Resistive Inspiratory Muscle Training in Sleep-Disordered Breathing of Traumatic Tetraplegia

Tyng-Guey Wang, MD, Yen-Ho Wang, MD, Fu-Tan Tang, MD, Kwan-Hwa Lin, PhD, PT, I-Nan Lien, MD


Objective: To assess the effect of resistive inspiratory muscle training (RIMT) on the static pulmonary function and sleep-induced breathing disorder of individuals with chronic cervical cord injury.

Design: Before-after training.

Setting: Home-setting training program.

Patients: Fourteen complete traumatic tetraplegic patients (12 men, 2 women; mean age, 41.1 ± 14y; range, 19–56y) injured for more than 6 months.

Intervention: Subjects participated in a 6-week RIMT program for 15 minutes twice daily at a training intensity of 60% of maximum inspiratory pressure (MIP). The participants were reevaluated at the end of 6-week training.

Main Outcome Measures: Lung volume, peak expiratory flow (PEF), MIP, and maximum expiratory pressure (MEP) were measured by using a spirometry and inspiratory force meter, respectively. Capnography was used to monitor nocturnal pulse oxyhemoglobin saturation (SpO2) and end-tidal carbon dioxide tension level (ETCO2) of the patients.

Results: The maximum voluntary ventilation (MVV) and MIP of individuals with chronic cervical cord injury substantially improved after RIMT. MIP increased from −68.7 ± 27.0 cmH2O to −77.3 ± 24.0 cmH2O and MVV rose from 62.7 ± 33.2 L to 73.4 ± 31.3 L (P < .05). Despite increasing from 3.5 ± 1.8 L/s to 4.0 ± 1.7 L/s, PEF was statistically insignificant. For the individuals with improved MIP, the duration of ETCO2 greater than 48 mmHg reduced from 2.2% to 1.0% (12 men, 2 women; mean age, 41.1 ± 14y; range, 19–56y) injured for more than 6 months.

Conclusion: These findings suggest that RIMT can enhance the respiratory muscle strength and endurance of chronic tetraplegia and further ameliorate the sleep-induced breathing disorder. Therefore, RIMT is suggested as a home program for patients with sleep-disordered breathing.

Key Words: Exercise; Inspiratory capacity; Muscles; Pulmonary function tests; Rehabilitation; Sleep apnea, syndromes; Spinal cord injuries.

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METHODS

Participants

Fifteen patients with traumatic tetraplegia were chosen from outpatient clinics in 2 teaching hospitals. The criteria of participants in this study included complete traumatic tetraplegia (American Spinal Injury Association [ASIA], Frankel grades A or B) with lesion level between the third and seventh cervical cord, age of at least 18 years, no premorbid lung or heart disease, and no medical complications during evaluation. All patients were seen at least 6 months after injury, and they all showed neurologic, physical, and psychologic stabilization. Among them, only 14 patients (12 men, 2 women) completed the inspiratory muscle training program. The mean age of the subjects was 41.1 years (range, 19–56 years), and the mean duration of postinjury was 3.7 ± 4.7 years (range, 6 mo–17 y). Three patients had a C4 injury, 5 had a C6 lesion, and 6 had a C7 injury. The patient who quit the program did so because of a severe lung infection, which necessitated a tracheostomy to clear the airway secretion during training. The informed consent in accordance with the research protocol was obtained from each subject.

Lung Function Measurement

The lung function parameters (ie, forced vital capacity [FVC], forced expiratory volume in 1 second [FEV1], peak expiratory flow [PEF], maximal minute voluntary ventilation [MVV]) were measured before and after the inspiratory muscle training by a portable spirometry. The maximal value of several attempts in a sitting position was recorded. The percentage of normal prediction was calculated according to the normal value of Asians, which was provided by the manufacturer. Then, patients were asked to make a maximum inspiratory effort at functional residual capacity (FRC) against an occluded airway that was connected to an inspiratory force meter. The highest value of 5 to 7 trials was assumed to be the maximum inspiratory pressure (MIP) at FRC. The maximum expiratory pressure (MEP) was obtained in the same manner as the total lung capacity (TLC) level. MIP and MEP indicated the strength of respiratory muscle.

Nocturnal Breathing Status

SpO2 and end-tidal carbon dioxide (ETCO2) were simultaneously monitored by a capnography. The capnography was used to record data at 12-second intervals. The information of SpO2 was obtained by a finger sensor. The overnight mean, minimum SpO2, and percentage of sleep time when SpO2 was less than 95%, 90%, 85%, and 80% were calculated. The data can either be read directly on the machine or recorded in a memory card. Medical System provides software to analyze the details. Careful attention was paid to keep the pick-up finger warm.

