Use of intercostal nerves for neurotization of the musculocutaneous nerve in infants with birth-related brachial plexus palsy

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Object. The use of intercostal nerves (ICNs) for the neurotization of the musculocutaneous nerve (MCN) in adult patients with traumatic brachial plexus palsy has been well described. However, its use for brachial plexus palsy in infants has rarely been reported. The authors surgically created 31 ICN–MCN communications for birth-related brachial plexus palsy and present the surgical results.

Methods. Thirty-one neurotizations of the MCN, performed using ICNs, were conducted in 30 patients with birth-related brachial plexus palsy. In most cases other procedures were combined to reconstruct all upper-extremity function. The mean patient age at surgery was 5.8 months and the mean follow-up period was 5.2 years. Intercostal nerves were transected 1 cm distal to the mammary line and their stumps were transferred to the axilla, where they were coapted directly to the MCN. Two ICNs were used in 26 cases and three ICNs in five cases.

The power of the biceps muscle of the arm was rated Grade M4 in 26 (84%) of 31 patients. In the 12 patients who underwent surgery when they were younger than 5 months of age, all exhibited a grade of M4 (100%) in their biceps muscle power. These results are better than those previously reported in adults.

Conclusions. Neurotization of the MCN by surgically connecting ICNs is a safe, reliable, and effective procedure for reconstruction of the brachial plexus in patients suffering from birth-related palsy.

Key Words • obstetric paralysis • neurotization • brachial plexus • musculocutaneous nerve • elbow flexion • children
Neurotization of musculocutaneous nerve using intercostal nerves

Clinical Material and Methods

We explored 85 brachial plexus lesions in 84 infants and surgically created 39 ICN–MCN communications in 38 patients. Excluding those patients who did not participate in follow-up review longer than 3 years, 30 patients bore with brachial plexus palsy who underwent 31 ICN–MCN procedures were included in this study. One patient with bilateral brachial plexus palsy underwent bilateral ICN–MCN neurotrophaphy separated by an interval of 2 months. Two ICNs were used in 26 cases and three in five cases. There were 21 male and nine female patients. In 19 cases the palsy involved the right side, in 10 the left, and in one both sides. At birth 11 patients had presented in the biceps position, whereas 19 patients had presented in the position. Clinically 11 lesions were associated with the upper type of palsy—the so-called Erb palsy—and 20 lesions were associated with total palsy. The average patient age at surgery was 5.8 months (range 3–14 months). Twelve patients underwent surgery while younger than 5 months of age, 15 patients while 5 to nearly 8 months, three patients while 8 to nearly 11 months, and one patient while 14 months of age. The average follow-up period was 5.2 years (range 3–12 years).

Surgery for the brachial plexus was indicated according to Gilbert’s criteria: in brief, the lack of clinical recovery of the biceps muscle of the arm at 3 months of age and older. To determine the type of injury (preganglionic or postganglionic and complete or incomplete) to each nerve root, myelography was performed preoperatively and somatosensory evoked potentials and evoked muscle response were recorded intraoperatively. If the lesion was concomitant with root avulsion, ICNs were used for reconstruction of the MCN, and proximal nerve stumps available in the brachial plexus were used for reconstruction of other nerves. If three or more nerve roots had been avulsed, accessory nerves and ICNs were used to reconstitute other nerves such as the axillary nerve to augment the proximal nerve stumps. Especially for reconstruction of shoulder function, which was damaged in most cases in this series, we preferred to use nerve grafts extending from the C-5 root stump to the anterior division of the posterior cord and the suprascapular nerve. Otherwise, we used ICNs for neurotizations of the axillary nerve and the accessory nerve for neurotization of the suprascapular nerves, in cases in which the C-5 root had been avulsed. The results achieved for shoulder function are beyond the scope of this article and will be presented elsewhere.

Surgical Procedures

Patients were positioned supine and general anesthesia was induced. Muscle relaxants were not used so that we could perform intraoperative electrophysiological examinations, described later in this paper. The entire affected arm was prepared so that it could be moved freely during surgery. The first step of the operation was to explore the supravacular lesion. A transverse linear incision approximately 4 cm long, made just superior to the clavicle was sufficient to explore the upper and middle brachial plexus. If the whole plexus was to be explored, an extended zigzag incision and osteotomy of the clavicle were required for good exploration of the lower plexus (Fig. 1 upper). After identifying the macroscopic appearance of the brachial plexus, each nerve root was stimulated electrically and the somatosensory evoked potentials and evoked muscle responses were recorded to determine the type of injury sustained by the nerve root; specific surgical procedures were selected on the basis of our findings.

