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A histochemical study of the biceps brachii muscle cross-innervated by intercostal nerves

6 cases of brachial plexus injuries operated with nerve-crossing

Hideo Kawai[1], Tsuyoshi Murase[1], Hidehiko Kawabata[2], Ichiro Ohta[3], Takashi Masatomi[3], Keiro Ono[3] and Ikuya Nonaka[4]

Direct nerve-crossing of intercostal nerves from the lateral thorax to the musculocutaneous nerve was performed in 6 patients after spinal nerve root avulsion with brachial plexus palsy. Elbow flexion power was regained well enough to move against gravity and some resistance in all cases. The muscles were examined histochemically 4 (1–9) years after the operation. The intercostally-innervated biceps brachii muscle showed motor predominance of slow-twitch Type 1 fiber regeneration much more than that of fast-twitch Type 2 fiber in 5 of our patients. Our study suggests that the motor nerves of slow-twitch fibers may have priority in peripheral nerve regeneration over those of fast-twitch fibers.

Departments of Orthopedics, [1]Hoshigaoka Koseinenkin Hospital, Osaka, [2]Osaka Medical Center and Research Institute for Maternal and Child Health, [3]Osaka University Medical School, and [4]Division of Ultrastructural Research, National Institute of Neuroscience, Kodaira-shi, Tokyo, Japan.
Correspondence: Dr. Hideo Kawai, Department of Orthopedics, Hoshigaoka Koseinenkin Hospital, 4-8-1 Hoshigaoka, Hirakata-shi, Osaka 573, Japan. Tel. +81-72 040 2641. Fax -72 040 2266
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Direct intercostal nerves crossing to the musculocutaneous nerve is the method of treatment for reinnervating the elbow flexor in a patient with brachial plexus palsy with root avulsion. The biceps brachii muscle, cross-innervated by intercostal nerves, functions voluntarily in association with respiratory functions for over 1 year after nerve surgery (Kawai et al. 1988, Nagano et al. 1989). Intercostal nerves comprise a mixture of sensory and motor nerves, where the motor segment innervates muscles composed of a mixture of slow- and fast- twitch fibers. In addition to ventilatory functions, the intercostal muscles participate in functions such as trunkal rotation, vocalization, coughing, vomiting, defecation and postural function in activities of daily life (Duron 1973, De Troyer et al. 1983, 1985). These dual involuntary and voluntary functions are closely related to the harmonious recruitment of the respiratory and trunkal muscles. Foreign reinnervation of a fast muscle with a nerve normally supplying a slow muscle, and vice versa, leads to transformation of the muscle's phenotype. Thus, the neural influence determining the contractile properties of fast and slow muscles has a profound and controlling effect on the structure and metabolic activity of the muscle fiber (Buller et al. 1960, Dubowitz 1967). We have examined the histochemical appearance of the recovered biceps brachii muscle after direct nerve-crossing of intercostal nerves to the musculocutaneous nerve in 6 cases of root avulsion with plexus paralysis.

Patients and methods

The musculocutaneous nerves of 6 traumatic brachial plexus palsy patients, aged 28 (17–46) years, were cross-innervated directly, without nerve grafts, with the third to seventh intercostal nerves, utilizing at least 2, and at most 4 intercostals. The cross-innervation was done 9 (5–13) weeks after injury (Table 1). At the time of nerve surgery, biopsies were obtained from the third external and internal intercostal muscles at the mid-clavicular line from the lateral thorax, and from the normal biceps brachii muscle on the unaffected side in Cases 1 and 6. The biceps brachii muscle, cross-innervated by intercostal nerves, was obtained at the times of other operations, such as internal fixation of humeral fractures or tendon transfers in the palsied hand. After intercostal cross-innervation, it took the biceps brachii muscles 4 (1–9) years to achieve good motor recovery.