To detect ETCO2, the capnography was recalibrated before each use and nasal prongs were used to sample expired air. In this study, ETCO2 was used to represent PaCO2. Although up to 3 mmHg greater than ETCO2 in people who spontaneously breathe normally, PaCO2 may be higher in individuals with intrinsic lung disease. Notably, the patients in this study showed no evidence of significant intrinsic lung disease that might cause hypercapnia. Another probable mismatching between the ETCO2 and PaCO2 in this study derives from the fact that the capnography-sampled air was exhaled only through the nostrils. Some subjects may occasionally exhale from the mouth instead of the nostrils during sleep. We assume that this should not have led to a significant difference among the subjects when comparing the initial and follow-up results at a 6-week interval on any particular subject unless the subject’s exhalation pattern had changed. The maximum nocturnal ETCO2 and the duration of ETCO2 above 40 and 48 mmHg during sleep were recorded. The patients were monitored by capnography for at least 2 nights. A complete study was considered to consist of at least 8 consecutive hours of nocturnal records with the nasal prongs and finger pick-up sensor securely in place.

Inspiratory Muscle Training Procedures

The inspiratory muscle training lasted 6 weeks and was performed by using a commercially available inspiratory muscle trainer. The device is composed of different colored plugs with various sized holes to obtain a specific resistance. Training resistance was set at 60% of MIP of initial evaluation. Once the specific training resistance was determined, a physiotherapist instructed each subject on use of the inspiratory muscle trainer. Training consisted of breathing through the inspiratory muscle trainer with a nose clip in place for 15 minutes twice daily. The program was conducted 6 days a week for 6 weeks at home. The patients were followed up at the end of the first week and then every 2 weeks thereafter to ensure the execution of training program.

Data Analysis

On completion of training, the patients underwent the same test protocol as in the pretraining test to evaluate the strength and endurance of the respiratory muscle and the nocturnal breathing status. All the parameters before and after training were statistically analyzed by a Student paired t test, in which a probability below .05 was considered significant.

RESULTS

Training Effect on Pulmonary Function

The lung function test revealed that the FVC and MIP of the patients reduced to around 60% of predicted normal, which indicated a moderate obstructive lung disease without an obvious obstructive component. Their expiratory muscles were also weaker than inspiratory muscles, and this was common among the patients with cervical cord injury. After 6 weeks of training, the mean MVV and MIP of the patients were significantly improved (P < .05), whereas the FVC and MEP remained nearly unchanged (table 1). Despite increasing from 3.5 ± 1.8 L/s to 4.0 ± 1.7 L/s, PEF did not achieve statistical significance. Improvements of MVV and MEP were around 10% of baseline data.

Training Effect on Nocturnal Breathing Status

All the monitoring parameters involving the nocturnal breathing status, eg, the mean and maximum ETCO2, mean and lowest SpO2, duration of abnormal high ETCO2 and low SpO2, did not differ after the training program (table 2). However, patients tended to improve in most of the parameters. Of the 14 patients, 8 had improved MEP, 7 had an elevated MVV, and 6 had an increased PEF. Comparing the nocturnal breathing status of the 8 subjects who had improved MEP, the result revealed a reduction of the duration of abnormal ETCO2 and SpO2 (table 3). The duration of ETCO2 above 48 mmHg reduced from 2.2% ± 3.3% to 1.0% ± 2.0% of total sleep time (P = .05) and the duration of SpO2 below 90% reduced from 1.8% ± 2.8% to 1.3% ± 2.4% of total sleep time (P < .05). Nevertheless, patients with either an increased PEF or MVV did not significantly differ in nocturnal breathing status before and after training (tables 4, 5).
DISCUSSION

This study showed that 6 weeks of regular RIMT increased respiratory muscle strength, endurance, and probably the ability of sputum clearance in individuals with chronic cervical cord injury. As shown in table 1, inspiratory muscle training increases the MIP and MVV, which represent the capacity of respiratory muscle strength, endurance, and probably the ability to improve respiratory muscles. RIMT-related studies have verified that respiratory muscles respond favorably to this training.