In cases in which surgical creation of nerve communication between the ICN and the MCN was indicated, another linear incision was made at the axilla to identify the MCN (Fig. 1 upper). The MCN was cut at its divergence from the lateral cord. Intrafunicular dissection was not necessary to create direct nerve communication between the ICNs and the MCN. A third incision was made along the fourth intercostal space, starting at the middle axillary line and extending up to the mammary line (Fig. 1 upper). Subcutaneous tissue was dissected along the skin incision and the inferior border of the major pectoral muscle was reflected upward. Portions of the rib origin of this muscle and the anterior serratus muscle were cut and would be repaired afterwards. The third, fourth, and, sometimes, fifth ribs were exposed subperiostally. It was not necessary to cut the ribs. The ribs were elevated using a blunt hook during subsequent dissection. Through a small transverse incision created at the periostium behind the rib, the ICN was identified and followed distally and proximally (Fig. 1 center). Each ICN was cut 1 cm distal to the mammary line and mobilized proximally up to the posterior axillary line. To preserve the functional continuity of the ICNs, it is important to treat them as gently as possible because in infants the ICNs are thin and fragile. Two or three ICNs were bound together with fibrin glue and passed to the axilla through a subcutaneous tunnel, where two or three nerve sutures were made using No. 9–0 nylon and fibrin glue reinforcement, with the aid of a microscope (Fig. 1 lower). The length of the ICNs allowed a tension-free suture with 90° abduction and 90° external rotation of the shoulder joint; interpositional nerve grafts were not necessary. Immobilization of the shoulder, with the elbow at 90° flexion and the shoulder at 60° abduction, 30° flexion, and 60° external rotation, was achieved using a spica cast, which remained in place for 3 to 4 weeks, following which a gentle range of motion exercise was initiated.

Evaluation Methods

Muscle power, presence or absence of contracture of the elbow joint, ability to move the elbow joint independent of respiration and shoulder position, and possible drawbacks of sacrificing the ICNs were evaluated at the final follow-up examination. Muscle power was assessed using the standard British Research Council Muscle Movement Scale grades of M0 to M4. Grade M0 signifies no contraction and M1 a trace of contraction. Grade M2 is used to indicate active flexion more than 90° with gravity eliminated and Grade M3 active flexion more than 90° against gravity. Grade M4 was recorded when there was active movement against gravity and resistance, with no limited range of joint motion. We did not use Grade M5 in this study because it is difficult to elicit maximum voluntary muscle contraction in a young child. The elbow joint contracture was regarded as positive when it was greater than 10°. The movement was regarded as independent when the patient could perform full flexion and extension of the elbow joint during deep breathing, with the arm both ele-
vated and dropped. Sensory deficits of the chest wall and lateral forearm were examined by comparing the ability on the normal side. An anteroposterior roentgenogram of the chest was obtained to determine the extent of thoracic cage deformity and scoliosis of the thoracic spine. Presence or absence of difficulties in the patient’s activities of daily living and concerns about donor site were determined on the basis of interviews with patients and their parents.

Results

Exploration of the Brachial Plexus

Intraoperative electrophysiological examination re-

vealed that 58 of 155 nerve roots in 31 brachial plexus-es had been avulsed from the cervical spinal cord, averaging 1.9 avulsed nerve roots per brachial plexus. Electrical stimulation of the C-5, C-6, and C-7 nerve roots did not elicit muscle contraction of the biceps muscle in any case. However, in three cases, there was a weak reaction of the biceps muscle when the MCN was stimulated at the axilla.

Among 11 patients suffering from the upper type of palsy, four harbored C5–6 lesions and seven C5–7 lesions (the patient with bilateral palsies fell into this category). Among 20 patients suffering from total palsy, 10 harbored C5–8 lesions and 10 C5–T1 lesions (Table 1).

Muscle Power

Twenty-six (84%) of 31 patients gained biceps muscle power to the level of Grade M4. Three patients exhibited Grade M3 and two Grade M2. All 12 patients (100%) who underwent surgery before they were 5 months of age demonstrated Grade M4 capabilities postoperatively. Among 15 patients who underwent surgery between 5 and 8 months of age, 12 (80%) exhibited Grade M4 capacities. Three patients underwent surgery while between 8 and 11 months of age and two (67%) of these achieved Grade M4. The last patient, who underwent surgery at 14 months of age, had Grade M3 power postoperatively (Table 1 and Fig. 2).

