INTERCOSTAL NERVE TRANSFER IN INFANTS WITH OBSTETRIC BRACHIAL PLEXUS PALSY

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The use of intercostal nerve (ICN) transfer to repair brachial plexus lesions associated with root avulsions is a well known procedure in adults. However, there is a paucity of reports on the use of ICN in infants with obstetrical brachial plexus palsy (OBPP). This study included 46 infants with obstetric brachial plexus palsy who underwent 62 neurotization procedures. Clinically, 2 cases had upper trunk injury, 19 had upper-middle trunk injury, 3 had lower trunk injury, and 22 had total palsy. The average age at surgery was 14 months. Twelve patients underwent surgery younger than 6 months of age, 11 patients at 6 to <9 months, 9 patients at 9–12 months, and 14 patients at >12 months. The average follow-up period was 49 months. ICN transfer resulted in 76% satisfactory (good and excellent) outcome, and was best for restoration of elbow flexion (93.5%). Functional results were best when the operation was done before the age of 9 months; however, the difference between age groups was statistically insignificant. Functional results were also independent of the extent of the original injury. Nine children had preoperative and postoperative CT chest scans. All the nine children developed basal pulmonary atelectasis postoperatively. Pulmonary atelectasis was mostly ipsilateral and was not correlated to the patient age (months), or the duration of anesthesia (in minutes). We conclude that, intercostals nerve transfer is an effective procedure for restoration of function in infants with OBPP and root avulsions. The procedure is associated with variable degree of ipsilateral pulmonary atelectasis. Microsurgery 28:499–504, 2008.

The concept for intercostal nerve (ICN) transfer to repair brachial plexus injuries can be credited to Yeoman, working with Seddon, and Seddon.[1] Although Seddon reported the use of the second-fourth ICN transfer to the distal musculocutaneous nerve (MCN), Dolenc[2] performed multiple intercostal transfers to several additional distal elements of the plexus, including axillary, median, and radial nerves. Dolenc used sural and ulnar nerves as interposed grafts and reported considerable success, although few details were provided.[2] Subsequently, several other surgeons independently adopted this technique for reinnervation of the MCN, but with variable success.[3–9] Friedman et al.[10] used standardized techniques involving transfer of three ICNs (third-fifth) to the distal MCN, without interposed grafts, which led to more consistent results, approaching MRC grade 3 or better function in ~ 50% of the patients. More recently, investigators studying intercostal-MCN transfer have demonstrated significantly improved results, (MRC grade 3 elbow flexion in 64–88% of reported cases).[3,11–16] There is a paucity of reports on the use of intercostals nerve transfer in infants with obstetrical brachial plexus palsy (OBPP). One study by Kawabata et al. showed that ICN transfer to MCN in infants with OBPP produced reliably good outcomes (MRC grade 4 elbow flexion in nearly 85% of patients).[17]

Following general anesthesia, young children (aged 1–3 years) seem to develop pulmonary atelectasis more readily than adults,[18] possibly because of the far greater thoracic wall compliance, resulting in less outwardly directed lung distension forces. The resultant atelectasis could reduce ventilatory efficiency, increase diaphragmatic fatigue, and thereby further increase the tendency for atelectasis development.[19] The effect of loss of inspiratory muscle tone caused by ICN harvesting on pulmonary atelectasis was not reported in previous studies.

The aim of this study is to evaluate the outcome of ICN transfer to different nerve recipients in infants with OBPP and to document potential respiratory complications, if any.

