J Rehabil Med 2006; 38: 32–36

Taylor & Francis
Taylor & Francis Group

EFFECT OF NEUROMUSCULAR ELECTRICAL STIMULATION ON COUGH CAPACITY AND PULMONARY FUNCTION IN PATIENTS WITH ACUTE CERVICAL CORD INJURY

Pao-Tsai Cheng, Chia-Ling Chen, Chin-Man Wang and Chia-Ying Chung

From the Department of Physical Medicine and Rehabilitation, Chang Gung Memorial Hospital, Chang Gung University, Tao-Yuan, Taiwan

Objective: **To assess the effectiveness of neuromuscular electrical stimulation (NMES) on cough capacity and prevention of pulmonary complication in patients with acute cervical cord injury.**

Design: **A randomized controlled trial.**

Subjects: **Twenty-six tetraplegic patients with cervical spinal cord injury, 13 in the NMES therapy group and 13 in the control group.**

Methods: **NMES was applied to the clavicular portion of the pectoralis major and abdominal muscle. Pulmonary function tests were performed before and after therapy, and at 3 months and 6 months follow-up. The pulmonary complications in this 6-month follow-up period were also recorded.**

Results: **After the 4-week therapy, and at 3 months and 6 months follow-up testing, patients in the NMES therapy group displayed significant improvement in their peak expiratory flow, forced expiratory volume in 1 second, forced vital capacity, maximal expiratory pressure and maximal inspiratory pressure, compared with those in the control group ($p < 0.05$). Patients in the NMES therapy group also had fewer pulmonary complications in the follow-up period.**

Conclusion: **NMES over the pectoralis and abdominal muscles might improve cough capacity and pulmonary function in cervical spinal cord injury with tetraplegia. This improvement might last for 6 months. With this improvement, pulmonary complications were reduced.**

Key words: neuromuscular electrical stimulation, cervical spinal cord injury, randomized controlled trial, tetraplegia, cough capacity, pulmonary function, pulmonary complication.

J Rehabil Med 2006; 38: 32–36

Correspondence address: Pao-Tsai Cheng, Department of Physical Medicine and Rehabilitation, Chang Gung Memorial Hospital, 5 Fu-Hsing St, Kuei-Shan Hsiang, Tao-Yuan, Taiwan. E-mail: ptcheng@adm.cgmh.org.tw

Submitted December 17, 2004; accepted May 23, 2005

INTRODUCTION

Respiratory problems are a major cause of mortality in both acute and chronic cervical spinal cord injures (CSCI) (1). Respiratory problems in tetraplegic patients may be caused by loss of control of abdominal muscles, intercostal muscles and a partial or complete loss of diaphragmatic function. Interventions to strengthen respiratory muscles, including abdominal weight training, incentive spirometry, face masks, positive pressure trainers and resistive inspiratory muscle training, have been used to improve the pulmonary function of tetraplegic patients (2–7). However, the effect of respiratory muscle training on pulmonary function of patients with CSCI has differed markedly.

McMichan et al. (8), using serial pulmonary function testing, found that there was a greater compromise of expiration than inspiration with time in patients with tetraplegia. Lack of abdominal and chest wall expiratory muscle activity diminishes ability to cough and clear secretions (9). Since ineffective coughing and retention of secretions are the main causes of pulmonary complications such as atelectasis and bronchopulmonary infections in patients with tetraplegia (10), strategies to enhance the effectiveness of coughing and thus improve clearance of bronchial secretions in the acute stage of CSCI are important.

De Troyer et al. (11) observed that active expiration in patients with tetraplegia depends largely on the clavicular portion of the pectoralis major. Consequently, they suggested designing specific training programs to increase the strength and endurance of these muscle bundles. Estenne et al. (12) reported that isometric exercise training of the clavicular portion of the pectoralis major muscle might improve expiratory function as well as cough capacity for tetraplegic patients. Braun et al. (13) in their study showed a 13.8% increase in peak flow when using the abdominal push assist. Kirby et al. (14) reported improved coughing by manual compression or positive pressure ventilation. Other authors (15–17) used functional electrical stimulation to the abdominal wall muscles of their patients with tetraplegia, showed that electrical stimulation of abdominal muscles associated with abdominal binder could improve cough capacity.