There was no relationship between type of paralysis and postoperative outcome. Three (75%) of four patients with paralysis at C5–6 demonstrated Grade M4 outcomes and the other, Grade M3. Five (71%) of seven patients with C5–7 paralysis showed Grade M4 abilities and the other two had Grade M2 outcomes. All 10 patients (100%) with C5–8 paralysis demonstrated Grade M4 muscle power. Among the 10 patients with C5–T1 paralysis, eight (80%) displayed Grade M4 muscle power and two Grade M3 (Table 1 and Fig. 3). Four (80%) of five patients in whom three ICNs were used exhibited Grade M4 muscle capacities and the other Grade M3, whereas 23 (88%) of 26 pa-
patients in whom two ICNs were used demonstrated Grade M4 muscle power.

Contracture and Independence of Movement

No patient had extension contracture and three patients had flexion contracture of the elbow joint. The latter patients suffered from total palsy and recovery of their triceps muscles was poor; in one patient recovery was complicated by a growth-plate injury of the distal humerus, which was unrelated to the birth palsy or the brachial plexus operation. The mean amplitude of the flexion contracture was 23˚ in these three cases.

Active motion of the elbow joint was smooth in all cases. All patients could flex the elbow joint in any arm position. While taking deep breaths, they could use the biceps muscle independently of respiration. In three cases, a hard cough induced a slight involuntary elbow flexion. Nevertheless, our patients, including these three, appeared to have no difficulties in daily living. The patient who underwent surgery to achieve neurotization bilaterally could flex both right and left elbow independently (Fig. 4).

Donor Site Complications

No sensory deficit was noted at the chest wall or forearm and no patient felt any strange ectopic sensation at the chest wall when being touched at the forearm. No respiratory dysfunction seemed to be experienced, even when the patient was running, although precise evaluation was not performed. Roentgenographic examination at the final follow-up visit revealed no development of scoliosis of the spine in any patient. On x-ray films, mild growth retardation of ribs corresponding to the sites of donor ICNs was found in seven patients, all of whom underwent surgery while younger than 5 months of age, although this thoracic cage deformity could not be detected clinically.

Discussion

Neurosurgical reconstruction of the brachial plexus in patients suffering from birth palsy was first reported by Kennedy16 in 1903. However, Sever26 reported a larger series in 1925 and concluded that there was no definitive advantage in direct repair of the brachial plexus; thereafter, reports of the procedure in the literature disappeared for a long time. In the 1980s, advances in microsurgical technologies enabled surgeons to repair damaged nerves more precisely and brachial plexus surgery was again performed in patients suffering from birth palsy. Plexoplexal nerve grafting is the most common procedure for traction injury of the brachial plexus,3,10,17,20,25,29,32 whereas ICNs,22 accessory nerve,2 cervical plexus,4 phrenic nerve,11 and the C-7 root on the contralateral side32 have also been used in combination procedures. Many large series of adult cases have been reported. However, there have been no large series of these surgical methods in infants so far, although we14,15 and other surgeons1,27 have used ICNs and accessory nerves for neurotization in patients born with brachial plexus palsy.

The ICN was first used by Seddon25 for treatment of brachial plexus injuries in adults. He interposed nerve grafts between the ICNs and the MCN. During a second era of such surgeries, Tsuyama and colleagues30 modified the Seddon method by coapting the nerves directly; they reported that this modification improved functional outcome. Malessy and Thomeer18 reviewed the cases of 202 adult patients in whom direct ICNs–MCN nerve coaptation had been performed from six reports in the literature. According to these reports, a grade of M3 or greater muscle strength had been achieved in 157 patients (78%). In our infant series, a grade of M4 or greater was achieved in 84% of cases (26 of 31 patients) and a grade of M3 or greater was achieved in 94% of the cases (29 of 31 patients). The nervous system in infants has greater abilities to regenerate and adapt to new circumstances than the nervous system in adults. The denervation period becomes shorter in infants than in adults because the distance between a neurorrhaphy site and a target muscle is relatively shorter and the speed of axonal growth is faster. These facts can sufficiently explain why the results of our series were better than those of adult series.
The timing of ICN–MCN neurotization and brachial plexus surgery in infants is still controversial. Nagano, et al.,22 concluded that in adults with brachial plexus injury neurotization should be accomplished within 6 months after the initial injury. However, physiological background and hence the final goal for brachial plexus surgery in infants are different from those in adults. In adult brachial plexus surgery, hand reconstruction is almost impossible, whereas in infants the goal of brachial plexus surgery includes gain not only of shoulder and elbow functions, but also of hand function. Waters31 has concluded that microsurgical repair for shoulder and elbow functions should not be accepted if the patient is under six months of age. We agree with this opinion, believing that it is more practical to observe patients for five months after birth to avoid performing unnecessary operations. However, when we plan to reconstruct hand function as well, we prefer to operate when the patient is 3 months of age, as does Gilbert9 who recommended microsurgical repair when the patient was 7 months (right side) and 8 months (left side) of age. Note the independent flexion of both right and left elbows.

