Chapter 12

Intercostal and pectoral nerve transfers to reinnervate the biceps muscle in obstetric brachial plexus lesions

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submitted

Background In obstetric brachial plexus lesions (OBPL) with avulsion injury, nerve grafting for biceps muscle reinnervation may not be possible due either to the lack of a proximal stump or because available proximal stumps are used for restoration of hand function. In such cases, the intercostal nerves (ICNs) or medial pectoral nerve (MPN) can serve as a donor nerve in an end-to-end transfer to the musculocutaneous nerve (MCN). The results of only a limited number of patients after ICN-MCN or MPN-MCN transfer have been described in the current literature. In the present study the results of both techniques are reported from a single institution.

Methods We analyzed a consecutive series of 42 patients (1995-2008) in whom ICN-MCN or MPN-MCN transfers for biceps reanimation had been applied. From 1995 to 2000 we always used the ICN-MCN transfer, and from 2001 to 2008 both techniques were applied. We performed MPN-MCN transfer when C8 and T1 function was intact. Seventeen of 42 patients had an ICN-MCN transfer, of whom 11 had a global lesion, mostly a flail arm. The remaining 25 patients had an MPN-MCN transfer, of whom 14 had an avulsion of both C5 and C6.

Results Biceps muscle force >= MRC 3 was achieved in 37/42 patients (88%) after a mean follow-up of 44 months. The results in the MPN-MCN group were somewhat better than in the ICN-MCN group (92% vs. 82% resp., not statistically significant). No adverse effects were noted in both groups, especially no rib cage deformity.

Conclusion The overall success rate was satisfying. The observed small difference in results between the MPN-MCN and ICN-MCN transfers may be explained by the more severe brachial plexus lesions who were included in the ICN-MCN group.

An Obstetric Brachial Plexus Lesion (OBPL) is caused by traction to the brachial plexus during labour.[1,2] In the majority of cases delivery of the upper shoulder is blocked by the mother's symphysis (shoulder dystocia). If additional traction is applied to the child's head, the angle between neck and shoulder is forcefully widened, overstretching the ipsilateral brachial plexus. A less common injury pattern concerns infants born in a breech position, which carries a high risk for the occurrence of root avulsions.[3,4]

The traction injury may vary from neurapraxia or axonotmesis to neurotmesis and avulsion of rootlets from the spinal cord.[5] As the infant reaches the age of three months, we consider impaired hand function to be an absolute indication for nerve surgery as soon as possible.[6] Similarly, we recommend operative intervention to infants with OBPL who demonstrate no spontaneous recovery of shoulder external rotation and elbow flexion / forearm supination by 3-4 months of age.[7] This strategy is in line with other authors.[8-11] The primary goal of nerve repair in patients with OBPL is restoration of hand grasp function. The second priority is restoration of biceps function. The third goal is reanimation of glenohumeral movements; and fourth is, when indicated, extension of the elbow, wrist and fingers. The surgical repair strategy depends upon the number of viable proximal spinal nerve stumps available for grafting, the cross sectional area of the stumps, and the availability of donor nerves for neurotization.

Preferentially we perform autologous nerve grafting to restore the original anatomical pathways. Proximal stumps, however, may not be available either due to avulsion injury or because the proximal stump is used as outlet to reanimate hand function. In such instances, biceps muscle reinnervation for elbow flexion cannot be obtained with nerve grafting, so nerve transfer is applied. In this technique, a donor nerve is used that was not damaged in the traction lesion, which is coapted end-to-end to the musculocutaneous nerve (MCN). The most frequently used donor nerves are the intercostal nerves (ICNs) or medial pectoral nerve (MPN). So far, a limited number reports on ICN-MCN or MPN-MCN transfers have been published, comprising a total of 64 patients following ICN-MCN transfer[12-14] and 45 patients following MPN-MCN transfer[15,16] in infants with OBPL.

In the present paper we evaluated the results of both ICN-MCN and MPN-MCN transfer to reanimate biceps function from a single institution. The aim is to evaluate both techniques in order to further assess their value in OBPL surgery.