Neuromuscular electrical stimulation (NMES) is a method of applying safe levels of electric current to activate the damaged or disabled nervous system. Functional uses of NMES following spinal cord injury include application in standing, walking, hand grasp, respiratory assist, bladder, bowel and sexual function. This study was designed to establish whether cough efficacy and pulmonary function could be improved through application of NMES to the pectoralis major and abdominal

 ISSN 1650-1977
DOI: 10.1080/16501970510043387

muscles of tetraplegic patients. The effects of NMES on avoidance of pulmonary complications in patients with CSCI were evaluated.

METHODS

Twenty-six patients with traumatic cervical cord injury, 13 in the NMES-therapy group and 13 in the control group, finished the follow-up examination and were enrolled for final analysis. All subjects had suffered complete tetraplegia, as defined by the American Spinal Cord Injury Association (ASIA) adaptation of Frankel classification A and B, with lesion level between the fourth and seventh cervical cord. The duration of CSCI was within 3 months. Patients with primary lung disease (identified from history, physical examination and chest X-ray), cardiovascular problem, evidence of abdominal pathology, head injury with mental illness, presence of respiratory failure with tracheostomy or ventilator were disqualified from this study. Following the principle of simple block randomization, subjects were put into the NMES therapy group or control group. Each patient gave their informed consent in writing following an explanation of all processes.

Procedures

Control group patients underwent a conventional rehabilitation program for spinal cord injury, such as passive range of motion, mattress exercise, sitting balance or upper extremity functional training. Patients in the NMES therapy group underwent the conventional program plus NMES therapy. Surface electrodes were applied over the motor points of the clavicular portion of the bilateral pectoralis and abdominal muscles. An electrode was placed on the abdominal wall near the umbilicus of each patient and the stimulation intensity adjusted to cause muscle contraction. Then the electrode was moved to the other area near the umbilicus, and if more prominent muscle contractions were noted with the same stimulation intensity, the stimulation intensity was decreased to the level that still could induce muscle contractions. The electrode was moved and the stimulation intensity changed around the near area of the umbilicus to determine the location where muscle contractions could be seen when applying the smallest stimulation intensity. This was called "maximal muscle contractions". During NMES, the electrodes were applied to the location where maximal muscle contractions could be observed. This location was usually on the abdominal wall 3 cm from the umbilicus, although it differed slightly among patients. Electrical impulses were conducted using 2 commercially available neuromuscular stimulators (Respond Select Neuromuscular Stimulator, EMPI Inc., St Paul, Minnesota, USA). The pulse frequency, duration, waveform and duty cycle are important parameters. The device delivered symmetrical biphasic waveform stimulation at a frequency of 30 Hz with a pulse width of 300 μseconds. Rise time of the waveform was 0.5 seconds and on/off time was set at 4 seconds/4 seconds. Output from the stimulation device was current-regulated, from 0 to 100 mA. The stimulus intensity was adjusted to the patient muscle contractions and patient could tolerate it well. Patients received NMES therapy for 30 minutes daily, 5 days a week for 4 weeks.

Pulmonary function parameters including vital capacity (VC), forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), and peak expiratory flow (PEF) were obtained by using a High-Grade Spirometer (Chest Graph HI-701, CHEST, MI, Inc. 3-6-10, Tokyo, Japan). Maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) indicating the strength of inspiratory and expiratory muscles were measured by the Micro Medical mouth pressure meter (Micro Medical Limited 2001, Rochester, UK). The MIP was measured following exhalation to residual volume, and the MEP was measured following inspiration to total lung capacity. In this study, the pulmonary function test was performed by the same tester who did not know which patient had received NMES treatment. Because effective execution of this test necessitated learning, failure to instruct the subject to perform optimally would result in spurious data. The measuring processes were described and 3 trials with adequate rest between tests were performed for each measure. The best values were gathered for data analysis. These measurements were performed with the patient lying in a supine position. To investigate the effectiveness of NMES therapy on pulmonary function in patients with tetraplegia during the acute CSCI period, a pulmonary function test including VC, FVC, FEV1, PEF, MIP and MEP was performed before and after the 4 weeks therapy and at 3- and 6-month follow-up. At the 6-month follow-up, patients were asked about frequency and severity of pulmonary complications throughout this period. Pulmonary complication was defined as any kind of bronchopneumonia or atelectasis. Bronchopneumonia or atelectasis was diagnosed if the chest X-film showed pneumonic patches, increasing infiltrations or atelectasis. Clinically, patients had symptoms such as dyspnoea, profuse sputum or fever that needed antibiotics and intensive chest care including sputum suction, oxygen inhalation and bronchodilator treatment.

