End-to-Side Neurorrhaphy to Restore Elbow Flexion in Brachial Plexus Injury

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Background: *End-to-side (ETS) neurorrhaphy is a controversial technique that is used for nerve transfer to achieve functional recovery. The advantage of this technique is the safety of donor nerve function. In this study, patients with extended upper-arm brachial plexus injury and significant hand weakness that did not meet the clinical criteria for end-to-end nerve transfer (Oberlin transfer) were treated by ETS neurorrhaphy to achieve biceps muscle reinnervation.*
Objective: *To evaluate the outcome of ETS for biceps muscle reinnervation in brachial plexus injury patients.*
Material and Method: *Thirteen patients with complete upper-arm and incomplete lower-arm brachial plexus injuries were treated by ETS of the motor branch of the biceps muscle to the ulnar or median nerves using the epineurial window technique.*
Results: *Motor recovery was observed in nine of 13 patients. Good results were achieved in six patients who attained biceps motor power ≥ M3. No additional neurological deficits of the ulnar or median nerves were identified after the surgery.*
Conclusion: *End-to-side neurorrhaphy is a viable treatment option for restoration of biceps muscle function if conventional end-to-end nerve transfer cannot be performed.*

Keywords: *Brachial plexus, Nerve transfer, Injuries, Median nerve, Ulnar nerve, Paralysis, Biceps muscle, Reinnervation, End-to-side neurorrhaphy*

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Brachial plexus injury (BPI) has varying degrees of nerve injury and widely variable clinical presentation. Patients may present with temporary loss of function due to neurapraxia or permanent loss of whole arm function from total nerve root avulsion injury. The number and severity of injured nerve roots will influence the functions that need to be restored, the available donor nerves, and the prognosis of related treatments. Elbow flexion is generally considered to be a first priority function restoration in most BPI patients. There are various methods for reinnervating the biceps muscle, depending on the available donor nerve. Extraplexal donor nerves, such as spinal accessory nerve, phrenic nerve, and intercostal nerves, have been proven effective and are long established nerve options for restoring biceps function(1-4). The novel concept of close-target donor nerve transfer has significantly improved upper-arm BPI treatment outcomes(5). If intraplexal donors are available, close-target nerve transfer from fascicles of the intact ulnar or median nerve (Oberlin transfer) have many noted advantages, including proximity to the target muscle, shorter recovery time, no need for interposition nerve graft, and achieving more reliable result than when using extraplexal donors. To avoid donor site morbidity and maintain intact ulnar or median nerve function, meticulous microsurgical technique, and knowledge of nerve topographic anatomy is essential. In typical upper-arm BPI patients, study has shown that Oberlin transfer is safe with low risk of donor site morbidity(6).

However, in some upper-arm BPI patients in whom the lower part of the brachial plexus (C8, T1) was also partially injured, hand function may not fully recover at the time of surgical treatment. Harvesting of the ulnar or median nerve fascicles in these patients may place the patient at significant risk of donor site morbidity, potentially worsening hand function deficits. In an attempt to benefit from the advantages of close-target motor transfer, but avoiding the risk of further injuring hand functions, end-to-side (ETS) neurorrhaphy was considered as a treatment option in this patient population.

The aim of this study was to report the clinical results of ETS for elbow flexion restoration by coaptation of the proximal end of the motor branch of the biceps muscle to the side of the functionally intact

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area of the ulnar or median nerve in extended upper-arm BPI patients.

Material and Method

This retrospective study reviewed patients treated for brachial plexus injury at our center between January 1, 2001 and December 31, 2006 study period. The protocol for this study was approved by the Siriraj Institutional Review Board (SIRB), Faculty of Medicine Siriraj Hospital, Mahidol University. Thirteen patients who were treated by end-to-side neurorrhaphy of the motor branch that supplies the biceps muscle with the ulnar or median nerve were included. All patients had undergone preoperative cervical myelography and electro diagnostic evaluation. Patients were scheduled for surgery as soon as the preoperative investigations were completed. In this series, all patients had evidence of lower root (C8, T1) injury including: initial total arm paralysis, incomplete recovery of hand function, myelographic lesions, and/or incomplete injury of C8, T1 roots from electro diagnostic studies. Pre-operative power of finger flexion was graded according to the British Medical Research Council (MRC) system.