MATERIALS AND METHODS

The study includes a retrospective review of 46 infants with obstetric brachial plexus palsy who underwent neurotization using the intercostals nerves, and who had at least 12 months of follow-up. A total of 62 neurotization procedures were performed. Patients included 27 males and 19 females. The palsy involved the right side in 22 cases, and the left side in 24 cases. Clinically, 2 cases had upper trunk injury, 19 had upper-middle trunk injury, 3 had lower trunk injury, and 22 had total palsy. The average age at surgery was 14 months (range 4–24 months). Twelve patients underwent surgery younger than

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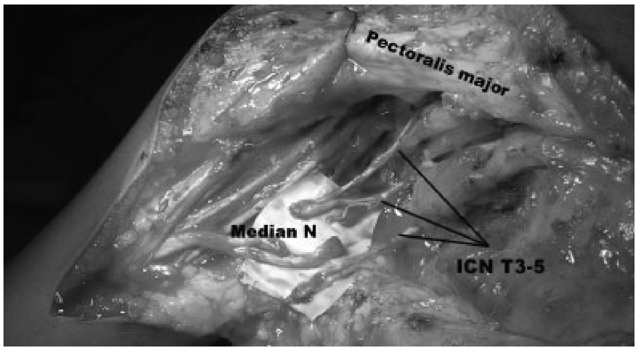

Figure 1. Exposure of intercostal nerves.

Table 1. Details of the Neurotization Procedures

Recipient nerve	Number of procedures
Musculocutaneous	31
Lateral root of median	14[a]
Medial root of median	7
Ulnar	3[b]
Suprascapular	1
Axillary	1[c]
Radial	1
Posterior division of upper trunk	2
Middle trunk	2
Total	62

[a] *All done in conjuction with musculocutaneous nerve.*
[b] *One case done in conjuction with medial root of medial nerve.*
[c] *Done in conjunction with radial nerve.*

6 months of age, 11 patients at 6 to <9 months, 9 patients at 9–12 months, and 14 patients at >12 months. The average follow-up period was 49 months (range 12–86 months).

Surgical Technique

To access the ICNs, a curved incision is extended from midpoint of the clavicle and extending downward to below the level of the nipple. Subcutaneous tissue was dissected along the skin incision and the inferior border of the pectoralis major muscle was reflected upward. A mass of adipose tissue is removed from the axillary fossa to create a space for subsequent nerve repair. The third, fourth, and fifth ICNs are carefully dissected between the internal and external intercostal muscles from the nipple line to the posterior axillary line (Fig. 1). Sometimes, the third ICN lies high behind the third rib and, in such cases; a portion of the third rib may have to be removed. The deep central branch (mostly motor) continues along the rib, while the superficial lateral branch (mostly sensory) courses inferiorly and laterally. Details of the neurotization procedures are summarized in Table 1. For neurotization to the MCN, we have used the mixed nerve to mixed nerve coaptation technique described by Chuang et al.[20] The cut surface of the MCN is separated into three sections: one large section in the center and two small sections on each side. The deep central branches of the ICNs are coapted to the central portion, while the superficial lateral branches are coapted to the two side portions.

The arm was adducted and the hand was kept close to the opposite shoulder using crepe bandage without embarrassing respiratory movements. The neck was supported by Philadelphia collar to prevent stretching of concomitant nerve grafts. All patients were admitted to the microsurgical IC Unit, kept sedated for the first 24 hours and observed for vital signs and blood oxygen saturation. The average ICU stay was 1.9 days (1–7). Oral feeding was allowed as soon as the infant was aware and fully conscious.

Table 2. Toronto Score

Grade	
	Nonfunctional: No external resistance/gravity eliminated
0	No active contraction
1	Palpable contraction—no motion
2	Motion ≤ half range
3	Motion > half range
4	Full motion
	Functional: Against gravity or variable resistance
5	Motion ≤ half range
6	Motion > half range
7	Full motion

Postoperative Functional Motor Evaluation

All patients were assessed clinically using Toronto muscle scoring system[21] (Table 2).Video study was used to confirm motor examination findings and document the degree of functional recovery. A score of 4 or less is considered poor, 5 is fair, 6 is good, and 7 is excellent. A score of 6 or more is satisfactory, while a score of 5 or less is unsatisfactory. Functional results in the different age and lesion groups were compared using the Chi square test.