Data analysis

The physical characteristics of the NMES therapy and control group were analysed by unpaired t-test. To determine the effectiveness of NMES on pulmonary function in the 2 groups (NMES therapy and control) and at 4 time points (pre-therapy, post-therapy, 3-month and 6-month follow-up), a repeated measures data analysis was performed using a repeated measures analysis of variance by PC-SAS (version 8.1). If a time effect was observed, *post-hoc* paired sample t-tests determined in which testing sessions the difference lay. Differences in pulmonary complication occurrence between the NMES therapy and control groups were compared with a chi-square test. The level of significant difference was set at $p < 0.05$.

RESULTS

Clinical characteristics of subjects in the NMES therapy and control groups are displayed in Table I. No significant difference was found between these 2 groups regarding age, sex, duration of CSCI, body height or body weight. All patients demonstrated a decreased flow and volume in the first testing. The mean PEF of patients with tetraplegia was 36% of prediction in the control group and 33% of prediction in the NMES therapy group. The VC and FVC were around 39% of predicted value in each group, while FEV1 was around 50% of predicted value in both groups. The mean MEP value was approximately 310 mmH_2O and MIP was 390 mmH_2O in each group.

The effectiveness of NMES therapy on pulmonary function in patients with tetraplegia is presented in Table II. Significant improvements were found in the VC, FVC, FEV1, PEF, MIP and MEP in the NMES therapy group after 4 weeks therapy, and at 3-month and 6-month follow-up testing, $p < 0.05$.

The pulmonary complication occurrence among patients in the NMES therapy group had reduced at the 6-month follow-up. Six (46.1%) of the 13 patients in the control group suffered pulmonary complications in the follow-up period, while only 1 (7.7%) of the 13 patients in the NMES therapy group had pulmonary complications during this period ($p < 0.05$). Of the 6

Table I. *Clinical characteristics of subjects in the neuromuscular electrical stimulation therapy and control groups given as means (SD)*

	Training group	Control group
Age (years)	34.7 (12.5)	38.8 (14.9)
Sex M/F (n)	11/2	10/3
Height (centimetre)	167.9 (6.2)	164.0 (7.9)
Weight (kg)	61.7 (11.0)	59.7 (7.5)
Duration of injury (months)	2.4 (0.7)	2.5 (0.8)

Table II. *Comparison of neuromuscular electrical stimulation (NMES) therapy group and control group at different assessment times given as mean values*

	Pre-NMES		Post-NMES		3-month follow-up		6-month follow-up		
	NMES	Control	NMES	Control	NMES	Control	NMES	Control	*p*
VC (1)	1.74	1.79	2.29	1.85	2.45	1.93	2.49	2.08	0.004
(SD)	(0.6)	(0.5)	(0.7)	(0.5)	(0.6)	(0.5)	(0.6)	(0.5)	
VC (%pred)	37.6	39.5	45.6	40.2	48.1	41.3	48.7	44.0	0.006
(SD)	(10.4)	(9.1)	(14.6)	(8.2)	(14.1)	(9.5)	(13.1)	(10.7)	
FVC (1)	1.71	1.79	2.26	1.82	2.42	1.91	2.51	1.99	0.003
(SD)	(0.6)	(0.6)	(0.7)	(0.6)	(0.6)	(0.6)	(0.5)	(0.5)	
FVC (%pred)	37.1	39.2	45.0	39.9	47.9	40.2	49.5	42.4	0.002
(SD)	(10.1)	(9.6)	(12.2)	(9.3)	(12.9)	(10.4)	(13.3)	(10.8)	
FEV1 (1/s)	1.78	1.74	2.0	1.74	2.19	1.75	2.30	1.77	0.011
(SD)	(0.7)	(0.8)	(0.7)	(0.8)	(0.8)	(0.8)	(10.1)	(0.9)	
FEV1 (%pred)	50.7	48.9	56.4	48.4	62.2	49.4	64.9	49.5	0.009
(SD)	(8.6)	(9.2)	(9.6)	(9.1)	(10.2)	(9.7)	(10.7)	(10.4)	
PEF (1/s)	2.96	2.91	3.93	2.90	4.18	3.11	4.24	3.17	<0.001
(SD)	(0.8)	(0.8)	(0.9)	(0.7)	(0.9)	(0.8)	(0.8)	(0.8)	
PEF (%pred)	33.7	36.3	43.7	36.1	46.9	40.4	48.0	41.1	<0.001
(SD)	(9.6)	(8.7)	(11.4)	(8.5)	(10.7)	(8.1)	(8.8)	(9.0)	
MIP (mmH_2O)	395	395	492	410	528	471	548	483	0.016
(SD)	(102)	(79)	(107)	(68)	(117)	(78)	(117)	(103)	
MEP (mmH_2O)	308	315	398	331	441	350	466	388	<0.001
(SD)	(91)	(61)	(93)	(61)	(88)	(66)	(76)	(75)	