The effect of respiratory muscle training on pulmonary function of SCI patients has varied markedly in various studies.9-11,22-26 A study21 involving 6 patients with cervical cord injury indicated that FVC, MVV, PEF, and MIP significantly increased after 7 weeks of RIMT. In that study, MVV improved the most among all lung function parameters. Another study23 of 10 patients with tetraplegia revealed that PEF increased in value from 371L/min to 412L/min after 6 weeks of training period, but the other parameters of pulmonary function did not change. Rutchik et al24 found that regular RIMT in subjects with cervical cord injury significantly improved their FVC, TLC, FRC, and MIP but did not decrease the perception of dyspnea in a group of 10 patients. Theoretically, RIMT can improve MIP and MVV because the program directly strengthens the inspiratory muscle. FVC might also be improved because it can accurately reflect the strength of inspiratory muscle in individuals with normal lung compliance. Small groups of patients were used during most of the training program, and this may be the reason why different results were obtained. However, our study indicated that the MVV and MIP improved as expected, but FVC did not. This finding can be attributed to the following reasons. First, the patients in our study had been injured for a period ranging from 6 months to 17 years. The prolonged lack of full lung expansion might have impaired their pulmonary compliance. Under this circumstance, FVC no longer represents the inspiratory muscle strength. Second, the small size of the sample group might be also responsible for the stationary value of FVC.

Our results indicated a prominent increase of PEF, although no specific training was undertaken for the expiratory muscle. PEF was determined by vital capacity, strength of expiratory muscle, and function of oropharyngeal muscle. The subjects in our study were asked to breathe by mouth and to blow the training device 30 minutes daily to strengthen their inspiratory muscle.
P muscle. This procedure might also strengthen the patients’ oropharyngeal muscle simultaneously. Such an improvement in the strength of oropharyngeal muscle may account for the elevation of PEF.

Two possibilities had been proposed to explain the improvement of respiratory muscle function after RIMT. Gross et al19 used RIMT to train 6 chronic tetraplegic patients with a 30-minute training program daily and found that inspiratory muscle strength and endurance significantly increased. They suggested that the increase in the oxidative capacity of individual muscles of the diaphragm and further transformation of easily fatigable-resistant fibers into fatigable-resistant fibers could be the mechanism. Loveridge et al24 found that controls and a trained group of 12 tetraplegic patients showed similar improvement of maximal and sustainable inspiratory pressure after 8 weeks of RIMT. A possible explanation for this improvement is an altered breathing strategy (slow and deep breathing pattern) rather than a training effect of respiratory muscles strength and endurance. Our results indicated an obvious increase of the maximal and sustainable inspiratory pressure after 8 weeks of RIMT. A possible explanation for this improvement is an altered breathing strategy (slow and deep breathing pattern) rather than the modiﬁcation of breathing strategy.

SDB is common among individuals with SCI.1-8 Braun et al1 monitored oxygen saturation of 11 patients with SCI by ear oximeter, 2 of whom desaturated greater than 10% from baseline during sleep. Star and Osterman3 and Vella et al3 described 3 patients with a long-standing cervical cord injury who had a respiratory arrest after elective surgery, thereby implying the existence of unrecognized sleep apnea syndrome in cervical cord injury patients. Bonekat et al5 described 4 SCI patients who had undergone nocturnal polysomnography and complained of disturbed sleep. Disordered breathing was diagnosed in all. A study6 of 10 individuals with tetraplegia revealed that all had occasional desaturation below 90% during sleep and 30% had desaturation below 90% for over 10% of sleep time. Another study7 of 22 patients with SCI, over 40 years of age, indicated that 6 patients (27%) clearly had abnormal obstructive sleep apnea (OSA). In a study7 involving 16 tetraplegic patients with a low clinical suspicion for SDB, 10 (62.5%) had a signiﬁcant decrease in oxygen saturation during sleep. Polysomnography was performed on 7 patients. Three of them showed abnormal patterns, which consisted of both obstructive and central events. A large study8 with 40 tetraplegic patients with complete and incomplete lesion revealed that 11 had an Apnea-Hypopnea Index score greater than 15. A more recent study9 of 33 patients with cervical cord injury with a wide range of motor loss indicated that the prevalence of OSA in subjects with cervical cord injury was 15% higher than in a corresponding, nonobese, noninjured population.