Surgical procedure

Operations were performed under general anesthesia without the use of a paralytic agent. Patients were placed in the supine position with the head tilted slightly up and with a small sandbag under the scapula. A supraclavicular approach was used to explore the brachial plexus lesions. Diagnosis was confirmed by intraoperative findings and electrical stimulation. Either a phrenic or spinal accessory nerve was transferred to the suprascapular nerve to facilitate shoulder abduction. The musculocutaneous nerve was then explored via a medial-arm incision. The branch supplying the biceps muscle and the median and ulnar nerves were identified (Fig. 1). Intraoperative electrical stimulation of the median and ulnar nerves was used to determine type of nerve transfer. If the median or ulnar nerve had motor power greater than M4, then the fascicles of the better of the two nerves were used for end-to-end transfer to the motor branch of the biceps muscle (Oberlin transfer). Those cases were not included in this study. If the median or ulnar nerve had finger flexion equal to or less than M4, ETS transfer of the biceps muscle motor branch to the intact area of the ulnar or median nerve was performed. The implantation site was identified by low amplitude electrical nerve stimulation (Aesculap AG, Tuttlingen, Germany). The area that responded with the most muscle contraction was selected. An elliptical epineurial window on the median or ulnar nerve was created under microscopic field. ETS neurorrhaphy of the proximal end of the motor branch of the biceps muscle to the ulnar or median nerve was performed using four epineurial stitches with 8-0 nylon (Fig. 2). Patients were immobilized by interlocking sling for 3 weeks after surgery.

Results

Demographic data, preoperative hand motor power, and treatment results are presented in Table 1. Thirteen patients were included in this series. There were 11 males and 2 females with a median age at surgery of 26 years (range 13 to 67). Twelve patients were injured in motorcycle accidents and one patient was a pedestrian injury; all cases were closed injuries. Six patients presented with total arm paralysis immediately after injury. All patients were diagnosed with extended complete upper-arm (C5-7) BPI with

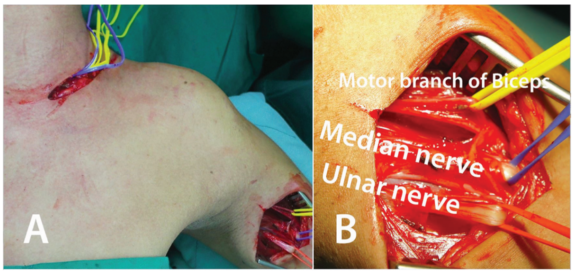

Fig. 1 (A) Brachial plexus exploration performedvia supraclavicular incision. (B) Medial upper arm incision was used to explore the motor branch of the biceps muscle, median nerve, and ulnar nerve.

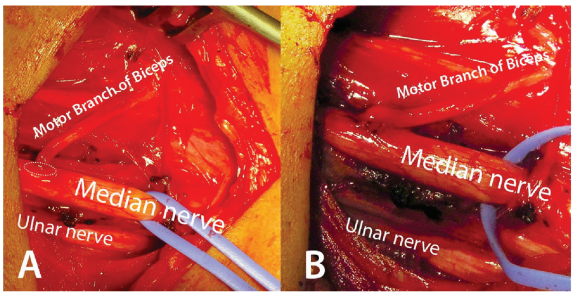

Fig. 2 (A) An elliptical epineurial window (white dotted line) was created on a functionally intact area of the median nerve. (B) End-to-side neurorrhaphy of the motor branch of the biceps muscle to the median nerve was performedusing four epineurial stitches with 8-0 nylon.

