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RESEARCH ARTICLE

Nerve Transfers for Restoration of Elbow Flexion following Adult Brachial Plexus Injury

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ABSTRACT

Restoration of elbow flexion is a fundamental functional requirement following adult brachial plexus injury. Nerve transfer offers advantages over grafting and has shown better motor recovery. Contemporary literature regarding elbow flexion reconstruction is reviewed and compared. Intraplexal expendable nerve donors for C5, C6, C7 injuries allow nerve regeneration closer to the end organ and hence improved outcomes. A strategic approach using intraplexal donors for elbow restoration allows reservation of extraplexal donors for transfer to reconstruct shoulder function.

Introduction

Brachial Plexus injuries can result in severe functional deficits. Accurate early diagnosis and prompt appropriate intervention are necessary in order to obtain optimal outcome. Elbow flexion takes precedence in brachial plexus reconstruction followed by shoulder stability, abduction and external rotation. Elbow extension, which allows intentional positioning in space, is considered secondary to these functions. Over the past two decades there has been a paradigm shift away from nerve grafting and muscle transfers for elbow flexion reconstruction with the popularisation of distal nerve transfer. The authors presents a review of elbow flexion reconstruction using nerve transfer in adult brachial plexus injury and progress made in recent years.

Methods

A search was conducted using Pubmed for publications on the subject of adult brachial injury and elbow reconstruction. Keywords included “brachial plexus injury”, “brachial plexus reconstruction” “elbow reconstruction”, “elbow flexion” and “nerve transfer”. Abstracts were reviewed and papers specifically addressing elbow flexion restoration using nerve transfer in adult injuries were included. Publications relating to obstetric reconstruction and those not published in English were excluded from evaluation.

Results

Background

As brachial plexus injuries lie at the proximal aspect of the upper limb, the time for axonal regeneration to reach the end organ can be considerable and the complex topographical nature of the plexus and proximal terminal branches can allow diversion of axons away from their correct anatomical destination. Such mismatch of motor axons regenerating to sensory organs or motor axons regenerating to the wrong muscle, results in a significant drop off of axons eventually reaching their correct end organ destination. As well as poor motor and sensory recovery, the possibility exists for co-contraction of antagonist muscles, further hampering recovery. Additionally control of motor function relies on A alpha efferents so appropriate targeting is also needed for afferent motor fibres and motor efferents. The ideal condition is a direct nerve repair suitable for open injuries from sharp penetrating trauma.. Closed traction injuries are more common and may result in nerve root avulsions or more distal ruptures. Avulsions are not repairable and ruptures require grafts to bridge the gaps although condition of the nerve following injury cannot be readily determined intra-operatively and some series report inferior results [1], as there is poor regeneration potential due to axonal loss from apoptosis

Large nerve gaps have historically been treated by nerve grafting but the results from this have not led to reliable and acceptable functionally improved outcomes. This can be explained by the fact that the axons have to pass through two coaptation sites and at each, axons are lost. The absolute critical time by which muscle needs to be reinnervated before permanent loss of motor end plates is unknown but likely between 12 to 18 months and so time constraints exist which is key in management planning [2].

Where proximal avulsion has precluded direct repair, intra or extraplexal nerve transfers (distal spinal accessory, intercostals and phrenic nerve) have been used with or without grafting to provide regenerating proximal axons [3]. For proximal musculature such as supraspinatus and infraspinatus the distance for axons to advance via the suprascapular nerve to muscle is relatively short. However, transfer into the plexus or terminal nerve branches to regenerate to more distal musculature inherently means a longer distance to the end organ, longer recovery time and more chance of axonal mismatch and poorer functional outcome.

Muscles transfers can be used to restore biceps and brachialis function however this mandates the use of a donor muscle with non anatomical origin or insertion and different excursion and power. Additionally re-education for the new function is required. Nerve transfer has the advantages of using the native "anatomical" muscle with adequate excursion and potential power to produce optimal function with the caveat of time constraints for reinnervation of a denervated muscle. Additionally this procedure converts a high nerve lesion to a low lesion bringing the regenerating axonal front in close proximity to the end organ immediately.

Nerve transfer

In 1993 a study reported medial pectoral nerve transfer to musculocutaneous for biceps reconstruction in five clinical cases of brachial plexus injury following a cavaderic topographical nerve study on 21 cadavers [4]. The advantage of this intraplexal nerve transfer was the proximity of the donor nerve to the biceps and resultant speedier reinnervation time in comparison to traditional extraplexal transfers.