Patients

All infants with OBPL who were operated in our tertiary referral center during a period of 14 years (1/1/1995-31/12/2008) were analyzed (n = 425). The study concerns a retrospective comparative chart review. The decision to perform surgery was made when a complete paralysis of the arm and hand at three months of age was present or because recovery of shoulder function and of the biceps muscle did not occur between 4-6 months of age, as outlined in detail in previous reports.[6,7] All children were evaluated by pre-operative CT-myelography.[17]

The surgical records were examined. Only those infants with OBPL were included in whom ICN-MCN or MPN-MCN transfers for biceps reanimation had been applied. From these 42 infants charts were reviewed, and details are provided in Table 1. The patients were followed at six month intervals, and the strength of the biceps muscle was assessed using the Medical Research Council (MRC) grading system.[18] As the difference between MRC grade 3 or 4 is difficult to assess in a young infant, the outcome of biceps force was scored as dichotomous (>= MRC 3 or < MRC 3). The results were statistically analyzed using Fisher's exact test with the SPSS package (version 17, SPSS Inc, Chicago, USA).

In the initial period from 1995-2000 we only used the ICN-MCN transfer. From 2001 onward the ICN-MCN transfer was applied in patients with a global lesion and MPN-MCN transfer preferentially in C5-C6 or C5-C6-C7 lesions. Eleven of the 17 patients with ICN-MCN transfer had a global lesion comprising all nerve roots of the brachial plexus. The MPN-MCN was applied in 14 cases of avulsion injury to both C5 and C6, which had often resulted from breech delivery. Alternatively, the MPN-MCN transfer was applied in four patients with a superior trunk neuroma-in-continuity with predominantly neurotmesis in the outflow to the anterior division of the superior trunk, and predominantly axonotmesis in the outflow to the suprascapular nerve and posterior division of the superior trunk.

Surgical Technique

The supraclavicular part of the brachial plexus is always explored in the lateral neck triangle through a straight incision parallel to the clavicle. Our assessment of the severity of the lesion of each clinically involved spinal nerve was described elsewhere in detail.[19] In short, a distinction is made between axonotmetic and neurotmetic lesions including nerve root avulsions based on 1) visual evidence of nerve continuity at the intraforaminal level combined with 2) the presence or absence of root filaments on CT-myelography; 3) visual / microscopic assessment of the location and extent of

Table 1: **Patient characteristics**

			nerve transfer	
			ICN-MCN (n=17)	**MPN-MCN (n=25)**
breech presentation: n (%)			2 (12%)	10 (40%)
mean age at surgery (months)			5.5	6
year; lesion severity	1995-2000	C5, C6	2	-
		C5-C7	1	-
		C5-T1	7	-
	2001-2008	C5, C6	-	11
		C5-C7	3	14
		C5-T1	4	-
diagnosis C5/C6	avulsion C5, avulsion C6		9	14
	neuroma C5, avulsion C6		8	7
	neuroma C5 and C6		-	4

neuroma formation; 4) selective electrical stimulation of the involved nerves using a bipolar electrode.

Depending on the assessment of the lesion severity of the outflow to the MCN, a decision is made how to reanimate the biceps muscle. Nerve grafting from a viable stump (C5 or C6) is our first choice, as assessed with frozen section analysis.[20] If this was not possible, a nerve transfer was applied. Based on innervation patterns, we only considered the MPN-MCN transfer is a viable option when at least C8 and T1 are intact, else an ICN-MCN transfer is performed.

Musculo-cutaneous acceptor nerve

The MCN is dissected first to confirm absent biceps muscle response on direct stimulation of the nerve, as was expected from the supraclavicular findings of a severe proximal nerve lesion. The infraclavicular part of the MCN can be identified in its course dorsal to the pectoralis major and minor muscles through an incision in the lower part of the deltoideo-pectoral groove which further extends distally over the proximal medial bicipital groove. For definite identification of the MCN, its anatomical relation to the lateral cord is dissected proximally, and the division between MCN and the lateral part of the median nerve is identified. The MCN is followed distally until its runs into the biceps muscle.