Table 1. Patient demographic, clinical, and outcome data

Gender*, age (years)	Pre-op finger flexor motor power (M0-M5)	Donor nerve	Time from injury to surgery (months)	Time from surgery to recovery of biceps ≥ M2 (months)	Duration of follow-up (month)	Biceps strength at last follow-up (M0-M5)
M, 30	4	Ulnar	4	9	72	4
M, 54	3	Ulnar	8	5	45	4
F, 13	4	Ulnar	3	6	48	4
M, 24	4	Ulnar	4	5	36	4
M, 67	2	Ulnar	7	10	43	3
F, 23	4	Ulnar	6	11	16	3
M, 20	4	Ulnar	11	-	3	0
M, 50	4	Ulnar	5	-	3	0
M, 26	4	Ulnar	7	-	4	0
M, 27	4	Median	3	7	30	2
M, 16	3	Median	8	12	30	2
M, 20	3	Median	7	-	36	1
F, 41	2	Median	5	-	24	0

* Gender: M = male; F = female

incomplete lower-arm (C8, T1) injury. Preoperative finger flexor power was M4 in eight patients, M3 in three patients, and M2 in two patients. Although eight patients had M4 level finger flexor power, none of these patients had enough hand strength to produce measurable grip strength. Nine patients had a follow-up duration longer than 24 months. Another one patient had her last follow-up at 16 months and her biceps muscle recovery was graded as M3. The mean follow-up of these 10 patients was 38 months (range 16 to 72). Mean interval between injury and surgery was 6 months (range 3 to 11). Mean duration from surgery to biceps muscle recovery in patients that achieved M2 was 8 months (range 5 to 12). Motor recovery was found in 9 cases. Good results were achieved in 6 of 13 patients, with four patients and two patients achieving biceps motor power of M4 and M3, respectively.

In this series, three patients were lost to follow-up early and we were unsuccessful in persuading them to return so we could evaluate results of treatment. Using the list-wise deletion method to manage these missing data, 6 of 10 patients achieved good results (M3 or M4). Patients in whom the ulnar nerve was used as a donor achieved better results than patients in whom the median nerve was used. Given the small number of patients and the missing data in this study, we decided to be conservative and report worst-case scenario results by classifying the missing patients as having had no biceps motor recovery. Accordingly, at least 69% (9 of 13) of patients had motor recovery and 46% (6 of 13) of patients achieved good results.

There was no additional neurological deficit in any of the donor nerves after surgery in any patient. There was no improvement in hand function after surgery in this series. The phrenic nerve was used in seven patients and the spinal accessory nerve was used in six patients for transferring to the suprascapular nerve. Axillary nerve function was not restored in this series, since there were not enough available donors.

Discussion

The ETS neurorrhaphy nerve repair technique was first described over a century ago[7], but it was almost abandoned as a result of later failures in clinical study[8]. ETS neurorrhaphy was revived in 1992, with advancements in neurobiology that started with a series of animal studies from Viterbo et al[9-11]. In human clinical practice, debate surrounding the efficacy and clinical usefulness of this technique continues. Bertelli and Ghizoni reported a case series of seven patients in 2003 that compared between ETS neurorrhaphy and fascicular transfer, but they found no functional recovery in the ETS group[12]. A year later, Pienaar et al, reported the failure of ETS neurorrhaphy in C5, C6 upper-arm brachial plexus injuries[13]. They used ETS transfer of the axillary nerve to the radial nerve in four cases, musculocutaneous nerve to median nerve in three cases, and musculocutaneous nerve to ulnar nerve in two cases. There was no evidence of motor recovery in any patients in that study; however, nearly 50% of their cases were lost to follow-up.

