so it was impossible to include all of them. Second, the articles considered were case series and some nonrandomized and noncontrolled studies (Level of evidence III-IV). According with the last paragraph we highlight the need to develop a study that contains the methodological and demographical information mentioned before. There are a few clinical trials on brachial plexus surgery with a lack of high methodological rigor, highlighting the need to increase the level of scientific evidence in the production related to this topic [7, 16].

Čebron U. et al. (2021) evaluated the most frequently cited articles according to the type of surgery relative to adult BPI, observing that in the last 30 years, the most cited articles are related to nerve transfer, nerve graft, and muscle/tendon transfer [68]. For that reason, in recent years, the study of techniques such as surgical neurolysis and end-to-end suture has been abandoned considerably. Accordingly, our study highlights the need to retake the study of these techniques by comparing them with current trends in surgical management, because these displaced techniques show effective results in terms of motor recovery.

5. Conclusion

This study, beyond comparing the effectiveness of the different techniques, shows that they are all effective for motor recovery. Therefore, it is necessary to reassess those that have been displaced over time (surgical neurolysis and end-to-end suture), added to the popularization of new techniques (nerve transfer and muscle/tendon transfer). Conversely, these results highlight the need to increase the level of evidence and methodological rigor in the literature related to brachial plexus surgery, carrying out well-powered, well-controlled, and well-randomized studies to have clearer knowledge about the precise indications of each one of these surgical alternatives in the management of BPI.

Conflict of interest

The authors declare no conflict of interest.

Permissions

The permission to use the images/materials included in this study has been obtained.

Acronyms and abbreviations

BMRC	British Medical Research Council motor grading scale
BPI	Brachial Plexus Injury
DASH	Disability of the Arm Shoulder and Hand questionnaire
MC	Many Concerns
NC	Not Clear
PICO	Patient population, Intervention, Control, Outcome
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
ROM	Range of Motion
U	Unclear

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