Medial pectoral donor nerve

The MPNs are approached through a separate incision in the skin line on the caudal border of the pectoralis major muscle. The MPNs can be identified by retracting the pectoralis major muscle cranially. The "medial" pectoral nerve usually does not consist of a single nerve, but appears as a plexiform structure of nerve branches, which arise in part from the anterior division of the medial trunk and from the anterior division of the inferior trunk.[21] MPN function thus remains intact in C5-C6 or C5-C6-C7 lesions. Intraoperative nerve stimulation is indispensable step for the identification of the MPNs since small vessels simulate their appearance and course. Additionally, forceful contraction of the inferior part of the pectoralis muscle on direct stimulation is mandatory before the MPN can be used as donor. After identification of one or more functioning medial pectoral nerve branches, they should be cut as distally as possible. The MCN was already dissected by the same incision which is used to dissect the MPN. If the diameter of the MPN-branches and the MCN correspond well, the MCN is cut and an end-to-end coaptation is performed. The total cross sectional area of the medial pectoral nerve branches is often less than that of the MCN. If so, the epineurium of the MCN is opened approximately 270^0 and subsequently the perineurium is opened and the cross sectional diameter of the individual fascicles is assessed. Subsequently, the MCN fascicle or fascicles with a diameter comparable to the MPNs is isolated over a length of approximately 1 cm. The target MCN fascicles are cut, while the remainder is left intact. A direct coaptation is made between the MCN fascicle and the MPNs. In the present series, in 13 of 25 MPN-MCN transfers that we performed, the MCN was partially left intact.

Intercostal donor nerve

Alternatively the intercostal nerves (ICNs) are dissected. We previously described the technique for intercostal nerve transfer in adults.[22] We apply the same surgical technique in infants with OBPL. Either ICNs 3-5 or 4-6 are exposed by means of an undulating, skin incision over the ipsilateral chest: the incision starts at the anterior axillary line at the inferior border of the pectoralis major muscle and continues beneath the nipple, extending medially to the costosternal junction. The inferior part of the pectoralis major muscle is shifted upward, with partial detachment of its sternal insertion if necessary. The rib attachments of the serratus anterior muscle remain intact. The main branch of the ICN is identified halfway in its ventral course between the external and internal interosseus intercostal muscle by means of blunt dissection in the muscle fiber direction and dissected free over its entire anterior course. Care should be taken to keep the periosteum of the ribs intact in order to avoid rib cage deformities during growth. ICN motor responses are assessed by using electrical nerve stimulation. If feasible, sensory branches are identified by their course toward the skin and left intact after they have been interfascicularly dissected from the main nerve. The three ICNs are then transected as close as possible to the sternum to obtain sufficient length for direct coaptation to the MCN and are tunneled to the axilla. The infraclavicular and intercostal wounds remain separated from each other by an area of intact skin at the anterior axilla, facilitating wound closure and healing. In female infants, if the anatomical localization of sensory innervation to the nipple is uncertain, the third ICN is left untouched to preserve at least partial sensation to the breast. The MCN is cut proximally after freeing it from the lateral cord until fascicular intermingling is encountered. No attempt is made to identify the motor branches within the MCN. The epineurium of the MCN is carefully dissected at the site of the stump in order to perform a targeted coaptation of the ICNs to the MCN fascicles. Before coaptation, the infant's arm is abducted 90°. The ICNs are coapted to the centrally located MC nerve fascicles by means of fibrin glue.

In all but one ICN-MCN patients three intercostal nerves were coapted directly to the musculocutaneous nerve. In one patient a 1 cm graft proved necessary because, due to unsatisfying appearance of the target nerve, the MCN was cut further distally than usual.

Results

One patient had a total failure (MRC 0), four patients had some biceps contraction, but not against gravity (MRC 1/MRC 2), nine patients had MRC 3, and 28 were scored as MRC4. Because of the difficulty of scoring volitional force in young children, the results were dichotomized as MRC < 3 and MRC >= 3. Biceps force >= MRC 3 was achieved in 37/42 patients (88%) after a mean follow-up of 44 months. (Table 2) The results in the PEC-MCN group were somewhat better than in the ICN-MCN group (92% vs. 82% resp.), but not statistically significant (p=0.38, Fisher's exact test). No adverse effects were noted in both groups, especially no rib cage deformity.

Discussion

In the present paper we analyzed a consecutive series of 42 patients in whom MPN-MCN and ICN-MCN transfers for biceps reanimation had been applied. Biceps force >= MRC 3 was achieved in 37/42 patients (88%).

The main merit of the present study is that both nerve transfer techniques were reported from a single institution, eliminating surgeon or patient bias: the nerve transfers were performed by the same surgeons, and the same patient selection criteria were applied for surgical treatment. In the first part of study period from 1995-2000, we only used the ICN-MCN transfer, which was, at that time the preferred technique in the treatment of traumatic brachial plexus lesion in adult patients.[22] After 2001 our preference shifted, and from 2001 onward the ICN-MCN transfer was only applied in infants with a global lesion and MPN-MCN transfer preferentially in C5-C6 or C5-C7 lesions. In 2002-2004, in three cases with a C5-C7 lesion, the ICN-MCN transfer was chosen instead of the MPN-MCN transfer, because by that time we considered an intact C7 function mandatory for a good MPN function. The two different techniques will be discussed separately.