Many studies, however, have reported the feasibility of ETS nerve transfer in clinical practice. Franciosi et al[14] reported five cases of upper-arm BPI that were treated by ETS nerve transfer of the musculocutaneous nerve to the intact ulnar nerve. Four patients (80%) achieved grade 4 elbow flexion in four to six months after surgery[14]. Mennen reported a large series of 56 patients that were treated by ETS neurorrhaphy[15,16]. He emphasized the importance of surgical techniques and reported better results for proximal motor re-innervation (e.g., biceps muscle) and distal sensory re-innervation. A later clinical study by Millesi and Schmidhammer[17] reported reliably use fulmotor recoveries with ETS neurorrhaphy. They recommended using small-size nerves with single main function and concluded that ETS neurorrhaphy could be used as an effective alternative method in cases where end-to-end neurorrhaphy could not be performed[17].

Restoration of elbow flexion in BPI patients was significantly improved using close-target fascicular transfer technique[5]. The result of Oberlin transfer was found to be better than other extraplexal donors for elbow flexion reconstruction. In upper-arm type BPI (C5, C6, or C5-7). Garg et al reviewed 31 studies and found that 83% of 299 patients with Oberlin transfer achieved M4 strength or greater, as compared with 56% of 57 patients in nerve graft group[18]. At our center, we experienced the same results and always use fascicular transfer for biceps muscle reinnervation whenever possible. However and in some patients, we have encountered ulnar and median nerves in less than perfect condition. Most of these patients had some evidence of lower plexus (C8, T1) injury. In the present study, six patients had complete total plexus paralysis at initial presentation. In most cases, we plan for nerve reconstruction three to six months after injury. In cases where the lower root injury is only neurapraxia, recovery of ulnar or median nerve function is normally sufficiently adequate by three to six months after injury. In these patients, Oberlin transfer will be used for biceps muscle reinnervation. However, in cases of more severe injury, recovery of lower root function is less predictable. In this series, surgery was performed at an average time of six months (range 3 to 11) after injury. At the time of surgery, all patients still had partial deficits of ulnar and median nerve function. As such, we hesitated to use the Oberlin transfer method in these patients.

The remaining options for elbow flexion restoration in these patients include extraplexal donor nerve transfer with interposition nerve graft and primary free functioning muscle transfer. In the patients that did not meet the clinical criteria for Oberlin transfer, we decided to treat them by ETS neurorrhaphy. This treatment strategy facilitated preservation of extraplexal donors for other reconstructions, such as shoulder abduction and elbow extension. Moreover, a donor nerve for secondary free functioning muscle transfer might be needed afterward, either to augment elbow flexion or finger flexion if these functions failed to adequately recover.

The results of the study by Millesi and Schmidhammer[17] were better than the results from our study. Using the musculocutaneous nerve, 66% (4 of 6) of their patients had M3 strength or greater[17]. In our study, 46% of patients achieved M3 strength or greater. We postulate that partial injury to donor nerves in our patients may have adversely affected the results. This study was not attempting to promote or prove that ETS neurorrhaphy will produce results equivalent to those of Oberlin transfer. ETS neurorrhaphy should be considered when other available donor nerves are limited. One key drawback to the ETS neurorrhaphy technique is that it does not produce consistent results[19]. Some surgeons have abandoned this procedure as a result of its unreliable outcomes. In our view, ETS neurorrhaphy should not be considered a routine technique for every case that does not meet the criteria for Oberlin transfer. Careful patient selection, thorough review and consideration of all clinical and situational factors, and meticulous surgical technique should all be considered and incorporated into an ETS neurorrhaphy treatment strategy.

Conclusion

Although this study was limited by a small study population and a 23% loss to follow-up rate, our results demonstrated that ETS neurorrhaphy is a clinically feasible method for motor re-innervation. The patients in this study had nearly total plexus injury. Using the ETS neurorrhaphy technique, we were able to reserve donor nerves for other functional restorations and minimize the risk of donor nerve morbidity. As a result of the acknowledged inconsistent results associated with this procedure, other procedures, such as free functioning muscle transfer, should also be considered as secondary treatment options.

