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P Chalidapong; K Sananpanich; J Klaphajone
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Electromyographic comparison of various exercises to improve elbow flexion following intercostal nerve transfer

P. Chalidapong,
K. Sananpanich,
J. Klaphajone

From Faculty of Medicine, Chiang Mai University, Chiang Mai, Thailand

We compared the quantitative electromyographic activity of the elbow flexors during four exercises (forced inspiration, forced expiration, trunk flexion and attempted elbow flexion), following intercostal nerve transfer to the musculocutaneous nerve in 32 patients who had sustained root avulsion brachial plexus injuries. Quantitative electromyographic evaluation of the mean and maximum amplitude was repeated three times for each exercise. We found that mean and maximum elbow flexor activity was highest during trunk flexion, followed by attempted elbow flexion, forced inspiration and finally forced expiration. The difference between each group was significant ($p < 0.001$), with the exception of the difference between trunk flexion and attempted elbow flexion. Consequently, we recommend trunk flexion exercises to aid rehabilitation following intercostal nerve transfer.

Following a brachial plexus injury there are several nerve repair techniques that can partially restore function in the post-ganglionic lesion. However, successful nerve repair is not possible in a pre-ganglionic injury because the spontaneous recovery of nerve function is unlikely[1,2] and the success in avulsed nerve re-implantation limited.[3]

Nerve transfer can be used to restore motor power in the pre-ganglionic lesion. Yeoman and Seddon[4] introduced intercostal nerve transfer for restoration of biceps brachii function. The concept encouraged many surgeons to perform direct intercostal nerve suture or interposition with graft. They also tried other donor nerves, such as the spinal accessory,[5] the thoracodorsal,[6] some fascicles of the ulnar,[7,8] the phrenic,[9] the contralateral C7 root,[10] the medial pectoral[11] and the hypoglossal.[12] Nerve transfer procedures are widely accepted after root avulsion, especially for biceps brachii function.[13-19]

A semi-quantitative meta-analysis showed that intercostal nerve transfer to the musculocutaneous nerve, without interposition graft, achieved a power of elbow flexion ≥ Medical Research Council (MRC) grade 3 in 72% of patients.[20] Biceps brachii recovered in the majority of the patients studied, after third and fourth intercostal nerve transfer to motor branches of the musculocutaneous nerve, which supply the long and short heads of biceps brachii.[15] Pulmonary function deficit after intercostal nerve transfer was less than after phrenic nerve transfer.[21] The efferent activity of reinnervated biceps brachii by intercostal nerve transfer is relatively well-known.[18,22,23] The functions of the intercostal muscles are respiratory activity (external part for inspiration and internal for expiration)[22-27] and trunk flexion.[28] In spite of many studies on intercostal nerve transfer, there is no consensus on the most appropriate rehabilitation programme following the procedure.

We used quantitative electromyography (EMG) to compare four different exercise patterns during re-innervation, namely facilitatory effect of forced inspiration, forced expiration, trunk flexion and attempted elbow flexion.

Patients and Methods

Between December 2003 and February 2005, 32 patients, 29 men and three women, with a mean age of 25.56 years (18 to 40) underwent third and fourth intercostal nerve transfer to the nerve of the elbow flexor (31 biceps brachii and one free vascularised gracilis). The reinnervated elbow flexor muscles had to have motor power of at least MRC 1. Only patients eligible for quantitative electromyographic examination were included. The median assessment period was 389.5 days (mean 437; 165 to 1065) post-operatively. Each patient was asked to flex the affected elbow by attempting four exercise patterns including forced inspiration, forced expiration, trunk flexion, and to attempt flexion of the elbow, the extent of the latter being decided by each patient. The sequence of the four exer-

▪ P. Chalidapong, BSc, MD, Associate Professor
▪ K. Sananpanich, MD, Assistant Professor
Department of Orthopaedics
▪ J. Klaphajone, MD, Assistant Professor
Department of Rehabilitation Medicine
Faculty of Medicine, Chiang Mai University, Chiang Mai 50200, Thailand.

Correspondence should be sent to Dr P. Chalidapong; e-mail: pchalida@mail.med.cmu.ac.th

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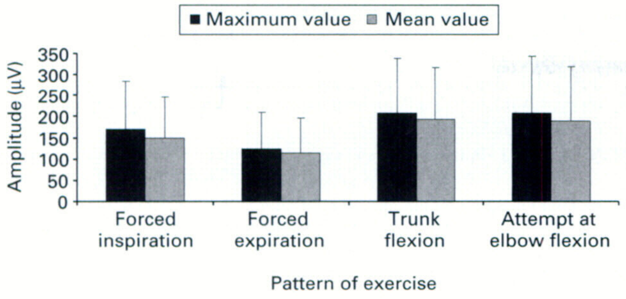

Fig. 1

The electromyographic amplitudes of the reinnervated elbow flexor muscle during the performance of four patterns of exercise.