CT Chest Evaluation

To identify and quantify anesthesia-induced pulmonary atelectasis in infants who underwent ICN transfer using standard ventilation technique during anesthesia, 5-mm thickness computed tomography scans of the chest were performed in nine consecutive cases: preoperatively, to serve as a control, on the first, and on the third to sixth postoperative days. CT scans were quantitatively analyzed using the frequency distribution of Housefield units (Gattinoni et al., 1988).[22] The area of atelectasis in cm^2 was correlated to the patient age (months), and the duration of anesthesia (in minutes). Associations were

Table 3. Functional Motor Recovery in Different Neurotization Procedures

Recipient (number of procedures)	Evaluated function	Functional motor recovery (%) Poor	Fair	Good	Excellent	Satisfactory (%)
Musculocutaneous (31)	Elbow flexion	2 (6.5%)	–	2 (6.5%)	27 (87%)	93.5
Medial root of median (7)	Finger and wrist flexion	1 (14%)	2 (28%)	1 (14%)	3 (43%)	57
Suprascapular (1)	Shoulder external rotation	–	–	1 (100%)	–	100
Axillary (1)	Shoulder abduction	–	1 (33%)	–	–	67
PDUT (2)		–	–	2 (67%)	–	
PDUT (2) Middle trunk (2) Radial (1)	Elbow extension	2 (40%)	–	–	3 (60%)	60
PDUT (2) Middle trunk (2) Radial (1)	Finger and wrist extension	2 (40%)	–	1 (20%)	2 (40%)	60
Ulnar (3)	Intrinsic	3	–	–	–	0
Total	55	10	3	7 (13%)	35 (63%)	76

PDUT, posterior division of upper trunk.

Figure 2. Biceps recovery 36 months following intercostal to musculocutaneous nerve transfer, an example of Toronto grade 6 recovery.

performed by Pearson correlation test. $P < 0.05$ was the accepted level for statistical significance.

RESULTS

Generally, ICN transfer resulted in 76% satisfactory (good and excellent) outcome (Table 3). The procedure was best for restoration of elbow flexion (93.5%) (Figure 2), followed by shoulder abduction (67%), and was equivocally effective for restoration of elbow extension, wrist and finger extension, and wrist and finger flexion (60%). The procedure failed to restore ulnar inrinsics. Initially, contraction of the muscles neurotized by ICNs could be initiated by deep breathing. After 1 year, all patients were able to use the neurotized muscles voluntarily independent of respiration. Sensations along the lateral aspect of the forearm and hand were restored to at least grade S2. Two-point discrimination and stereognosis were difficult to be examined at this age group. Functional results were best when the operation was done before the age of 9 months (Table 4), but the difference between age groups was statistically insignificant ($P = 0.757$). Functional results were also independent of the extent of the original injury, whether partial or total plexus injury ($P = 0.0715$) (Table 5).

All of the nine patients studied (100%) demonstrated basal atelectasis on postoperative CT scans (Figures 3A–3E). Mean size of the atelectatic area was 6.86 ± 0.71 cm^2 on the first postoperative day and 8.76 ± 0.92 cm^2 on the third to sixth postoperative day with a mean increase of 27.7%. Atelectasis was ipsilateral at the side of operative reconstruction in eight cases and bilateral in one case, but never solely contralateral. Atelectasis was complicated by pneumonia in two cases that resolved by appropriate antibiotic treatment. Statistical analysis failed to reveal any correlation between the size of atelectatic densities (cm^2), the patient age (months), or the duration of anesthesia (in minutes).