VC = vital capacity; FVC = forced vital capacity; FEV1 = forced expiratory volume in 1 second; PEF = peak expiratory flow.
% pred = percentage of predicted value.

patients with pulmonary complications in the control group, 1 underwent tracheotomy and ventilator.

DISCUSSION

Secretion control is crucial in pulmonary management to prevent atelectasis and pneumonia. Cough is principally a forced expiratory act providing the high linear velocity to expel mucus and any foreign particles from the larynx, trachea and larger bronchi (18). Improving the cough ability of patients with tetraplegia may enhance their pulmonary function, consequently preventing lung complications. A previous study (19) found that the greatest rise in mortality appears in the initial 6–12 months following trauma. After the first 1–2 years, the mortality curve parallels that of average individuals. To reduce the pulmonary complication and mortality rate, this work was restricted to acute patients with CSCI injured within 3 months.

FVC measures the maximal volume output of the respiratory system. As such, the FVC reflects the integrity of all components involved with pulmonary mechanism. FVC is also a reliable indicator of cough effectiveness because the peak flow during the cough is comparable with the mean peak flow in a FVC test (13). FEV1 is known to depend primarily on the strength of the expiratory muscles and the diameter of the upper airways. FEV1 values were used to evaluate how much the functioning of expiratory muscles was preserved and also indirectly assess the capacity to expectorate. PEF is determined by vital capacity, strength of expiratory muscle and function of oropharyngeal muscle. The increased PEF suggests a better cough ability, thereby improving the capacity of individuals with CSCI to eliminate bronchial secretion, possibly preventing respiratory complications. Kelly & Luce (20) reported that the most sensitive indicator of respiratory impairment due to neuromuscular disorders is the MEP. Therefore, this study measured the VC, FVC, PEF, FEV1, MIP and MEP as indicators of cough capacity for patients with tetraplegia.

The abdominal muscles are powerful muscles for expiration, playing an important role in functions such as forced expiration and coughing (21). When the abdominal muscles contract, they pull the abdominal wall inward, creating an increase in intra-abdominal pressure. This moves the diaphragm cranially into the thoracic cavity, a displacement that results in increased pleural pressure and a decrease in lung volume. When a tetraplegic patient was asked to expire forcefully, or to cough, little force was noticed because of the paralysed chest wall and abdominal muscles. Expiratory muscle weakness impairs cough-induced dynamic compression and the linear velocity of airflow through the large intrathoracic airways. Consequently, the effectiveness of cough is severely reduced in tetraplegic patients. Linn et al. (22), surveying 222 spinal cord injury patients, found that the typical pulmonary function loss associated with complete motor lesions at C5 and above was around half of normal control for FVC, FEV1 and PEF rate. VC was commonly between 1.2 and 1.5 l following CSCI (23). Patients with CSCI had an MEP of less than 30% of that in normal control persons (8, 13). Similar to their findings, the mean VC, FVC, PEF and FEV1 of the patients with tetraplegia in the present study were around one-third to one-half the predicted value. The MIP and MEP value was less than 400 mmH_2O (around 30% of that in normal controls).

The clavicular portion of the pectoralis major plays a crucial part in the mechanism of active expiration in patients with

tetraplegia (11). Patients with tetraplegia with neurological level at C5 or below cough mainly by contracting the clavicular portion of their pectoralis major (11, 24), however, pectoralis muscle exercises would not be possible in patients with CSCI with an injury level at or above the fourth cervical (C4) neurological level. The application of NMES on the pectoralis major muscle could cause muscle contractions, enable these subjects to generate greater intrathoracic pressure swing during coughing and hence clear bronchial secretions from more peripheral airways. Alternatively, where the abdominal and intercostal muscles are totally paralysed in tetraplegic patients with CSCI, NMES could assist abdominal muscle contractions, enabling patients with tetraplegia to compromise their deficits.

