Upper brachial plexus injury in adults: comparative effectiveness of different repair techniques

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OBJECT Adult upper trunk brachial plexus injuries result in significant disability. Several surgical treatment strategies exist, including nerve grafting, nerve transfers, and a combination of both approaches. However, no existing data clearly indicate the most successful strategy for restoring elbow flexion and shoulder abduction in these patients. The authors reviewed the literature to compare outcomes of the three surgical repair techniques listed above to determine the optimal approach to traumatic injury to the upper brachial plexus in adults.

METHODS Both PubMed and EMBASE databases were searched for English-language articles containing the MeSH topic "brachial plexus" in conjunction with the word "injury" or "trauma" in the title and "surgery" or "repair" as a MeSH subheading or in the title, excluding pediatric articles and those articles limited to avulsions. The search was also limited to articles published after 1990 and containing at least 10 operated cases involving upper brachial plexus injuries. The search was supplemented with articles obtained through the "Related Articles" feature on PubMed and the bibliographies of selected publications. From the articles was collected information on the operation performed, number of operated cases, mean subject ages, sex distribution, interval between injury and surgery, source of nerve transfers, mean duration of follow-up, year of publication, and percentage of operative success in terms of elbow flexion and shoulder abduction of the injured limb. The recovery of elbow flexion and shoulder abduction was separately analyzed. A sub-analysis was also performed to assess the recovery of elbow flexion following various neurotization techniques.

RESULTS As regards the restoration of elbow flexion, nerve grafting led to significantly better outcomes than either nerve transfer or the combined techniques ($F = 4.71$, $p = 0.0097$). However, separating the Oberlin procedure from other neurotization techniques revealed that the former was significantly more successful ($F = 82.82$, $p < 0.001$). Moreover, in comparing the Oberlin procedure to nerve grafting or combined procedures, again the former was significantly more successful than either of the latter two approaches ($F = 53.14$; $p < 0.001$). In the restoration of shoulder abduction, nerve transfer was significantly more successful than the combined procedure ($p = 0.046$), which in turn was significantly better than nerve grafting procedures ($F = 5.53$, $p = 0.0044$).

CONCLUSIONS According to data in this study, in upper trunk brachial plexus injuries in adults, the Oberlin procedure and nerve transfers are the more successful approaches to restore elbow flexion and shoulder abduction, respectively, compared with nerve grafting or combined techniques. A prospective, randomized controlled trial would be necessary to fully elucidate differences in outcome among the various surgical approaches.

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KEY WORDS brachial plexus injury; upper trunk injury; nerve graft; nerve transfer; Oberlin procedure; peripheral nerve

UPPER trunk brachial plexus injuries involving the C5–6 roots result in significant disability due to a loss of shoulder abduction, external rotation, elbow flexion, and forearm supination. Involvement of the C-7 spinal root may lead to deficits involving additional movements, including finger, wrist, and elbow extension. The severity of these injuries varies from a neurapraxic

injury, which typically resolves spontaneously, to a complete avulsion injury, which has no potential for spontaneous recovery. In adults, the restoration of elbow flexion is the highest priority, followed by shoulder abduction and external rotation.^{3,68}

Historically, repair strategies have consisted of brachial plexus exploration and reconstruction with nerve graft-

ABBREVIATION MRC = Medical Research Council.

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ing. More recently, distal nerve transfers, which have traditionally been reserved for nerve root avulsion injuries, have been popularized for the treatment of postganglionic nerve injuries. This approach sacrifices a functional donor nerve fascicle in an attempt to reinnervate a recipient denervated target muscle. In fact, many surgeons now choose to forgo brachial plexus exploration and rely solely on distal nerve transfers.^{1,11,38,62} However, no prospective, randomized controlled trials have compared these surgical repair strategies. We reviewed the literature to evaluate the outcomes of three surgical approaches for the repair of postganglionic upper trunk brachial plexus injuries in adults, including nerve grafting, nerve transfer, and a combination of both techniques.

Methods

Literature Review

In January 2013, we searched the PubMed and EMBASE databases for articles containing the MeSH topic “brachial plexus” in conjunction with the word “injury” or “trauma” in the title and “surgery” or “repair” as a MeSH subheading or in the title, excluding pediatric articles and those articles limited to avulsions. We limited our search to English-language articles published after 1990 and articles containing at least 10 operated cases involving upper (or upper plus middle) brachial plexus injuries. The search was supplemented with articles obtained through the “Related Articles” feature of PubMed and the bibliographies of selected publications. All abstracts were reviewed, and those that were clearly unrelated to the purpose of our study were discarded. At least two authors reviewed each remaining article for relevance and data. If an article reported more than one surgical approach, we attempted to separate outcomes in each group. If this was not possible, the article was eliminated from further review unless at least 60% of the cases utilized a single approach. From the articles, we abstracted information on the operation performed, number of operated cases, mean subject ages, sex distribution, interval between injury and surgery, source of nerve transfers, mean duration of follow-up, year of publication, and percentage of operative success in terms of elbow flexion and shoulder abduction of the injured limb. We also recorded the mean length of nerve grafts when available. We defined success as a British Medical Research Council (MRC) score of at least 3.⁴²