The following year the transfer of redundant ulnar nerve fascicles to the motor nerve branch to biceps was described in a cavaderic study and 4 clinical cases of upper trunk injury [5]. The authors reported British Medical Research Councill (MRC) elbow flexion strength M4 in 3 cases and M3 in 1 case. There was no downgrade of ulnar nerve function. This was a logical approach to a difficult problem converting a high lesion to low and using redundant fascicles innervated by C8 and T1 to reinnervate biceps in an unscarred surgical field. This procedure became known as the "Oberlin procedure" or "ulnar fascicular transfer" (UFT).

The UFT was subsequently reported for C5-C6 and C5-C6-C7 avulsion injuries in a larger series [6]. The time from injury ranged from 4 months to 6 years. Elbow flexion MRC grade≥M3 was obtained in 11 of 18 cases and those with late intervention faired poorly. Less than half of the C5-C6-C7 patients obtained elbow flexion from the transfer and the authors only recommended use of the transfer for C5-C6 avulsion. A subsequent study reported better results with the UFT in 32 patients with C5-C6, C5-C6-C7 avulsions and posterior cord with distal musculocutaneous nerve injury [7]. Recovery of M4 elbow flexion occurred in 93% of patients. Clinical recovery was apparent at a mean of 3 months with M3 strength at a mean of 6 months. The time from injury to intervention ranged from 3 months to 1 year and likely to be a key factor in such optimal results.

Maximum elbow function from a nerve or muscle transfer requires stability of the shoulder. Reconstructive options for different functional deficits should be considered together in a strategic approach. C5-C6 and C5-C6-C7 avulsions require both shoulder and elbow reconstruction. The UFT not only allows elbow flexion reconstruction but preserves the distal spinal accessory nerve as a donor nerve option for reconstruction of shoulder stability [3]. C5/6/7 injuries will require serratus anterior reconstruction in addition to other shoulder muscles and triceps function may also require reconstruction. The use of nerve transfers from a muscle that has recovered from axonal injury may result in suboptimal outcome. This is supported by the findings of a recent study which demonstrated abnormal pre-operative electromyography in recovering donor nerves correlated with poorer outcome in nerve transfer [8]. However a confounding bias exists as the reconstruction requires delay for the donor recovery and therefore a higher risk of motor end plate degeneration at the recipient muscle.

The UFT was originally described transferring 2 fascicles [5], however one study specifically carried out UFT with 1 fascicle in 36 cases with C5-C6 or C5-C6-C7 avulsions [9]. The time from injury to operation ranged 3 to 8 months and 30 patients recovered M4 (83%) biceps over a mean follow-up of 22 months. Electromyography was performed at 1 month intervals to monitor reinnervation of biceps which occurred at a mean of 3 months. Two patients failed to reinnervate biceps and went onto free muscle transfer, both of whom had C5-C6-C7 avulsion. The authors reported that those with C5-C6 avulsions had better recovery in terms of mean strength, maximum strength, ratio with M4, and failure of recovery. However the numbers involved in the study are small and no statistically significant conclusion can be drawn in this regard. A plausible explanation is that C5-C6-C7 avulsion injuries are more likely to cause an incontinuity axonal injury to C8 which is the main root supply of axons to flexor carpi ulnaris and it is these very axons which are used for the UFT. The UFT consistently showed good ulnar nerve function distally in the wrist and hand with no significant long term functional deficit, confirming that the donor nerves are truely dispensable [5-7,9].

Nerve transfers from the terminal nerves, i.e. intraplexal donors of the plexus, are not applicable to C5-T1 avulsions. Such injuries mandate the use of extraplexal donors nerves. In 2001 a meta-analysis reported the use of the intercostals nerves and the spinal accessory nerve as the 2 most common donor nerves for elbow flexion reconstruction, being used in 54% and 39% of cases respectively [10]. The authors specifically investigated the use of interpositional nerve grafting in intercostal nerve transfers to musculocutaneous nerve and found 72% of cases without graft obtained M3+ elbow flexion compared with 47% with grafting ($p<0.01$). Donor nerve choice was also assessed showing that 41% of intercostal nerve transfers obtained M4+ elbow flexion with 29% of spinal accessory nerve transfers ($p<0.01$). This may be explained by the requirement to use interpositional nerve grafting when using the spinal accessory nerve for elbow flexion reconstruction (unless shortening the clavicle) although it has been established that the spinal accessory nerve contains 4 times the number of motor axons than the intercostals nerves [11]. For upper plexal avulsions more distal nerve transfers have shown superior outcomes and extraplexal donor nerves for elbow reconstruction should be reserved for panplexal avulsions.