Eighteen of 20 patients with total palsies (C5–T1 palsies) recovered grade M4 muscle power. This result indicates that there is no relationship between the severity of the brachial plexus injury and the extent of recovery of the biceps muscle innervated by the ICN. From myelo graphic examinations, we have found that a traction injury sometimes extends beyond the brachial plexus. We have experienced situations in which the C-3 and C-4 nerve roots had been avulsed and some in which the T-2 nerve root had been avulsed. However, there were no cases in which the T-3 or lower nerves were damaged. Therefore the T-3 or the lower ICNs can be used safely as donors for neurotization in patients born with brachial plexus palsy.

De Grandis and colleagues6 stated that associated movements are present in patients suffering from brachial plexus birth palsy and proved electrophysiologically that this is due to simultaneous innervation by the same motor neuron of two or more motor subunits in different muscles. Tada, et al.,28 reported that misdirected sprouting from the proximal end of the injured axon results in confused reinnervation. Clinically spontaneous recovery cannot avoid misdirection at the injured site and, hence, simultaneous contraction of biceps and triceps muscles in the arm is not infrequent. When these two antagonistic muscles contract at the same time, the joint movement will be awkward and incomplete. By using ICNs to reinnervate the MCN, simultaneous contraction between the biceps and other muscles could be avoided because the ICNs were independent of the brachial plexus and have no relationship with movement of the upper extremity. Being free from cocontraction, smooth elbow joint motion at any arm position became possible in our series.

Flexion contracture of the elbow joint is common in patients with brachial plexus birth palsy, but the cause of this flexion contracture is not clear. Muscle imbalance, abnormal stress, and simultaneous contraction have been advocated as causative factors.21 De Grandis and colleagues6 have pointed that the misdirection of axons may lead to impairment of fine motility and may lead to the onset of joint contractures by reducing articular excursion. We observed only three elbows with flexion contracture of the 31 elbows examined in this series. We believe that prevention of flexion contracture at the elbow joint is another advantage of using ICN for MCN neurotization.

There was no complaint from patients or family members concerning involuntary contraction of the biceps muscle during daily life activities and this has been proved by electromyography (data not shown). In three cases, however, a hard cough induced involuntary elbow flexion, even a long time after the operation. This means that the switch of motor regulation in the central nervous system was not always complete, even in young children. On the contrary, sensory function seemed to be completely adapted to the new condition.

Giddins and colleagues8 reported that there was no evidence of significant respiratory dysfunction after ICNs were used to produce neurotization in adults. In infants and young children, it is difficult to assess precise lung functions by using measurements such as forced vital capacity and forced expiratory volume at one second; however, we have the same impression in our infant series. Nevertheless, it may be safe to avoid using ICNs for neurotization in the presence of phrenic nerve palsy.

Thoracic cage deformity, which was observed in younger patients in this series, was mild and did not elicit complaints from patients or their parents. Because severe paralysis alone could result in asymmetry of the arms and thorax, we believe that the deformity caused by ICN deprivation is negligible. Roentgenographic studies documenting the adverse effects of this procedure must be continued until the patient’s growth spurt finishes, but there appears to be no problem that is major enough to recommend cessation of this surgical procedure.

Narakas24 has pointed out that adequate reinnervation is...
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beyond the reach of the majority of the donors in brachial plexus surgery. One intercostal nerve contains 2000 to 3000 acetylcholine esterase–positive axons, whereas the number of myelinated fibers in normal brachial plexus is 160,000 according to Bonnel and cited by Brunelli and Brunelli. The quality of proximal nerve stumps that have been lacerated by traction injury is commonly very poor. In a case in which there has been nerve root avulsion, there is a definitive paucity of available proximal nerves. In our opinion, all possible donor nerves must be recruited to reconstruct brachial plexus with root avulsion(s) to obtain the best result.

Conclusions

When one or more nerve roots in the brachial plexus have been avulsed, all injured nerves must be reconstructed by using four or fewer nerve stumps, if surgeons are wedded to using plexoplexal nerve grafts. In these cases the axons would scatter and, eventually, recovery would be poor. Because use of ICNs in neurotization of the MCN in birth palsy presented excellent results and left negligible donor site morbidity, it can be used safely and effectively. We recommend use of ICNs in reconstruction of the MCN during surgery in patients born with brachial plexus palsy. This saves proximal nerve stumps available in the brachial plexus for reconstruction of the other nerves, when the lesion is concomitant with root avulsions.

References


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