Analysis

We compared three operations, including nerve repair (grafting), nerve transfer, and combinations of both techniques, to determine the optimal approach in an adult presenting with traumatic injury to the upper brachial plexus. The recoveries of both shoulder abduction and elbow flexion were assessed separately. We also performed a subanalysis in which we compared recovery of elbow flexion after each of the three nerve transfer techniques: partial ulnar nerve transfer (Oberlin procedure), intercostal transfer, and other procedures. Variables were abstracted from individual publications, tested to exclude heterogeneity,³³ and pooled. We pooled data on success rates and demographics meta-analytically by using an in-

verse variance-weighted random-effects model.¹⁷ Rates of different approaches were compared using 1-way ANOVA, with Bonferroni correction for ad hoc comparisons. The effects of patient age, injury-to-surgery period, and other covariates (predictive factors) were evaluated using meta-regression. Meta-analytical pooling, meta-regressions, and statistical comparisons of outcomes involved the use of Stata version 12 (StataCorp LP). A p value < 0.05 was considered significant.

Results

Literature Review

Our search yielded 2330 publications, many of which lacked utilizable data (Fig. 1). We used 71 case series in our analysis, including 5 series reporting more than one surgical approach (Table 1).^{2,4–10,12–16,18–20,22–27,29–32,35–37,39–41,43,44,46,48–61,63–67,69–82} However, none was a controlled trial, and all must be considered Class IV evidence. Fifteen series (747 cases) reported the results of nerve grafting. In the nerve transfer group, there were 54 reports with a total of 2440 cases. For combined procedures, the totals were 8 and 587, respectively. A breakdown of the nerve transfer group yielded 300 cases with partial ulnar transfer, 1052 with intercostal transfer, and 1088 undergoing other transfer procedures.

Demographics, Surgical Timing, and Follow-Up

Findings on patient demographics, surgical timing, and follow-up are summarized according to treatment

FIG. 1. Summary of the structured literature review performed, showing numbers of abstracts reviewed, articles read and/or used in our analysis, and reasons for rejections.

TABLE 1. Case series used in an analysis of surgical procedures for upper brachial plexus injuries in adults

Authors & Year	No. of Operated Cases	Operation
Allieu et al., 1997	43	Graft
	17	Transfer
Berger & Becker, 1994	58	Transfer
Bertelli & Ghizoni, 2004 ⁷	10	Transfer
Bertelli & Ghizoni, 2004 ⁵	12	Combined
Bertelli & Ghizoni, 2010 ⁶	37	Combined
Bertelli & Ghizoni, 2010 ⁸	22	Combined
Bhandari et al., 2009	20	Transfer
Bhandari & Deb, 2011	40	Transfer
Chuang et al., 1992	66	Transfer
Chuang et al., 1995	11	Transfer
Coulet et al., 2010	40	Transfer
Doi et al., 2003	22	Transfer
Dubuisson & Kline, 2002	59	Combined
El-Gammal & Fathi, 2002	29	Transfer
Ferraresi et al., 2004	43	Transfer
Friedman et al., 1990	14	Transfer
Goubier & Teboul, 2007	10	Transfer
Gu et al., 1990	164	Transfer
Haninsec et al., 2007	95	Graft
Haninsec & Kaiser, 2012	14	Transfer
Hou & Xu, 2002	23	Transfer
Htut et al., 2007	26	Transfer
Jivan et al., 2009	27	Graft
Kakinoki et al., 2010	16	Transfer
Kandenwein et al., 2005	119	Graft
Kim et al., 2003	175	Graft
Kline, 1989	38	Transfer
Leechavengvongs et al., 1998	32	Transfer
Leechavengvongs et al., 2006	15	Transfer
Liverneaux et al., 2006	15	Transfer
Malessy & Thomeer, 1998	25	Transfer
Malessy et al., 1999	12	Graft
Malessy et al., 2004	24	Graft
	29	Transfer
Merrell et al., 2001	15	Transfer
Moiyadi et al., 2007	51	Transfer
Nagano et al., 1989	149	Transfer
Nagano et al., 1992	79	Transfer
	16	Graft
Nagano et al., 1995	112	Transfer
Nath et al., 2006	40	Transfer
Ochiai et al., 1993	21	Transfer
Ogino & Naito, 1995	20	Transfer
Okinaga & Nagano, 1999	11	Transfer
Ray et al., 2011	29	Transfer
Ricardo, 2005	13	Graft