The specimens of intercostal muscles as well as of the biceps brachii muscle, 10 mm in length and 4 mm in diameter, were rapidly frozen in isopentane cooled by liquid nitrogen for histochemical study. Serial-fro-

Table 1. 6 cases of intercostal nerve crossing to musculocutaneous nerve for traumatic brachial plexus palsy with root avulsion

Case	Age at surgery	Weeks from injury to surgery	Intercostal nerves transferred	Strength of biceps brachii muscle	Muscle examination (years)
1	23	5	III–V	4	2
2	18	10	V–VII	4	2
3	44	10	III–VI	4	3
4	46	11	III–V	4	7
5	18	6	III, IV	4	9
6	17	13	III, IV	3	1

Table 2. Percentage of histochemical types of intercostally innervated biceps brachii muscle fibers

Case	Type 1	Type 2A	Type 2B	Type 2C	Fiber size (μm)
1	100	0	0	0	5–80
2	94	0	2	4	5–100
3	35	30	30	5	10–130
4	95	2	0	3	5–100
5	97	1	1	1	5–100
6	62	8	12	18	5–120

zen sections were stained with hematoxylin and eosin, modified Gomori trichrome, and a battery of histochemical methods, including NADH tetrazolium reductase (NADH-TR) and myosin adenosine triphosphatase (ATPase), with preincubation at pH 10.7, 4.6, and 4.2. Types 1, 2A, 2B, and 2C fibers were classified on serial sections stained with ATPase. Photomicrographs of these sections were used for measuring fiber type distribution and fiber type size.

Results

In all biceps brachii muscles with cross-innervation, there was marked variation in fiber size. Small-to-large group atrophy was recognized in 5 cases. In addition, there were scattered atrophic fibers with pyknotic nuclear clumps and small angular fibers. No clearly necrotic fibers were seen. The most striking morphologic feature was Type 1 fiber predominance in nonatrophic to hypertrophic fibers in all muscles, suggesting an active reinnervating process (Table 2). The fiber type distribution of the examined muscles was as follows: Type 1, 2A, 2B, and 2C fibers comprised 64, 12, 19, and 5 percent, respectively, in the third external intercostal muscle, and 41, 25, 29, and 5 percent, respectively, in the third internal intercostal muscle.

The external intercostal muscle thus showed Type 1 fiber predominance, but the internal intercostal muscle had a relatively even distribution of fiber types (Figures 1 and 2). Fiber types of the normal biceps brachii muscle were Type 1 39 percent, Type 2A 34 percent, Type 2B 27 percent in Case 1, and Type 1 37 percent, Type 2A 18 percent, Type 2B 43 percent, and Type 2C 2 percent in Case 6. The fiber size was 40–80 μm. The normal biceps brachii muscle showed an evenly distributed checkerboard pattern of Types 1, 2A, and 2B fibers (Figure 3). By contrast, the fibers of the intercostally innervated biceps brachii muscle were almost all Type 1 fibers in 5 out of 6 cases (Figure 4).

Discussion

In free muscle transplantation with microneurovascular anastomosis, improved recovery in transferred rabbit rectus femoris muscles was reported to demonstrate a higher proportion of Type 1 fibers (Frey et al. 1983). This Type 1 fiber predominance was also found in 2 patients with free gracilis muscle transfer and microneurovascular anastomosis for long-standing facial palsy (Oldfors et al. 1989). In our study, Type 1 fiber predominance was demonstrated in well-recovered biceps brachii muscle transferred by intercostal nerves. The reason for this relationship of Type 1 fiber predominance and good motor recovery remains to be elucidated, as Type 1 fibers are generally found to produce less isometric force than Type 2 fibers. A higher percentage of Type 1 fibers in the free muscle transfer and nerve-crossing may be a reflection of a more favorable response to the nerve regeneration. Type 1 fiber predominance in the biceps brachii muscle innervated by intercostal nerves suggests better reinnerva-

Histochemical muscle studies. ATPase with pre-incubation at pH 4.6.