A further study presented 32 cases of C5-C6 and C5-C6-C7 nerve root lesions who underwent UFT and provided indications to supplement outcome with a modified Steindler flexorplasty [12]. After excluding 3 cases which had a delay of 2 years from injury to nerve transfer, 83% of cases obtained ≥M3 elbow flexion. Steindler flexorplasty was undertaken following nerve transfer in 10 cases with ≤M3 elbow flexion (2 M3, 4 M2, 4 M0) and resulted in 6 cases with M4, 2 cases with M3 and 2 cases with M2 elbow flexion. The authors recommend this procedure for M2, M1 or M0 elbow flexion >1 year following UFT and for M3 > 15 months following UFT. The UFT results were not as promising as those reported by previous studies [7,9]. However these two series had reduced preoperative delay and the authors illustrate a linear relationship between preoperative delay and quality of result [12].

The importance of brachialis muscle as the primary elbow flexor with biceps being a secondary elbow flexor and a primary forearm supinator has been noted [13]. These authors highlighted the finite number of redundant donor motor axons available from the UFT given the requirement to preserve ulnar function and reported 8 cases (4 upper trunk and 4 panplexal injuries) where an additional nerve transfer was undertaken to reinnervate brachialis to augment the functional result. The donor nerves included medial pectoral, intercostal, thoracodorsal and triceps branch with interpositional grafts used in most of the medial pectoral nerve transfers. Following the UFT the additional donor nerves where transferred to the brachialis branch of the musculocutaneous nerve. Grade M4 and M4+ elbow flexion was obtained in 5 and 3 cases respectively. Although neurolysis of lateral antibrachial cutaneous nerve was undertaken to separate out these fascicles and facilitate transfer to the pure motor component to brachialis muscle in some patients, this maneouver did not appear to have any clinical impact. The results of nerve transfer to both biceps and brachialis were superior to any reported in the literature at the time.

This group subsequently developed the concept of biceps and brachialis reinnervation based on the UFT by designing a new technique transferring expendable median nerve motor fascicles very close to the brachialis muscle as well as undertaking the established ulnar nerve fascicular transfer to biceps [14]. This "Double Fascicular Transfer" (DFT) which was reported in 6 patients with brachial plexus injuries (not only avulsions), has not only the benefits of reinnervation of 2 muscles for elbow flexion but also a very short reinnervation distance and time for each muscle. Expendable motor fascicles of the median nerve to FCR, FDS or PL were used as donor fascicles for transfer. Additionally, the authors transferred ulnar nerve fascicles to brachialis and median nerve fascicles to biceps in 3 of the cases. Clinical reinnervation was present at a mean of 5.5 months and elbow flexion was M4+ in 4 cases and M4 in 2 cases at a mean follow-up of 20.5 months. Two subsequent series confirmed good results with the DFT for elbow flexion reconstruction in C5-C6 and C5-C6-C7 injuries [15,16]. All cases,10 and 4 respectively regained M4 function.

A further report of the UFT procedure in 15 cases of "upper plexus" injury with preoperative delay of between 2 and 6 months showed good results with restoration of elbow flexion to M4 in 13 cases (87%) and M3 in 2 cases [17]. However these results are inferior to DFT technique. Reinnervation of brachialis and biceps by DFT produce superior results to UFT and reduce the requirements for secondary procedures such as Steindler flexorplasty [14,15].

A case series of nerve transfer cases for C5-C6 and C5-C6-C7 root injury was reported using ulnar fascicular transfer (4 cases), double fascicular transfer (10 cases) as well as various extraplexal donor transfers to musculocutaneous nerve (6 cases). The mean period to reinnervation recorded by EMG was 2.5 months and 2.8 months for biceps and brachialis respectively. The mean reinnervation time for extraplexal donor nerve was longer. The authors concluded that DFT produced better results than UFT for elbow reconstruction but breakdown of MRC grading by the transfer type was not provided [18].

The first comparative study of UFT verses DFT for elbow flexion was reported in 2011 [19]. Outcome measures included DASH score, quantitative flexion, supination and grip strength as well as MRC grading. Grade M4 elbow flexion was obtained in 14 of the 21 single transfers (67%) and 24 of 30 double transfers (80%). The initial DASH scores were significantly worse in the UFT group compared with DFT, inferring selection bias between groups. However the post-operative DASH scores were similar. Quantitative muscle strength results were only available for 40% of the cases (22 of 55). For cases of inadequate DASH data, cases were excluded from analysis rather than being included on the basis of intention to treat. The authors concluded similar outcomes between single and double nerve transfers. However no statistically valid conclusion can be drawn form this study given the missing data, exclusion of patients from analysis, lack of power and retrospective nature.

