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EDITORIAL

Use of intercostal nerves for different target neurotization in brachial plexus reconstruction

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Abstract

Intercostal nerve transfer is a valuable procedure in devastating plexopathies. Intercostal nerves are a very good choice for elbow flexion or extension and shoulder abduction when the intraplexus donor nerves are not available. The best results are obtained in obstetric brachial plexus palsy patients, when direct nerve transfer is performed within six months from the injury. Unlike the adult posttraumatic patients after median and ulnar nerve neurotization with intercostal nerves, almost all obstetric brachial plexus palsy patients achieve protective sensation in the hand and some of them achieve active wrist and finger flexion. Use in combination with proper muscles, intercostal nerve transfer can yield adequate power to the paretic upper limb. Reinnervation of native muscles (*i.e.*, latissimus dorsi) should always be sought as they can successfully be transferred later on for further functional restoration.

Key words: Intercostal nerve; Brachial plexus reconstruction; Reinnervation; Root avulsion

Core tip: Intercostal nerves are a very good choice for elbow flexion or extension and shoulder abduction when the intraplexus donor nerves are not available. Use in combination with proper muscles, intercostal nerve transfer can yield adequate power to the paretic upper limb. Reinnervation of native muscles (*i.e.*, latissimus dorsi) should always be sought as they can successfully be transferred later on for further functional restoration.

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INTRODUCTION

Nerve transfer or neurotization procedure can provide a useful function in cases of brachial plexus palsy with global spinal nerve root avulsion or irreparable proximal lesion. During a neurotization procedure a healthy donor nerve is separated from its territory, and its proximal stump is then connected directly or *via* a nerve graft to the distal stump of an injured nerve or implanted directly into a more critical denervated muscle target.

Sacrificing a donor nerve must be worthwhile. More specifically, the function gained has to be of greater value than the function lost and the donor nerve must contain adequate number of motor fibers to affect target reinnervation. Additionally, sufficient brain plasticity must take place to affect the restored function. These principles are operable in cases when intercostal nerves are used to neurotize different targets.

Yeoman *et al*[1] first in 1963 transferred several intercostals nerves into the musculocutaneous nerve using the

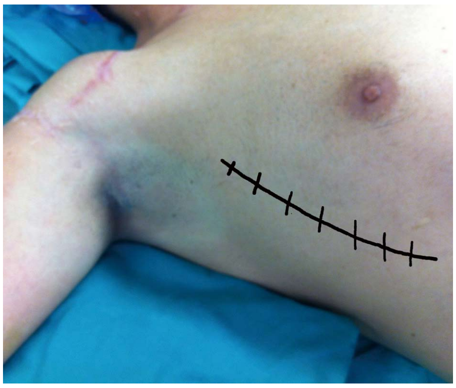

Figure 1 A curved incision starts at the anterior axillary line at the level of the upper chest and extents caudally towards the midline of the abdomen at the level of the umbilicus, depending on the number of intercostals nerves to be harvested.

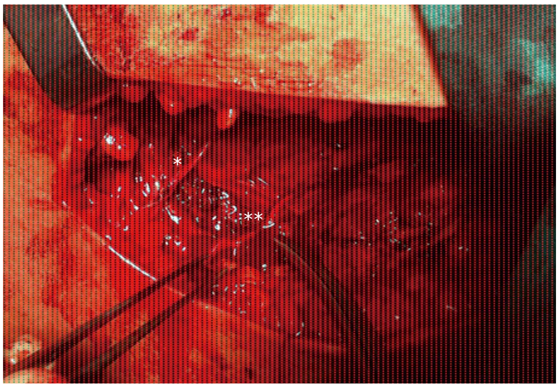

Figure 2 The motor branch is identified on top of the innermost intercostal muscle and dissected from the costochondral junction anteriorly to the posterior axillary line posteriorly. The intercostal nerves are passed to the axilla through a subcutaneous tunnel so they can be sutured to the recipient nerve. Note the intercostal nerve 5 (*) and the intercostal nerve 6 (**) after their dissection and mobilization.

ulnar nerve as a graft. This technique was modified and further developed by Kotani *et al*[2] and Tsuyama *et al*[3] ten years later. The pioneers in brachial plexus surgery such as Millesi, Narakas, Celli, Morelli, Terzis, and Gu commonly used intercostal nerve transfer for brachial plexus reconstruction[4-13].