What is already known this topic?

ETS neurorrhaphy provided inconsistent results in term of functional recovery. However, the risk of donor nerve morbidity was minimal.

What this study adds?

ETS neurorrhaphy is a clinically reasonable method for motor re-innervation of small-size nerve with single main function, when end-to-end neurorrhaphy could not be performed.

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Potential conflicts of interest

None.

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การผ่าตัดย้ายเส้นประสาทเพื่อทำหน้าที่งอข้อศอก โดยวิธีต่อส่วนปลายกับด้านข้างของเส้นประสาทในผู้ป่วยบาดเจ็บข่ายประสาทแขนเบรเคียล

รุ่งศักดิ์ ลิ่มทองแท่ง, ต่อพล วัฒนา, สายชล ว่องตระกูล, ภานุพันธ์ ทรงเจริญ

ภูมิหลัง: *การต่อส่วนปลายเส้นประสาทกับด้านข้างของเส้นประสาท เป็นวิธีการรักษาซึ่งมีข้อถกเถียงกันในแง่ของผลสำเร็จที่ทำให้กล้ามเนื้อสามารถกลับมาทำงานได้ ส่วนข้อดีคือสามารถนำเส้นประสาทต้นทางมาใช้ได้โดยไม่สูญเสียหน้าที่ของเส้นประสาทนั้นไป ในการศึกษานี้ใช้การต่อส่วนปลายเส้นประสาทของกล้ามเนื้อไบเซปเข้ากับด้านข้างของเส้นประสาทมีเดียนหรืออัลนาร์ ในผู้ป่วยบาดเจ็บข่ายประสาทแขนเบรเคียลส่วนบนที่มีการบาดเจ็บของข่ายประสาทส่วนล่างบางส่วน ทำให้กล้ามเนื้อมืออ่อนแรงและไม่สามารถตัดบางส่วนของเส้นประสาทมีเดียนหรืออัลนาร์ มาใช้ในการต่อโดยตรงได้*

วัตถุประสงค์: *เพื่อประเมินผลการรักษาโดยวิธีการต่อส่วนปลายเส้นประสาทกับด้านข้างของเส้นประสาทเพื่อย้ายเส้นประสาทไปเลี้ยงกล้ามเนื้อไบเซป ในผู้ป่วยบาดเจ็บข่ายประสาทแขนเบรเคียล*

วัสดุและวิธีการ: *ในการศึกษานี้มีผู้ป่วยบาดเจ็บข่ายประสาทแขนเบรเคียล 13 ราย ที่ได้รับการผ่าตัดรักษาโดยการต่อส่วนปลายเส้นประสาทของกล้ามเนื้อไบเซปเข้ากับด้านข้างของเส้นประสาทมีเดียนหรืออัลนาร์ โดยใช้เทคนิคการเปิดเยื่อหุ้มเส้นประสาทชั้นนอก*

ผลการศึกษา: *พบการฟื้นตัวของกล้ามเนื้อไบเซปในผู้ป่วย 9 ใน 13 ราย โดยพบว่าผู้ป่วยที่ได้ผลดี 6 ราย มีกำลังงอข้อศอกมากกว่าหรือเท่ากับระดับ 3 หลังการผ่าตัด ไม่พบว่ามีผู้ป่วยที่สูญเสียการทำงานของเส้นประสาทมีเดียนหรืออัลนาร์ไปมากกว่าก่อนผ่าตัด*

สรุป: *การต่อส่วนปลายเส้นประสาทกับด้านข้างของเส้นประสาท เป็นทางเลือกที่สามารถนำมาใช้ในการย้ายเส้นประสาทของกล้ามเนื้อไบเซปได้ ในกรณีที่ไม่สามารถย้ายเส้นประสาทและเย็บต่อส่วนปลายโดยตรงตามวิธีมาตรฐานได้*