Several important parameters can be adjusted when performing NMES. These adjustments include pulse amplitude, duration, frequency, duty cycle and waveform. Monophasic stimulation, wherein ion flow is unidirectional, is generally not appropriate for long-term use because it can cause electrode and tissue breakdown. Therefore, we used symmetric biphasic waveform for NMES treatment. As for the stimulus frequency, most training regimens with low-frequency stimulation increases muscle endurance. Increasing pulse frequency provided for temporal summation of force output. A frequency of 50 Hz or higher resulted in an increase in the power-generating ability of a muscle. Stimulation at these frequencies theoretically improved muscle power, but when delivered without adequate rest levels might result in premature muscle fatigue. For most applications, it is desirable to have a fused or tetanic muscle contraction. This contraction occurred physiologically at 20–30 Hz (25). In this study, NMES was set at 30 Hz, with a pulse width of 300 μseconds, for increasing both muscle strength and endurance.

Previous authors (15–17) applied functional electrical stimulation to the abdominal wall muscles of their patients with tetraplegia and demonstrated that functional electrical stimulation of abdominal muscles associated with abdominal binder could improve cough. Estenne et al. (12) reported that isometric exercise training of the clavicular portion of the pectoralis major muscle daily for 6 weeks may improve expiratory function as well as cough capacity for tetraplegic patients. They demonstrated that PEF and MEP of their patients improved following training. Crane et al. (26) observed that the mean FVC for subjects not experiencing complications was greater than those developing complications, and concluded that FVC was an important predictor of respiratory difficulties. Herein, the present study results conformed to their findings. Through NMES application to the pectoralis muscle and abdominal muscles, patients in the therapy group exhibited significant improvement in the VC, FVC, FEV1, PEF, MIP and MEP. With this improvement, patients could enhance cough ability, reduce retention of bronchial secretion, and therefore avoid pulmonary complications. Findings in this study that patients in the NMES therapy group had noticeably fewer pulmonary complications during the follow-up period further proved the effects of NMES training.

One may contend that NMES induced muscle contraction in completely paralysed abdominal muscles is sustainable following withdrawal of NMES. According to Sherwood et al. (27) and Dimitrijevic et al. (28), the term "discomplete" denoted the clinically defined complete absence of motor function with or without partial preservation of sensory functions, but with subclinical evidence for residual brain influence on spinal motor activity below the level of the spinal lesion. Furthermore, subjects in the trained group developed more motivation, paying more attention to the pectoralis muscle exercise. As a result, they may have continued to use the muscle more frequently and more strongly after the end of the therapy period and maintained increased muscle strength and endurance developed by the NMES therapy program.

The present study concluded that cough efficacy was significantly lowered and related to VC, FVC, FEV1, PEF, MEP and MIP in patients with CSCI with tetraplegia. The findings in this study implied that NMES over the pectoralis and abdominal muscles might improve the cough capacity in CSCI patients with tetraplegia. This subjectively and objectively related cough efficacy improved significantly and lasted for 6 months following therapy cessation. With this improvement, patients might be able to perform daily activities better and lower pulmonary complications. These findings provided important therapeutic implications. However, the sample size was quite small in this study and further study with a larger sample size is needed to obtain a more convincing result. Further investigation could involve assessing the effects of the new NMES patterns when combined with exercise for patients with CSCI.

ACKNOWLEDGEMENTS

We thank the National Science Council of the Republic of China, Taiwan for financially supporting this research under Contract No. NSC 91-2314-B-182A-147.

REFERENCES

1. DeVivo M, Kartus P, Stover S, Rutt R, Fine P. Cause of death for patients with spinal cord injuries. Arch Intern Med 1989; 149: 1761–1766.
2. Lin KH, Chung CC, Wu HD, Chang CW, Kou YR. Abdominal weight and inspiratory resistance: their immediate effects on inspiratory muscle function during maximal voluntary breathing in chronic tetraplegic patients. Arch Phys Med Rehabil 1999; 80: 741–745.
3. Gross D, Ladd HW, Riley EJ, Macklem PT, Grossino A. The effect of training on strength and endurance of the diaphragm in tetraplegia. Am J Med 1980; 68: 27–35.
4. Biering-Sorenson F, Lehmann Knudsen J, Schmit A, Bundgaard A, Christensen I. Effects of respiratory training with a mouth-nose-mask in tetraplegics. Paraplegia 1991; 29: 113–119.
5. Loveridge B, Badour M, Dubo H. Ventilatory muscle endurance training in quadriplegia: effects on breathing pattern. Paraplegia 1989; 27: 329–339.
6. Rutchik A, Weissman AR, Almenoff PL, Spungen AM, Bauman WA, Grimm DR. Resistive inspiratory muscle training in subjects with chronic cervical spinal cord injury. Arch Phys Med Rehabil 1998; 79: 293–297.