ANATOMY AND PHYSIOLOGY OF THE INTERCOSTAL NERVES

Intercostal nerves are the ventral primary rami of spinal nerves T1 to T11. The ventral primary ramus of T12 spinal nerve is the subcostal nerve. T1 takes part in the brachial plexus and T12 does not actually occupy an intercostal space. Therefore 10 thoracic nerves from T2 to T11 constitute the anterior branch of intercostal nerves. In the intercostal space there are three muscular layers: (1) external intercostal muscle; (2) internal intercostal muscle; and (3) the innermost intercostal muscle. The upper intercostal nerves (T3, T4, T5 and T6) run parallel to their ribs in between the middle and innermost intercostal muscles, while the lower intercostal nerves (T7, T8, T9, T10 and T11) lie superficial either to transversus thoracic or transversus abdominis muscles.

There are some anatomic differences between the intercostal nerves. The first intercostal nerve is a tiny ramus of the first thoracic nerve and runs along the lower margin of the first rib. This is a purely sensory nerve and travels towards the sternum to innervate the skin near the midline. The second intercostal nerve has a large sensory lateral branch that innervates the skin in the anterior portion of the axilla and forms a connection with the medial cutaneous nerve of the arm. Furthermore, this nerve, because of its very high location is not accessible for neurotization. The anterior portion of the second and third intercostal nerves runs deep to the external intercostal muscle under the rib margin. The fourth intercostal nerve is slightly thinner than the third, its sensory component supplies the skin of the nipple-areolar area, and must be avoided for harvesting. Intercostal nerves from the 7 to the 11 supply muscles and skin of the anterior abdominal wall and theoretically will carry on higher number of axons than the upper intercostal nerves.

An intercostal nerve contains no more than 1200-1300 myelinated fibers and only 40% of them are motor fibers. Freilinger *et al*[14] studied the motor fiber content in the six, seventh and eight intercostal nerves and found a relatively constant level between 30% and 40% in the six intercostal nerve. The highest percentage (40%) was reached just after the lateral cutaneous branch had left the main trunk. Each intercostal nerve innervates multifunctional muscles and affects the respiratory function and posture including trunk flexion-extension and rotation. After intercostal nerve transfer to a given muscle, central motor programs responsible for respiration and posture will be connected to the innervated muscle. Initially, the function will occur only after voluntary respiratory effort, but with time voluntary control over the restored function will be achieved. These changes of control imply central adaptation, involving rearrangement of motor programs for a given muscle function and respiration[15].

During nerve transfer procedure, there is always a great risk of wasting transferred motor nerve fibers into inappropriate channels. For this reason, the distal site of coaptation must be as close as possible to the entry point of the motor nerve into the muscle target. This requires harvesting greater length of the donor nerve (Figures 1 and 2). However, the more the dissection proceeds distally, the lower the available number of motor fibers in the intercostal nerve.

To avoid an interposed nerve graft, Celli *et al*[4] suggested dissection of the intercostal nerve from its origin in the back and tracing it anteriorly for a length of 30-40 cm. Morelli *et al*[8], in order to maintain the maximal number of motor fibers, suggested transection of the intercostal nerve close to its origin followed by lengthening with a long intermediate nerve graft to reach the target.

INDICATIONS

Intercostal nerves can be used for primary nerve repair

Table 1 Intraoperative scoring system used to estimate the severity score

Score	Description of lesion
0	Avulsion
1	Rupture/avulsion
2	Rupture
3	Rupture/traction
4	Traction
5	Normal

in early or in late cases when free muscle transfer is indicated. The primary nerve transfer contains direct coaptation with single muscle target (musculocutaneous nerve, axillary nerve, triceps branch, and direct coaptation with nerves of multiple muscle targets (ulnar and median nerves); However, innervation of muscle targets for muscle transfer contains (1) neurotization of long thoracic nerve for stabilization of scapula and shoulder abduction; (2) neurotization of the thoracodorsal nerve and using in a second stage the latissimus dorsi muscle as pedicle flap for restoration of elbow flexion or extension; and (3) neurotization of free muscles transferred for shoulder, elbow, or hand reanimation. In patients with history of rib fractures, chest tube placement, or thoracotomy appropriate electrodiagnostic studies of intercostal nerves involved should be performed preoperatively.

DATA ANALYSIS

Brachial plexus palsy with multiple root avulsion is a devastating injury due to paucity of proximal motor donors. The only alternative for restoration of useful function is the use of neurotization procedures. However, the available donor nerves for transfer are few.

Yeoman *et al*[1] first described intercostal nerve transfer for brachial plexus reconstruction. Subsequently, several authors have reported their experience with intercostal nerve transfer[4,16-29]. In order to restore maximum function of the arm, as many intercostal nerves as possible are harvested and transferred. However, the optimal number of intercostal nerves used for nerve transfer remains controversial. Nagano *et al*[26] showed 70% good to excellent results using two intercostal nerves for musculocutaneous nerve neurotization. Chuang *et al*[17] reported higher success rate when they used three intercostal nerves. Kawai *et al*[23] supported that at least two intercostal nerves are needed to achieve useful elbow flexion, but using more than two intercostal nerves the results were not significantly better than those obtained when only two intercostal nerves were used.