In chronic tetraplegia, several factors may predispose patients to a sleep-induced breathing disorder such as paralysis of intercostal and abdominal muscles and weakness of the diaphragm. Braun1 argued that SDB of individuals with SCI

### Table 3: Results of Nocturnal Breathing Status in Patients With Improved MIP (n = 8)

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Week 6</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean maximum ETCO2</td>
<td>47.5 ± 5.8</td>
<td>47.8 ± 2.5</td>
<td>−.16</td>
<td>.43</td>
</tr>
<tr>
<td>Duration of ETCO2 &gt;40mmHg*</td>
<td>36.3 ± 36.5</td>
<td>36 ± 30.1</td>
<td>.12</td>
<td>.45</td>
</tr>
<tr>
<td>Duration of ETCO2 &gt;48mmHg</td>
<td>2.2 ± 3.3</td>
<td>1.0 ± 2.0</td>
<td>1.94</td>
<td>.05</td>
</tr>
<tr>
<td>Minimum Spo2</td>
<td>87.8 ± 7.2</td>
<td>87.2 ± 6.4</td>
<td>.58</td>
<td>.29</td>
</tr>
<tr>
<td>Mean Spo2</td>
<td>96.7 ± 1.0</td>
<td>96.7 ± 0.5</td>
<td>0</td>
<td>.50</td>
</tr>
<tr>
<td>Duration of Spo2 &lt;95% †</td>
<td>9.3 ± 11.2</td>
<td>9.3 ± 12.4</td>
<td>0</td>
<td>.50</td>
</tr>
<tr>
<td>Duration of Spo2 &lt;90%</td>
<td>1.8 ± 2.8</td>
<td>1.3 ± 2.4</td>
<td>2.23</td>
<td>.03‡</td>
</tr>
<tr>
<td>Duration of Spo2 &lt;80%</td>
<td>0.3 ± 0.8</td>
<td>0</td>
<td>1</td>
<td>.18</td>
</tr>
<tr>
<td>Duration of Spo2 &lt;70%</td>
<td>0.2 ± 0.2</td>
<td>0</td>
<td>1</td>
<td>.18</td>
</tr>
</tbody>
</table>

NOTE. All the parameters are statistically analyzed by paired Student t tests.

* The duration of ETCO2 above 40mmHg during sleep divided by the patient’s total sleep time. The data were read directly from the histogram of the capnography.

† The duration of Spo2 below 95% during sleep divided by the patient’s total sleep time. The data were read directly from the histogram of the capnography.

‡ P < .05 is statistically significant.

### Table 4: Results of Nocturnal Breathing Status in Patients With Improved PEF (n = 6)

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Week 6</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean maximum ETCO2</td>
<td>51.6 ± 4.7</td>
<td>49.6 ± 4.6</td>
<td>1.5</td>
<td>.09</td>
</tr>
<tr>
<td>Duration of ETCO2 &gt;40mmHg*</td>
<td>59.7 ± 29.0</td>
<td>46.2 ± 30.0</td>
<td>1.07</td>
<td>.16</td>
</tr>
<tr>
<td>Duration of ETCO2 &gt;48mmHg</td>
<td>2.9 ± 2.9</td>
<td>2.4 ± 3.4</td>
<td>.46</td>
<td>.32</td>
</tr>
<tr>
<td>Mean Minimum Spo2</td>
<td>85.4 ± 13.5</td>
<td>85.1 ± 10.0</td>
<td>.15</td>
<td>.44</td>
</tr>
<tr>
<td>Mean Spo2</td>
<td>96.6 ± 1.7</td>
<td>96.6 ± 1.7</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Duration of Spo2 &lt;95% †</td>
<td>12.0 ± 21.8</td>
<td>13.7 ± 26.0</td>
<td>−1.07</td>
<td>.16</td>
</tr>
<tr>
<td>Duration of Spo2 &lt;90%</td>
<td>2.4 ± 4.4</td>
<td>3.0 ± 6.7</td>
<td>−.61</td>
<td>.27</td>
</tr>
<tr>
<td>Duration of Spo2 &lt;80%</td>
<td>0.3 ± 0.8</td>
<td>0.4 ± 1.1</td>
<td>−1</td>
<td>.17</td>
</tr>
<tr>
<td>Duration of Spo2 &lt;70%</td>
<td>0.1 ± 0.3</td>
<td>0.1 ± 0.3</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

NOTE. P < .05 is statistically significant. All the parameters are statistically analyzed by paired Student t tests.

* The duration of ETCO2 above 40mmHg at sleep divided by the patient’s total sleep time. The data were read directly from the histogram of capnography.