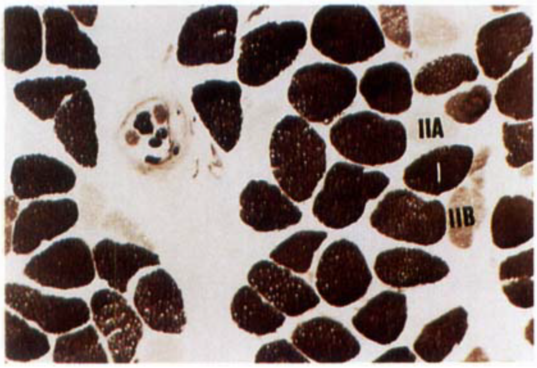

Figure 1. Normal third external intercostal muscle shows Type 1 fiber predominance: Type 1 (I) 63 percent; Type 2A (IIA) 9 percent; Type 2B (IIB), 18 percent and Type 2C 10 percent. ×50.

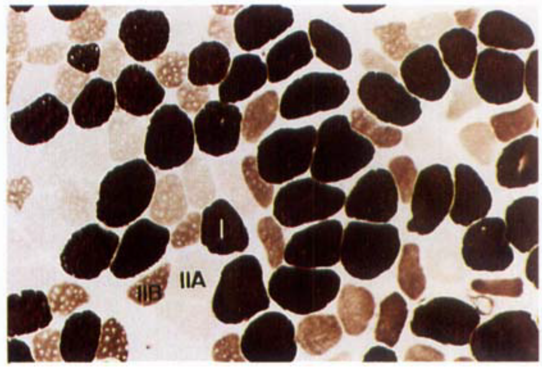

Figure 2. Normal third internal intercostal muscle demonstrates 40 percent of Type 1 (I), 25 percent of Type 2A (IIA), 25 percent of Type 2B (IIB) and 10 percent of Type 2C fibers. ×50.

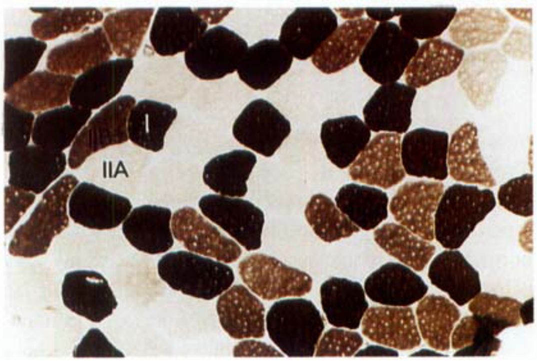

Figure 3. Normal biceps brachii muscle shows an evenly distributed checkerboard pattern of Type 1 (I) 39 percent, Type 2A (IIA) 34 percent and Type 2B (IIB) 27 percent. ×50.

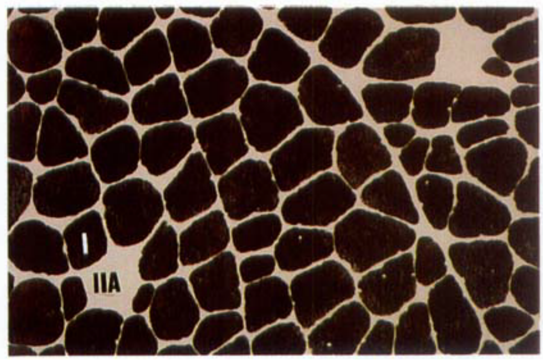

Figure 4. Case 5. Intercostally innervated biceps brachii muscle shows almost all Type 1 (I) and few Type 2A (IIA) fibers 9 years after intercostal cross-innervation to the musculocutaneous nerve. × 66.

tion, as the motor recovery was much better in the examined muscle. In the intercostal nerve transfer, the nerve fiber to innervate Type 1 muscle may be superior to that of Type 2 in neural regeneration, associated with Type 1 fiber predominance of the intercostal muscles.

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