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

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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.


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INTRODUCTION

Respiratory problems are a major cause of mortality in both acute and chronic cervical spinal cord injuries (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...
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 exercise cycle 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 stimulus intensity were controlled by the subject. The pulse duration was 0.5 seconds and the 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. 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 predicted value in each group, while FEV1 was around 50% of predicted value in both groups. The VC and FVC were around 33% of predicted value in the control group and 30% of predicted value in the NMES therapy group. The VC and FVC were around 30% of predicted value in each group, while FEV1 was around 50% of predicted value in both groups. The mean MEP value was approximately 310 mmH2O and MIP was 390 mmH2O in each group.

**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 mmH2O and MIP was 390 mmH2O 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, MEP and MIP 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>
<thead>
<tr>
<th>Age (years)</th>
<th>Training group</th>
<th>Control group</th>
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<tbody>
<tr>
<td>34.7 (12.5)</td>
<td>38.8 (14.9)</td>
<td></td>
</tr>
<tr>
<td>Sex M/F (n)</td>
<td>11/2</td>
<td>10/3</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>167.9 (6.2)</td>
<td>164.0 (7.9)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>61.7 (11.0)</td>
<td>59.7 (7.5)</td>
</tr>
<tr>
<td>Duration of injury (months)</td>
<td>2.4 (0.7)</td>
<td>2.5 (0.8)</td>
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patients with pulmonary complications in the control group, I 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 that in normal controls (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...
tетраплегии (11). У пациентов с тетраплегией с неврологическим уровнем на уровне C5 или ниже недостаточного кашля и pri sеtт on the clavicular portion of their pectoralis major (11, 24), however, pectoralis muscle exercises would not be possible in patients with CSCI at 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, MEP and MIP 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.

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