† The duration of Spo2 below 95% at asleep divided by the patient’s total sleep time. The data were read directly from the histogram of the capnography.
correlated with their age and diaphragmatic function but not with the injury level of the patients or the static pulmonary function parameters. Another study of 22 patients revealed no significant correlation among the degrees of hypoxic dripping, age, level of SCI, obesity index, neck circumference, and static lung function. McEvoy et al. showed that the Apnea Index correlated with neck circumference and was higher in patients who slept supine. A study of 33 patients indicated an inverse relationship between oxygen desaturation and motor score (as defined by ASIA) in the subgroup with complete injury. In summary, the SDB of people with SCI appears to correlate with the diaphragmatic function, neck circumference, but not static pulmonary function.

Several studies have suggested that untreated OSA is associated with increased cardiovascular mortality and morbidity. Sudden cardiovascular events such as stroke and myocardial infarction appear to be the major causes of death in patients with sleep apnea. OSA is believed to be associated with the impairment of cognitive function. A study involving 37 tetraplegic patients, with mean age of 34 ± 9.7 years, revealed that 50% of the patients had clinical significant SDB, and 19% of the total patients desaturated to less than 80% during their sleep. Neuropsychologic variables correlated significantly with the severity of sleep hypoxia but not with the Apnea-Hypopnea Index. The neuropsychologic functions were most affected by nocturnal desaturation, including verbal attention and concentration, immediate and short-term memory, cognitive flexibility, internal scanning, and working memory. The disturbance of cognitive function resulting from sleep apnea might have an adverse impact on rehabilitation in patients with SCI; this may be why proper management is recommended for some specific patients with tetraplegia.

Treatment options for able-bodied patients with OSA include weight reduction, removal or reduction of the sedating substance, surgical correction of specific abnormality of the upper airway, and nasal continuous positive airway pressure at night. Among these factors of causing SDB, weakened inspiratory muscle is common among SCI patients but does not appear in the able-bodied group. Therefore, inspiratory muscle training seems to be a reasonable and effective method to correct the sleep-induced breathing disorder of individuals with SCI. In our study, patients’ breathing status during sleep did not significantly change after inspiratory muscle training. However, when subjects with improved MIP were considered, the duration of ETCO2 greater than 40mmHg and SpO2 less than 90% significantly reduced. This finding suggests that the enhanced strength of inspiratory muscle might reduce the SDB in patients with cervical cord injury.

This study has several limitations. First, the inadequate sample size of the study generated large standard deviations in the measurements, particularly in the duration of abnormal SpO2 and ETCO2. Second, the variance of the breathing status on a nightly basis was occasionally questionable. Lack of an electroencephalographic study made the staging of sleep impossible. This error was minimized by using the monitors for more than 2 nights in some cases. The third was that the accuracy of capnography was questioned at all times. However, a study comparing ETCO2 with PaCO2 during sleep revealed that these values did not significantly differ. Moreover, the fact that the comparison in our study was performed in the same group of subjects minimized error. The fourth was that the failure to control compliance among the study group might have reduced the training effect, although the subjects were seen by the therapist every 2 weeks to monitor the training progress. Finally, the training intensity was kept at 60% of MIP of the initial test and was not adjusted according to the improvement in MIP after training. Therefore, the training intensity might not have reached 60% of MIP in the midstage of training, possibly causing the training intensity not to be strong enough to benefit the subjects. We recommend a larger group be tested for a longer training period and that training intensity be adjusted to make a more definite conclusion.

The current study showed that RIMT was effective in improving pulmonary function in patients with chronic cervical cord injury using a simple home-designed program. The training device was easily applied and inexpensive. Through the training, the SCI patients improved their strength and endurance of inspiratory muscle and PEF. With this improvement, they might be able to perform daily activities better and to reduce the pulmonary complications. Moreover, the inspiratory muscle training appeared to reduce the events of SDB in a particular subgroup of patients. It provides another option for management of SDB in SCI patients. We believe that home-designed inspiratory muscle training should be provided to every SCI patient with impaired respiratory function. It should be included in the regular home exercise program for chronic SCI patients.

**CONCLUSION**

A RIMT program performed at home can effectively improve the MIP, MVV, and PEF in a group of individuals with...
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chronic cervical cord injury. Improving PEF may decrease mucus plugging and accumulation of secretions, possibly lowering the incidence of respiratory complications in this population. In addition, improving MIP and MVV may ease the performing functional activities of daily living and reduce the breathlessness of the patients. Moreover, in a subgroup of increased MIP, RIMT may correct their sleep-induced breathing disorder and reduce the mortality and morbidity of this patient group.

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Suppliers


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d. DHD 22-7500; Diemolding, Healthcare Div, One Madison St, Wampsville, NY 13163.