DISCUSSION

Intercostal (ICNs) transfer to the MCN for elbow flexion restoration is one of the commonly used neurotization procedures. Kawabata et al. reported their experience with this procedure in OBPP patients and found that 84% of patients who were operated between 5 and 14

Table 4. Functional Motor Recovery in Relation to Age at Surgery

		Functional motor recovery (%)				
Age (months)	Evaluated functions	Poor	Fair	Good	Excellent	Satisfactory (%)
3 to <6	12	1 (8.3%)	1 (8.3%)	1 (8.3%)	9 (75%)	83.3
6 to <9	12	1 (8.3%)	1 (8.3%)	3 (25%)	7 (58.3%)	83.3
9–12	14	4 (28.6%)	0	1 (7.1%)	9 (64.3%)	71.4
>12	17	4 (23.5%)	1 (5.9%)	2 (11.8%)	10 (58.8%)	70.6
Total	55	10 (18.2%)	3 (5.5%)	7 (12.7%)	35 (63.6%)	76.3

Table 5. Functional Motor Recovery in Relation to the Type of Lesion

		Functional motor recovery (%)				
Age (months)	Evaluated functions	Poor	Fair	Good	Excellent	Satisfactory (%)
Upper (C5,6)	2	1 (50%)	1 (50%)	–	–	0
Upper middle (C5–7)	22	2 (9.1%)	2 (9.1%)	4 (18.1%)	14 (63.6%)	81
Lower (C8,T1)	5	2 (40%)	–	–	3 (60%)	60
Total (C5-T1)	26	5 (19.2%)	–	3 (11.5%)	18 (69.2%)	81
Total	55	10 (18.1%)	3 (5.4%)	7 (12.7%)	35 (63.6%)	76