Table I. The methods, chosen by the patients, by which elbow flexion was attempted

Method	Number of patients
1. Willing the elbow to flex	2
2. Forced inspiration	8
3. Forced expiration	0
4. Trunk flexion	6
5. Other methods*	6
6. Combinations†	10

* holding the breath, contraction of pectoralis
† combined activities of two or more of the above

cise patterns was random. There were three repetitions of each, in which flexion was held for three seconds, with a rest of at least 20 seconds between attempts.

If flexor strength was above MRC 1, the forearm was fixed, in order to avoid possible disturbance of the EMG signal. We used the Medtronic (Dantec) (Medtronic Functional Diagnostics A/S, Skovlunde, Denmark) EMG machine as well as a concentric needle to capture the muscle action potential of the elbow flexor. The ground electrode was placed on the lateral aspect of the upper arm. The needle was inserted 10 cm proximal to the line connecting the medial and lateral epicondyles in full elbow extension. For the last two seconds of each repetition of an exercise, an epoch length of the EMG signal was selected for analysis using the root-mean-square method. The maximum and mean activity for each exercise was calculated. Statistical analysis was repeated by analysis of variance. A p value of < 0.05 was considered to be significant.

Results

Figure 1 shows the mean and maximum EMG amplitude of the biceps brachii calculated from three repetitions of each exercise, in which there was no significant difference. The maximum EMG activities were 207.9 μV (SD 130.8) for trunk flexion, 207 μV (SD 135.9) for the attempt at flexion of the elbow, 171.0 μV (SD 112.6) for forced inspiration and 123.1 μV (SD 87.9) for forced expiration. The highest EMG activity was detected during the trunk flexion and the attempt at flexion of the elbow, but there was no statistically significant difference between them ($p = 0.97$). The forced inspiration exercise elicited significantly more EMG activity than the forced expiration ($p = 0.0003$).

The activities decided by the patient when attempting to flex the elbow are shown in Table I.

Discussion

An intercostal nerve is the anterior branch of a thoracic spinal nerve, which supplies the external intercostal, internal intercostal and transversus thoracis muscles.[29] It contains approximately 1200 to 1300 myelinated fibres, of which 40% are motor types. Up to 10% of these are lost with each 10 cm of distal progression from mid axillary line to the sternum.[30] Some investigators claim that the percentage of motor fibres in the third to seventh intercostal nerve is 30% and remains relatively constant over a large distance from the mid axillary line.[31] Inspiration is performed by the external intercostal muscle and expiration by the internal. However, the parasternal part of the latter is electrically active during inspiration[32] while the transversus thoracic muscle is active during expiration.[33] When changing posture from supine to upright, or during flexion and rotation of the rib cage, the external and internal intercostal muscles are agonists.[24,28] Our study shows that trunk flexion is a promising exercise in initial rehabilitation after intercostal nerve transfer to the nerve of the elbow flexor.

Our philosophy for the post-operative period includes psychological support, the reacquisition of voluntary control of elbow flexion and improvement in the three basic performance parameters of the muscle, namely movement, strength and endurance. The efficiency of muscle function depends partly on the number of cross linkages between the myosin and actin monofilaments. It appears that not only the abundance of myosin and actin molecules, but also the frequency of stimulus builds these cross linkages. The reinnervated contraction is apparently related to respiration in the early post-operative period, while two to three years later the muscle becomes capable of independent voluntary contraction. However, most patients who regain voluntary elbow flexion continue to show respiratory EMG activity related to strenuous movement of the thoracic cage (e.g. coughing and sneezing).[34]

There is evidence that the control of reinnervated muscles changes with time and involves ‘rewiring’ of the central nervous system. However, it is not known how, or to what extent this plasticity of the central nervous system occurs.[35-38] In the initial period after intercostal nerve transfer, we questioned whether inspiration or expiration was better for voluntary elbow movement and recovery of muscle strength. Although large EMG activity of elbow flexion was present on expiration and produced more muscle strength, our study showed that forced inspiration achieved higher mean and maximum values of quantitative EMG activity than forced expiration, but both were significantly less than

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trunk flexion. The difference in the mean and maximum values between trunk flexion and attempted elbow flexion was hardly perceptible.

Respiratory activity is minimal in quiet breathing, but increases with increasing ventilation. This can be enhanced by carbon dioxide stimulation and inspiratory mechanical loading.[39] Deliberate inspiratory efforts tend to make more use of the inspiratory intercostal muscle than involuntary carbon dioxide-stimulated inspiration.[24] These two techniques of rehabilitation consist of re-breathing carbon dioxide using a paper bag and wearing an elastic thoracic corset to increase inspiratory effort.[29] Our study suggests that patients can benefit from trunk flexion exercises without using such rehabilitation equipment.

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