The use of intra-operative electrodiagnosis was reported in 6 cases C5-C6 and C5-C6-C7 injuries undergoing UFT for elbow flexion [20]. This adjunctive procedure involves dissection of all fascicles and stimulation with electrodes in Flexor Carpi Ulnaris (FCU) and First Dorsal Interosseous (FDI). This is undertaken to optimise identification of the fascicle most selective for FCU and therefore favourable to provide reinnervation and preservation of residual ulnar nerve function. Three types of compound muscle action potential were identified with Type A showing high amplitude at FCU and moderate at FDI. Type A fascicles were used for all transfers and M4 elbow flexion restored in all cases. However all fascicles require internal neurolysis so the potential to downgrade ulnar nerve function is higher. Persistent sensory deficit occurred in one case in this series.

Intercostal nerve transfer verses UFT for elbow reconstruction were compared retrospectively in 40 patients with C5-C6 and C5-C6-C7 injuries showed a statistically significant difference in time to reinnervation at 9.9 and 5.1 months respectively [21]. Grade >M3 was restored in 20 of 23 cases with UFT compared with 10 of 17 of cases with intercostal transfer (p=0.04). No Patient operated on after 6 months in the intercostal group developed >M2. Interestingly transfers were all undertaken onto the common trunk of the musculocutaneous nerve just proximal to biceps branch, thereby allowing reinnervation of both biceps and brachialis but producing a longer reinnervation distance. Despite having limited length of donor nerve, this technique avoids an interpositional nerve graft however there is a risk of axonal loss through the lateral cutaneous nerve of forearm fascicles. Direct transfer onto motor biceps fascicles is possible with intraneural dissection along the musculocutaneous nerve and although it may mean a further distance of regrowth, ther e is no need for an interpositional graft.

A further restrospective study comparing intercostals nerve transfer with UFT confirmed a faster functional recovery of elbow flexion using the intraplexal donor with 17.9 weeks and 9.8 weeks for M1 recovery respectively [22]. Grade M3 was obtained at 62.5 and 36.8 weeks respectively. There were 8 cases in each group, however more extensive plexus injuries were in the intercostal transfer group. There were 2 cases of pneumothorax in the intercostal group and no ulnar nerve functional deficit in the UFT group. The authors failed to comment on the number of cases obtaining grade M4. Isolation of elbow flexion for the UFT occurred at a mean time of 65 weeks.

The first report of M5 elbow flexion restoration following nerve transfer was reported in 2011 in a series of 29 cases of DFT [23]. Recovery of M5 was seen in 8 cases, M4 in 15 cases and M3 in 4 cases. Only one patient did not recover elbow flexion but this case was not a traumatic brachioplexopathy. Despite good results using the medial pectoral nerve or thoracodorsal as a donor to reinnervate the brachialis in concert with UFT in their previous study, the authors suggest to reserve these donors as a second line when DFT is not possible due to the more extensive dissection required.

A subsequent retrospective series reported results for 2 UFTs and 7 DFTs for elbow reconstruction following C5-C6-C7 injury [24]. Grade M4 elbow flexion recovery was obtained in 8 of 9 cases. One case of DFP who was operated on at 11 months obtained M1. All patients underwent brachial plexus exploration prior to the distal nerve transfers. Interestingly pain was significantly reduced on visual analogue score assessment following nerve transfers ($p<0.05$) and the authors attribute this to decompression of the plexus at exploration.

A recent systematic review comparing intraplexal nerve transfer versus nerve grafting for elbow flexion in C5-C6 and C5-C6-C7 injuries found superior results with nerve transfer [1]. Elbow flexion strength ≥M4 and ≥M3 was found in 83% and 93% of nerve transfer cases respectively compared with 56% and 82% of nerve graft case respectively ($p<0.05$). Additionally outcomes were improved for C5-C6 injuries versus C5-C6-C7 injuries with 88% and 66% of cases regaining ≥M4 respectively ($p<0.05$). This was the largest review to date with statistical significance. The authors considered the MRC muscle strength grading system and ROM had good inter rater reliability to allow pooled data with a meaningful outcome.