7. Liaw MY, Lin MC, Cheng PT, Wong MK, Tang FT. Resistive inspiratory muscle training: its effectiveness in patients with acute complete cervical cord injury. Arch Phys Med Rehabil 2000; 81: 752–756.
8. McMichan JC, Michael L, Westbrook PR. Pulmonary dysfunction following tetraplegia: recognition, prevention and treatment. JAMA 1980; 243: 528–531.
9. Saltzstein R, Melvin J. Ventilatory compromise in spinal cord injury – a review. J Am Paraplegia Soc 1986; 9: 6–9.
10. Wetzel J, Lunsford BR, Peterson MJ, Alvarez SE. Respiratory rehabilitation of the patient with spinal cord injury. In: Irwin S, Tecklin JS, eds. Cardiopulmonary physical therapy. St. Louis, MO: Mosby; 1990, pp. 579–603.
11. De Troyer A, Estenne M, Heilporn A. Mechanism of active expiration in tetraplegic subjects. N Engl J Med 1986; 314: 740–744.
12. Estenne M, Knoop C, Vanvaerenbergh J, Heilporn A, De Troyer A. The effect of pectoralis muscle training in tetraplegic subjects. Am Rev Respir Dis 1989; 139: 1218–1222.
13. Braun SR, Giovannoni R, O'Connor M. Improving the cough in patients with spinal cord injury. Am J Phys Med Rehabil 1984; 63: 1–10.
14. Kirby NA, Barnerias MJ, Siebens AA. An evaluation of assisted cough in quadriparetic patients. Arch Phys Med Rehabil 1966; 47: 705–710.
15. Linder SH. Functional electrical stimulation to enhance cough in quadriplegia. Chest 1993; 103: 166–169.
16. Jaeger RJ, Turba RM, Yarkony GM, Roth EJ. Cough in spinal cord injured patients: comparison of three methods to produce cough. Arch Phys Med Rehabil 1993; 74: 1358–1361.
17. Lin KH, Lai YL, Wu HD, Wang TQ, Wang YO. Effect of an abdominal binder and electrical stimulation on cough in patients with spinal cord injury. J Formos Med Assoc 1998; 97: 292–295.
18. Fuller RW, Jackson DM. Physiology and treatment of cough. Thorax 1990; 45: 425–430.
19. DeVivo MJ, Black KJ, Stover SL. Causes of death during the first 12 years after spinal cord injury. Arch Phys Med Rehabil 1993; 74: 248–254.
20. Kelly B, Luce JM. The diagnosis and management of neuromuscular disease causing respiratory failure. Chest 1991; 99: 1485–1494.
21. DeTroyer A, Deisser P. The effects of intermittent positive pressure breathing on patients with respiratory muscle weakness. Am Rev Respir Dis 1981; 124: 132–137.
22. Linn WS, Adkins RH, Gong H, Waters RL. Pulmonary function in chronic spinal cord injury: a cross-sectional survey of 222 Southern California adult outpatients. Arch Phys Med Rehabil 2000; 81: 757–763.
23. Mansel JK, Norman JR. Respiratory complications and management of spinal cord injuries. Chest 1990; 97: 1446–1452.
24. Estenne M, De Troyer A. Cough in tetraplegic subjects: an active process. Ann Intern Med 1990; 112: 22–28.
25. Gorman PH. An update on functional electrical stimulation after spinal cord injury. Neurorehabil Neural Repair 2000; 14: 251–263.
26. Crane L, Klerk K, Ruhl A, Warner P, Ruhl C, Roach KE. The effects of exercise training on pulmonary function in patients with quadriplegia. Paraplegia 1994; 32: 435–441.
27. Sherwood AM, Dimitrijevic MR, McKay WB. Evidence of subclinical brain influence in clinically complete spinal cord injury: discomplete SCI. J Neurol Sci 1992; 110: 90–98.
28. Dimitrijevic MR, McKay WB, Sherwood AM. Motor control physiology below spinal cord injury: residual volitional control of motor units in paretic and paralyzed muscles. In: Seil FJ, ed. Advances in neurology, vol. 72: neuronal regeneration, reorganization and repair. Philadelphia: Lippincott-Raven Publishers; 1997, pp. 335–345.