(continued)

TABLE 1. Case series used in an analysis of surgical procedures for upper brachial plexus injuries in adults (continued)

Authors & Year	No. of Operated Cases	Operation
Richardson, 1997	10	Transfer
Ruch et al., 1995	17	Transfer
Samadian et al., 2009	17	Graft
Samardzic et al., 1992	22	Transfer
Samardzić et al., 2002	25	Transfer
	91	Combined
Samii et al., 1997	54	Graft
Samii et al., 2003	44	Combined
Siqueira & Martin, 2009	10	Transfer
Socolovsky et al., 2011	34	Graft
Socolovsky et al., 2012	18	Transfer
	17	Graft
Songcharoen, 1995	222	Transfer
	23	Graft
Songcharoen et al., 1996	216	Transfer
Sulaiman et al., 2009	131	Transfer
Sungpet et al., 2000 ⁷⁰	10	Transfer
Sungpet et al., 2000 ⁷¹	36	Transfer
Suzuki et al., 2007	12	Transfer
Teboul et al., 2004	34	Transfer
Terzis et al., 1999	204	Combined
Terzis & Kostas, 2006	118	Combined
Tonkin et al., 1996	17	Transfer
Vekris et al., 2010	78	Graft
Venkatramani et al., 2008	15	Transfer
Waikakul et al., 1999 ⁷⁹	96	Transfer
Waikakul et al., 1999 ⁸⁰	205	Transfer
Xu et al., 2002	15	Transfer
Xu et al., 2005	15	Transfer
Zyaei & Saied, 2010	10	Transfer

group in Table 2. There were no significant differences among the three groups with regard to patient age, sex ratio, or time between injury and surgical repair. Similarly, no significant pairwise differences existed. The duration of follow-up was significantly shorter in the nerve transfer group than in the graft or combined groups ($p < 0.001$ in each case).

Comparative Effectiveness

Restoration of Elbow Flexion

As shown in Table 3, nerve grafting resulted in significantly better outcomes than either nerve transfer or combined procedures ($F = 4.71$, $p = 0.0097$); pairwise comparisons demonstrated p values of 0.034 and 0.018, respectively. Our experience with favorable outcomes following the Oberlin procedure, as opposed to non-Oberlin nerve transfers, prompted a secondary analysis. Separating partial ulnar nerve transfer from the other neurotization procedures revealed that the former was significantly

TABLE 2. Summary of demographic and procedural factors for surgical groups treated for upper brachial plexus injuries

Factor	Graft Mean $\pm$ SD	Transfer Mean $\pm$ SD	Combined Mean $\pm$ SD	F	p Value
Age (yrs)	25.900 $\pm$ 3.256	26.418 $\pm$ 3.357	25.744 $\pm$ 0.696	0.205	0.815
Proportion of males	0.917 $\pm$ 0.031	0.913 $\pm$ 0.063	0.855 $\pm$ 0.047	2.682	0.079
Injury-to-surgery period (mos)	5.405 $\pm$ 2.713	5.078 $\pm$ 1.332	6.062 $\pm$ 1.187	0.954	0.391
Length of follow-up (mos)	44.082 $\pm$ 10.801	29.928 $\pm$ 10.973	35.725 $\pm$ 23.441	6.377	0.003

more successful ($F = 82.82$, $p < 0.001$; Table 3), although the two did not differ from each other ($p = 0.289$). Furthermore, when the Oberlin procedure was compared with nerve grafting or combined procedures, it was significantly more successful than either ($F = 53.14$; $p < 0.001$).

Restoration of Shoulder Abduction

Nerve transfer was significantly more successful than the combined procedure ($p = 0.046$), which in turn was significantly better than nerve grafting procedures ($F = 5.53$, $p = 0.0044$; Table 3).

Predictive Factors

The mean patient age, sex distribution, delay to repair, length of follow-up, or year of publication had no significant correlation with outcome, as analyzed by meta-regression. This was true for analyses for both elbow flexion and shoulder abduction. In the nerve grafting group, graft length did not correlate with success rates of either elbow or shoulder surgery.

Discussion

Consensus on the most successful surgical treatment strategy for upper trunk brachial plexus injuries in adults is lacking, and in the absence of a randomized controlled trial to guide clinical decision making, we reviewed the literature to evaluate outcomes of three surgical approaches for the repair of postganglionic upper trunk brachial plexus injuries in adults, including nerve grafting, nerve transfer, and a combination of both techniques. Our

results indicated that the Oberlin procedure and nerve transfers were more successful approaches to the restoration of elbow flexion and shoulder abduction, respectively, than nerve grafting or combined techniques.