ICN-MCN transfer

In the ICN-MCN transfer group (n=17), successful biceps reinnervation was reached in 82% of patients, 3 failures occurred. One failure could potentially be explained by the need to interpose a nerve graft. The use of a graft results in two coaptation sites, which is associated with decreased axonal outgrowth due to loss of axons at both the proximal and the distal coaptation site. In adults, the use of a nerve graft in ICN-MCN transfers was shown to lead to inferior results.[23] Another ICN-MCN patient had a chromosome abnormality, with developmental cognitive problems, which may be associated with impaired central control.

Other authors have presented their results of the ICN-MCN transfer. In a series of 31 patients by Kawabata et al 94% reached >= MRC 3.[12] El-Gammal also reported 94 % success (n=31), expressed as a Active Movement Score of 6 or 7.[13] Kawano describes 3 good results in 3 patients after delayed nerve transfer.[14] Terzis reported the use of the ICN-MCN transfer in 5 patients as part of a series of 54 reconstructions, but results of the ICN-MCN subgroup were not provided separately.[24]

Table 2: **Results**

lesion severity	nerve transfer	
	ICN-MCN (n=17)	MPN-MCN (n=25)
C5,C6	1/2	11/11
C5,C6 (C7)	2/2	9/10
C5,C6,C7	2/2	3/4
C5,C6,C7,C8,T1	9/11	-
Total	14/17	23/25

Success (MRC >= 3) divided by number of infants in each category

We did not note adverse effects in the ICN-MCN group, especially we did not see any rib cage deformity. Such deformities have been anecdotally mentioned, but we are not aware of any reports in the literature. Kawabata investigated his patient with x-ray films, and found mild growth retardation of ribs corresponding to the sites of donor ICNs in 7 / 31 patients, although clinically no thoracic cage deformity could not be detected.[12] We think that the crucial factor to avoid rib cage deformity is to leave the periosteum of the ribs intact during dissection of the intercostal nerves. In this way the growth of the ribs of the infant remains undisturbed in time. We did not encounter technical difficulties in localizing the ICNs by bluntly splitting the intercostal muscles and feel that there is no indication to dissect the periosteum.

Complications of intercostal nerve harvesting in a large group of adults were reported recently.[25] The main complication was a pleural tear which happened in 14 / 153 patients. One author studied 9 infants with OBPL after ICN harvesting with postoperative CT-scan to detect atelectasis.[13] In 8 / 9 patients basal atelectasis was present at the ipsilateral side, and in 1 patient bilateral atelectasis was found. Two of these patients developed pneumonia.

MPN-MCN transfer

In the MPN-MCN transfer group (n=25), successful biceps reinnervation was reached in 88% of patients, 2 failures occurred. One failure was in a patient with a C5-C6-partial C7 lesion and one in a patient with a C5-C6-C7 lesion. It has been claimed that results of MPN-MCN transfer diminish when the spinal nerve C7 is damaged, instead of a pure C5-C6 lesion; this will be discussed more in detail below.

Our results are comparable to the literature. A success rate of the MPN-MCN transfer at 88% biceps muscle >= MRC3 was reported by Blaauw.[15] Wellons reported 80% success rate of 20 MPN-MCN transfers, although this was defined as the ability to bring the hand to the mouth.[16]

We did not see adverse affects in the MPN-MCN transfer group. The consequence of using the MPN as donor, is partial denervation of the inferior part of the major pectoral muscles, which could result in diminished adduction power. This loss of adduction power was not investigated in our patient group, nor is it systematically studied in current literature. Clinically, however, we did not encounter patients with insufficient adduction.

The indication for MPN-MCN nerve transfers is two-fold. The first indication is straight-forward: in avulsion injury of C5 and C6, a proximal stump is not available as outlet for grafting. The second indication is less well recognized, and more rare (four of 25 MPN-MCN transfers in the current study). In case of a neuroma-in-continuity, we occasionally encountered strong intraoperative indication of axonal continuity to the suprascapular nerve (SSN) and posterior division of the superior trunk (PDST). In such cases, there is less scarring and neuroma formation in the trajectory from C5 to SSN and PDST. In addition, glenohumeral external rotation is observed upon targeted stimulation of the SSN and glenohumeral abduction is observed after stimulation of the PDST. However, no palpable biceps muscle function was seen when the C6 spinal

nerve or the anterior division of the superior trunk (ADST) was stimulated. Thus we considered the C6-ADST trajectory mainly neurotmetic.