A recent retrospective analysis of 194 patients elbow reconstruction for brachial plexus injury reported that intraplexal donors faired better than extraplexal donors with a median muscle strength grading of 3.33 and 3.00 ($p<0.01$) respectively [25]. However the case mix was heterogeneous, spread over 28 years and with more than 10 types of donor. Interpositional nerve grafting was required in 74.2% of patients. There were no cases of UFT or DFT. Intercostal nerve transfer in 39 patients obtained ≥M3 in 56.25% of the cases. These results are inferior to those reported in a previous meta-analysis, which found 72% of nerve transfer cases obtained ≥M 3 [10], however these were direct coaptations with no interpositional grafting. The authors recommended a strategy of primary grafting of the musculocutaneous nerve and the use of extraplexal donors such as intercostals for multiple root avulsion. However this is at odds with the majority of the current literature which would favour distal nerve transfer over interpositional grafting for the musculocutaneous which to date shows superior results.

A systematic review compared nerve repair, nerve transfer and nerve transfer with proximal repair for C5-C6 and C5-C6-C7 plexus injuries [26]. The study demonstrated that nerve transfer is more likely to produce grade M3 elbow flexion than either direct nerve repair ($p=0.03$) or nerve transfer and proximal repair ($p=0.02$). The authors recommend proximal supraclavicular exploration for diagnosis and management planning in all cases other than isolated biceps weakness. This study highlights that the long distance for nerve regeneration, root avulsion, nerve gap and segmental nerve loss are key considerations for distal nerve transfer.

A study comparing nerve grafting with nerve transfer for C5-C6 and C5-C6-C7 injuries reported superior results for nerve transfer [27]. There were 17 cases of proximal graft reconstruction and 18 cases of UFT to biceps. DFTs were excluded from this study. Given that those precluding graft reconstruction went onto have nerve transfer one would expect a more severe injury in the group who had transfers. Despite this 16 cases of transfer (88%) obtained ≥M3 biceps flexion compared to 8 cases of grafting (47%). There were no cases of permanent ulnar nerve dysfunction after transfers. The authors recommend nerve transfer for reconstruction after 3 months but for acute (<2weeks) still suggest grafting if available roots.

The first prospective study with a direct comparison of ulnar fascicular transfer verses double fascicular transfer for C5-C6 and C5-C6-C7 injury was reported in 2013 [28]. Consecutive cases were alternately assigned to each group totally 40 cases with 20 in each group. The authors used "flexion index" (FI) to assess elbow flexion recovery rather than MRC grading, dividing the elbow strength obtained on the injured side by that of the healthy side at 12 months. The authors reported that there was no significant difference in FI between the groups but noted that they would require 84 cases in their power calculation to obtain significance at $p<0.05$.

This study was not randomised and the assessor was not blinded. Additionally the hand dominance was not taken into account, which could have a bearing on the FI and there was no report of validation of the FI method of assessment.

Phrenic nerve transfer for elbow flexion restoration in Panplexal injuries was assessed in 33 patients [29]. Two types of transfer were compared, Type 1 with coaptation directly to the anterolateral bundle of the musculocutaneous nerve (14 cases) and Type 2 with an interpositional sural nerve graft to the anterolateral bundle of the anterior division of the upper trunk (19 cases). The results showed 64% (9 of 14) of Type 1 and 63% (12 of 19) of Type 2 obtained M4 elbow flexion with no significant difference. Those delayed by > 4 months had significantly poorer prognosis ($p=0.008$) whichever technique was used in keeping with existing literature. The use of a respiratory donor nerve necessitates consideration of the rehabilitation which requires complex relearning compared with a somatic donor.

Conclusion

In the last two decades a vast amount of literature has been published on the use of nerve transfer for restoration of elbow function after brachial plexus injury, but there are no randomised controlled trials to date. For isolated upper trunk injuries the literature supports the use of DFT with some series reporting MRC grade 5 power, although UFT has not been shown to be inferior in any direct comparison to date. These procedures have the advantage of converting a high lesion to low, shorter end organ reinervation time and allow reconstructive surgery in virginal, unscarred tissue, out of the zone of injury. Medial pectoral nerve remains a useful second line intraplexal donor for such cases. For pan plexal injuries intercostals transfers have shown the most promise allowing transfer most distally closer to the end organ and without interpositional grafting. Accessory nerve and phrenic nerve are other extraplexal donors which can be considered in such cases. Successful outcome relies of a strategic approach of early surgery and distal transfer of an undamaged donor. Further prospective direct comparison of techniques using comparable outcomes with a sufficiently powered study is required.

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