Our approach to pooling data from multiple published reports is similar to that used by Garg et al.²¹ as well as Yang and associates,⁸³ although the model itself is somewhat different. Unlike those authors, we extended our analysis to include different nerve transfers and were able to show that partial ulnar transfer seemed to result in greater success in elbow flexion recovery than did graft repair. Yang et al. did not identify a reconstruction strategy that was superior for the recovery of shoulder abduction, whereas our data, like those of Garg et al., suggested that nerve transfer is superior to nerve grafting in the case of shoulder abduction recovery as well.

In upper trunk brachial plexus injuries in adults, according to our data, the Oberlin procedure and nerve transfers are more successful approaches to the restoration of elbow flexion and shoulder abduction, respectively, compared with nerve grafting or combined techniques. While the debate over nerve grafting versus nerve transfer has been ongoing among peripheral nerve surgeons over the last few decades, it is still unclear how one approach produces better outcomes than another. We hypothesize that the superiority of nerve transfers in promoting nerve regeneration is probably the result of a combination of factors, including a shorter distance required for nerve regeneration, single suture junction, use of a vascularized albeit injured nerve transfer recipient, and reduced fibrosis at the operative site as compared with that at the injury site. In the absence of a prospective, randomized clinical trial, resolving the debate over nerve transfer versus nerve graft is unlikely. However, data in the present study arm the clinician with valuable information that can be used to counsel patients when considering various surgical approaches.

A comparative effectiveness study is not the equivalent of a well-run and well-powered randomized controlled trial. At best, it can approximate the results of such a trial. As in any mathematical model, the many simplifications and assumptions may have influenced our conclusions, and the differences among groups are relatively small. However, this suggests that the rather large sample size needed would make a clinical trial impractical, especially in light of the impact of injury type on the repair technique and the lack of clinical equipoise among peripheral nerve experts. Our use of a dichotomous outcome, such as MRC scores above and below 3, has been reported to reduce the statistical power of clinical trials,⁴⁵ although this is not always the case.²⁸

TABLE 3. Relative success of surgical procedures for upper brachial plexus injuries in adults

Procedure	Mean $\pm$ SD	F	p Value
Restoring elbow flexion		4.71	0.0097
Graft	0.692 $\pm$ 0.241		
Transfer	0.661 $\pm$ 0.153		
Combined	0.630 $\pm$ 0.268		
Restoring elbow flexion		82.82	<0.001
Oberlin	0.825 $\pm$ 0.122		
Intercostal	0.658 $\pm$ 0.167		
Other nerve transfer	0.678 $\pm$ 0.095		
Restoring shoulder abduction		5.53	0.0044
Graft	0.560 $\pm$ 0.260		
Transfer	0.654 $\pm$ 0.165		
Combined	0.633 $\pm$ 0.265		

This study has several additional limitations. Very few published case series reported outcomes stratified by injury mechanisms, and the indications for surgery were not uniform, thereby limiting our analysis. Thus, it is possible that the reported groups are not strictly comparable. Specifically, for the group undergoing combined procedures, it was not clear, based on the available literature, if both nerve grafts and transfers were performed to restore a common function. In addition, the reviewed literature lacked sufficient detail to determine which combinations of nerve grafts and transfers were most successful in restoring motor function. Moreover, in assessing outcomes for shoulder abduction, no distinction was made between specific targets for nerve reinnervation (that is, axillary versus suprascapular nerve), nor were adequate data available to separate success in restoring axillary versus suprascapular nerve function. In at least some cases, the findings at the time of exploration dictated surgical approach. If so, our comparison introduced a degree of selection bias, which might be avoided in a randomized controlled trial. We could not limit our analysis to cases in which there was clinical equipoise in surgical treatment, as very few publications separated outcomes of nerve transfers in patients with nerve root avulsions from those in patients with other brachial plexus lesions. In addition, variations in the intensity and duration of physical therapy can confound pooled results. Many secondary procedures, including osteotomies and tendon transfers, are available for these patients. Although they are widely used and affect function, we excluded them from this analysis since the goal of this study was to isolate the success of primary surgical approaches to brachial plexus injury.

The adult brachial plexus injury population is heterogeneous, and the clinician is responsible for considering several factors on an individual basis in developing an appropriate management plan for each patient. While our study provides a decision framework for the clinician to consider surgical treatment strategies, it should not serve as a substitute for the individualized clinical decision making required to manage these patients effectively. Furthermore, when considering brachial plexus reconstruction strategies, nerve transfers, without operative exploration of the supraclavicular brachial plexus, may limit the surgeon's appreciation of the unique pathology in each case.

Conclusions

In upper trunk brachial plexus injuries in adults, the Oberlin procedure and nerve transfers are more successful approaches to the restoration of elbow flexion and shoulder abduction, respectively, as compared with nerve grafting or combined techniques. A prospective, randomized controlled trial would be necessary to fully elucidate differences in outcomes among the various surgical approaches.

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