In such cases, total resection of the neuroma and graft reconstruction of the superior trunk may lead to poorer results of shoulder function than can be expected leaving the outflow to the SSN and PDST intact. In such cases the continuity to the SSN and PDST was not interrupted, not to jeopardize shoulder function. To absolutely ensure recovery of biceps function a MPN-MCN transfer is performed. This approach is similar to a recently published strategy for recovery of external rotation in case of spontaneous recovery of elbow flexion. The neuroma-in-continuity is left intact, and an accessory nerve to suprascapular nerve neurotization is performed.[26,27]

Choosing a nerve transfer for biceps reinnervation

The results in the MPN-MCN group were somewhat better than in the ICN-MCN group (92% vs. 82% resp.), which was not statistically significant maybe due to the small groups. This tendency could reflect the more severe lesion types in the ICN-MCN group, otherwise it could point towards an intrinsic better potential of the pectoral nerve as donor. In adults superior results of the MPN-MCN are reported compared to the ICN-MCN transfer.[28,29] An alternative theoretical explanation is that part of the biceps recovery has taken place in the fascicles of the MCN that we left intact in those 13 patient were we only partially sectioned the distal MCN during a MPN-MCN transfer.

The musculocutaneous nerve contains around 5000 motor axons, and distal to the coracobrachialis muscle 3000.[21] The intercostal nerves contains 500-700 axons, which would result in 1500-2100 motor axons available for transfer of three ICNs.[28] The MPN usually does not concern a single anatomic nerve, but consists of a plexiform complex of pectoral nerves, arising in part from the anterior division of the medial trunk and in part from the anterior division of the inferior trunk. Sometimes an arcade is encountered with the lateral pectoral nerve, which arises from the superior trunk. This has been published in cadaver studies[21,30], as well observed in surgical series[15]. According to axon counting in the pectoral nerves, the contribution from the medial trunk contains around 1800 axons, and the contribution from the inferior trunk around 1450.[21] When the spinal nerve C7 is involved in the traction lesion, loss of the C7 / medial trunk axons results in significantly lower axon count in the "medial" pectoral nerves available for transfer. This might explain inferior results of the MPN-MCN transfer in case of a C5-C6-C7 lesion compared to a C5-C6 lesion. Unfortunately, we cannot conclude from the results of our small study group, whether the use of the MPN-MCN transfer in case of a partial or total C7 lesion should be discouraged or is potentially effective. Currently, in C5-C6-C7 lesions we explore the MPNs. When strong pectoralis major muscle contractions on direct stimulation is encountered, we pursue with the MPN-MCN transfer. If not, we change our strategy and apply the ICN-MCN transfer.

Other donors for transfer to the MCN have been described in literature: the phrenic nerve, the hypoglossal nerve, contralateral C7, an isolated fascicle of the ulnar or median nerve, or an intact nerve in a end-to-side fashion. The use of the phrenic nerve

at an early age might carry the risk of pulmonary problems in the immediate postoperative period lasting to adulthood, so it is not employed in our center. We do not routinely use the ulnar nerve fascicle to MCN (biceps muscle branch) transfer nor the median nerve fascicle to the MCN (brachialis muscle branch) transfer[31-34] in infants as these techniques carry potential risks for the growth of the hand. The end-to-side option is not reliable enough for routine use.[35] The use of the hypoglossal nerve as donor was abandoned after it became apparent that volitional control is limited as movement of the tongue is always necessary to move the limb.[36] For the same reason we do not feel that the transfer of the contralateral C7 spinal nerve is indicated on a routine basis. In a recent paper 12 / 15 children indeed showed synchronous motion of the donor limb after contralateral C7 transfer, which was graded "considerable" in 5 and "slight" in 7 infants.[37]

Conclusion

The combined success rate of MPN-MCN and ICN-MCN nerve transfers was 88%. The observed difference in results between the MPN-MCN and ICN-MCN transfers may be explained by the more severe brachial plexus lesions that were included in the ICN-MCN group or by the intrinsic better recovery potential from MPN-MCN transfer. MPN-MCN transfer is our first choice, provided that direct MPN stimulation shows strong major pectoral muscle contractions. In all other cases, the ICN-MCN provide a reasonably reliable option for reanimation of the important biceps muscle.

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