There is a controversy on which intercostal nerves are the best for transfer. For brachial plexus reconstruction purposes, nine intercostal nerves are available: T3 through T11. Chuang *et al*[17] in their series showed no difference in the functional outcomes after using upper *vs* lower intercostals.

Different series have advocated the advantages of direct method of intercostal nerve coaptation without tension to the recipient nerve *vs* using nerve graft[10,20,25,27,30-33]. None of the patients in series of Friedman *et al*[20] who had interposed nerve graft between the transferred intercostal nerve and the musculocutaneous nerve obtained useful elbow flexion. Sedel[34] reported useful elbow flexion in five out of nine patients using nerve grafts. Songcharoen[28] showed muscle grading 3 or more in 65% of patients after intercostal to musculocutaneous nerve transfer (Table 1). Probably, when direct nerve repair is utilized, the distance to the target is shorter, and the regenerating axons pass through only one coaptation site instead of two when nerve graft has been used.

In late brachial plexus cases, when native muscle targets have been wasted, free muscle transfer innervated by intercostal nerves seem to be a viable procedure[16,18,35-39]. When planning a muscle transfer for upper extremity reanimation, in order to obtain the maximum result it is imperative to choose the correct muscle for needed function. Due to the greater power demands needed for proximal joint animation, free latissimus dorsi, rectus femoris or vastus lateralis muscles should be used for elbow flexion restoration, and the use of free gracilis muscle should be limited to hand reanimation.

The overall results after intercostal nerve transfer differ in many series. Chuang *et al*[17] showed that 67% of patients obtained a muscle strength of grade 4 or higher after intercostal to musculocutaneous nerve neurotization. Ruch *et al*[40] reported that 47% of patients obtained good or excellent results after musculocutaneous nerve neurotization with intercostal nerve transfer. Krakauer *et al*[24] showed that 6 out of 8 patients achieved a muscle grading of 3 or more after musculocutaneous nerve neurotization with intercostal nerves. Malessy *et al*[30] reviewed intercostal to musculocutaneous nerve transfers in adult patients performed in 6 different centers and found that a grade of 3 or more was achieved in 78% of the cases. Kawai *et al*[23] showed a muscle grading of +3 or more in 42% of patients after intercostal to musculocutaneous nerve transfer. Kawabata *et al*[41] reported his experience with intercostal nerve transfer in obstetric brachial plexus palsy patients and found that 84% of their patients achieved a muscle power of grade 4. Terzis *et al*[12] showed excellent results (M4 to M5-) in 5 out of 6 obstetric brachial plexus palsy patients when using intercostal to musculocutaneous nerve transfer and excellent result in 5 out of 11 patients when intercostal nerves were used for triceps nerve reinnervation[12].

Restoration of protective sensation it is imperative to maximize the upper extremity function. Kotani *et al*[2] reported limited recovery of sensibility in 11 out of 15 cases treated with intercostal nerve transfer for sensory restoration of the hand. Millesi[7,25] showed recovery of protective sensation in 15 out of 18 patients. Kawai *et al*[23] reported superficial pain recovery and some touch sensation in 5 out of 13 cases. Ihara *et al*[21] stated that intercostal nerve neurotization of the median nerve provided some touch sensation in 12 out of their 15 cases but no two-point discrimination was recorded. Doi *et al*[37] showed tactile gnosis after intercostal nerve transfer to the ulnar nerve in all their patients. Terzis *et al*[12] reported complete recovery of protective sensation and active wrist and finger flexion after intercostal to ulnar and/or median nerve neurotization in obstetric brachial plexus palsy patients.

CONCLUSION

Intercostal nerve transfer is a valuable procedure in devastating plexopathies. Intercostal nerves are a very good choice for elbow flexion or extension and shoulder abduction when the intraplexus donor nerves are not available. The best results are obtained in obstetric brachial plexus palsy patients, when direct nerve transfer is performed within six months from the injury. Unlike the adult posttraumatic patients after median and ulnar nerve neurotization with intercostal nerves, almost all obstetric brachial plexus palsy patients achieve protective sensation in the hand and some of them achieve active wrist and finger flexion. Use in combination with proper muscles, intercostal nerve transfer can yield adequate power to the paretic upper limb. Reinnervation of native muscles (*i.e.*, latissimus dorsi) should always be sought as they can successfully be transferred later on for further functional restoration.

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