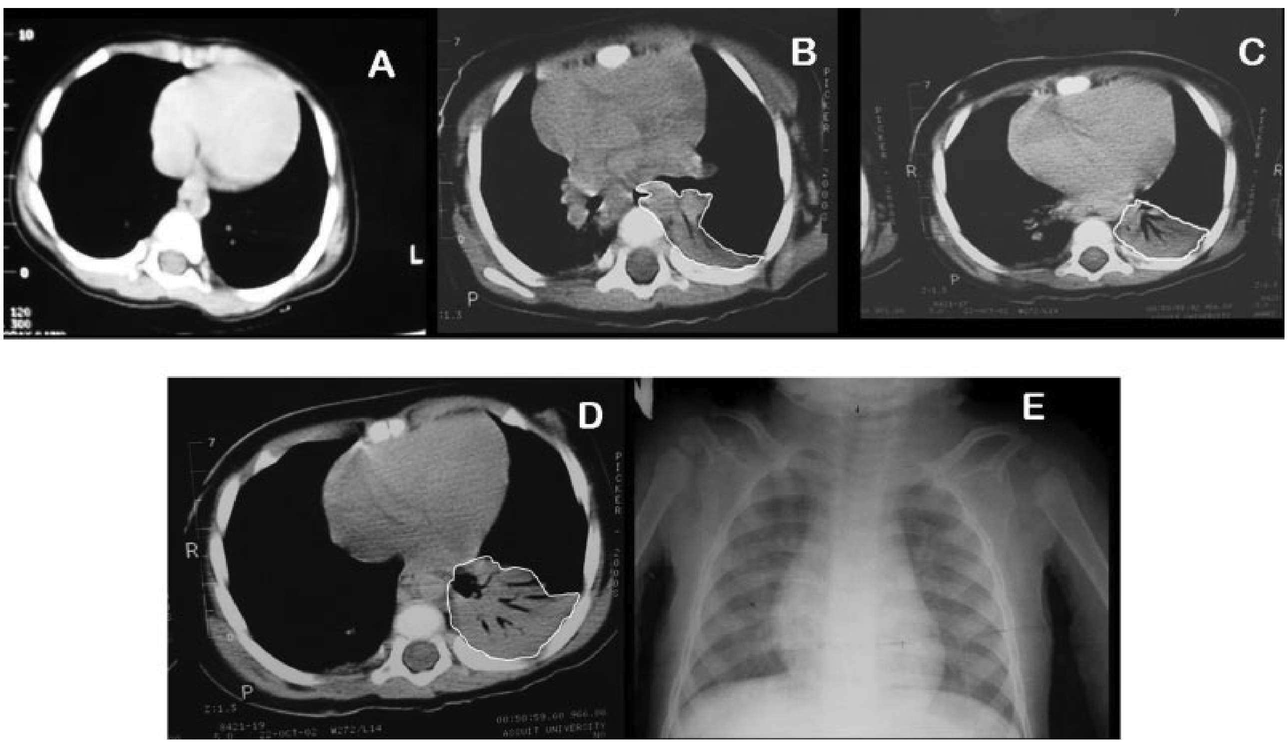

*Figure 3. Left sided pulmonary collapse complicated by postoperative pneumonia. Age: 18 months. Anesthesia time: 360 minutes. (**A**) Before induction, (**B**) Early postoperative. Atelectatic area = 4.19 cm^2, (**C**) Third day postoperative. Atelectatic area = 9.69 cm^2, (**D**) Sixth day postoperative. Atelectatic area = 12.65 cm^2, (**E**) Corresponding chest. X-ray failed to show either collapse or consolidation.*

months of age achieved a muscle grading of M4.[17] Nagano et al. reported that 70% of children achieved M4 after ICN to MCN transfer.[23] Krakauer and Wood showed that six of eight patients achieved grade M3 or more after MCN neurotization with the ICNs.[24] In Terzis series, five of six patients achieved an excellent result (muscle grading M4 to M5).[25] In this study, excluding the case of suprascapular neurotization, intercostals neurotization gave the best results when used for restoration of elbow flexion (93.5%) followed by shoulder abduction

(67%), and was equivocally effective for restoration of elbow extension, wrist and finger extension , and wrist and finger flexion. This can be explained by the fact that in case of musculocutaneous neurotization, motor branches of the intercostals nerves were coapted to the central part of the MCN distal to its exit from coracobrachialis and so all motor axons were directed mainly to a single muscle target, the biceps and to lesser extent, the brachialis. Other neurotizations were performed to a trunk, cord, or nerve that supplies groups of muscles performing different actions. The less satisfactory recovery of the deltoid compared to the biceps, although the former has a shorter distance from the innervation source, can be attributed theoretically to the more complex innervation pattern of the deltoid related to its embryological origin from three parts (anterior, middle, and posterior). Compared to adults, using the same technique, intercostals to MCN neurotization gave equivocally better results in infants, 87% versus 93.5% respectively.[11] This can be attributed to higher nerve regeneration potential and better cortical plasticity in infants.

Kawabata et al. reported that all 12 patients (100%) who underwent surgery before the age of 5 months achieved grade M4, while 12/15 (80%) who underwent surgery between 5 and 8 months of age, achieved grade M4.[17] The difference in the results between the two age groups was not statistically analyzed to confirm its significance. Only four cases were operated older than 8 months of age. In the present study, there was no difference in the results when the procedure was performed before or after the age of 6 months, but the results deteriorated, though insignificantly, after the age of 9 months. The results of intercostal neurotization are still acceptable in patients operated at or older than 1 year of age. One possible explanation is that, in older infants with root rupture, some axonal regeneration may have occurred across the neuroma maintaining the muscle condition, though not causing contraction. Thus, it is possible to operate in infants with OBPP after the age of 1 year. There was also no correlation between the results and the extent of brachial plexus injury whether it involves the upper trunk only, or both upper and middle trunks or whether it is total. This is because the neurotized function in the vast majority of cases was elbow flexion, which is dependent on a single muscle and does not require the interaction of different muscle groups with different sources of innervation.

ICN transfer is not a risk-free procedure. In contrast to other studies on the subject of anesthesia-induced atelectasis,[26] lung collapse observed in this series was mostly ipsilateral at the side of the operative reconstruction. An important factor in this study was the use of thoracic nerves (T_3, T_4, and T_5) supplying the intercostal muscles. Another factor was the effect of surgical retraction on lung expansion especially with the prolonged operative time. These factors together may cause loss of the inspiratory muscle tone, leading to further reduction of respiratory capacity and development of atelectasis.

We conclude that, intercostals nerve transfer is an effective procedure for restoration of function in infants with OBPP and root avulsions. The procedure is associated with variable degree of ipsilateral pulmonary atelectasis.

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