

Original Article

Relationship between inspiratory muscle strength and cough capacity in cervical spinal cord injured patients

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Study design: Prospective single centre study.

Objectives: Pulmonary rehabilitation focuses on improving the expiratory muscle function in order to increase the reduced cough capacity in patients with cervical spinal cord injuries (SCI). However, an improvement in the inspiratory function is also important for coughing effectively. Therefore, this study was to examine the significance of the inspiratory muscle strength on the cough capacity in the patients with a cervical SCI.

Setting: SCI unit, Yonsei Rehabilitation Hospital, Seoul, Korea.

Methods: The vital capacity (VC), maximum inspiratory pressure (MIP), and maximum expiratory pressure (MEP) were measured. Moreover, the unassisted peak cough flow (PCF) and assisted PCF under three conditions were evaluated.

Results: All three assisted cough methods showed a significantly higher value than the unassisted method ($P < 0.001$). The VC correlated with the voluntary cough capacity and the MIP ($R = 0.749$) correlated more significantly with the VC than the MEP ($R = 0.438$) ($P < 0.01$). The MIP showed a higher correlation with both the unassisted PCF and all three assisted PCFs than the MEP ($P < 0.001$).

Conclusions: The management of the inspiratory muscle strength should be considered in the pulmonary rehabilitation at cervical SCI patients.

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Keywords: spinal cord injuries; cough capacity; maximal inspiratory pressure

Introduction

Advances in the care of patients with spinal cord injuries (SCI) have significantly reduced both the acute and long-term mortality rates.^{1,2} Despite these improvements, respiratory complications are common in people with SCI and contribute significantly to associated morbidity, mortality, and economic burden.^{1–5} Ineffective cough is frequently a problem in the population with an SCI. The reasons are the loss of supraspinal control of the respiratory muscles below the spinal cord lesion.⁶ The inadequate clearance of the secretions related to the ineffective cough may lead to various respiratory complications in patients with an SCI.⁷ In addition, the weakened respiratory muscles can neither fully expand the lungs up to the maximum capacity nor compress them to the point of the smallest residual volume, leading to a reduction in the chest wall compliance by shortening and stiffening of the unstretched tissue and fibrosis of the weakened muscles.⁸

The spreading of the microatelectasis in the lungs also reduces the compliances of the lungs.⁹ This respiratory disability diminishes the lung capacity and impairs in the ability to cough.¹⁰ When the force of the cough is diminished, the airway secretion is not sufficiently eliminated. Impaired secretion clearance results in the development of mucus plugging, leading to complications such as atelectasis or pneumonia. Indeed, approximately 90% of respiratory failure suddenly develops as a result of an impaired clearance of the airways during inter-current chest colds as a result of the ineffective cough.¹¹ Therefore, the most important aspect of the pulmonary hygiene therapy for these patients is to improve the effectiveness of coughing.

For an effective cough, subjects initially inspire a large amount of air and apply an expiratory force against a closed glottis, generating a high thoraco-abdominal pressure. At this point, the glottis opens, resulting in strong expiratory flow.^{12,13} Based on this cough mechanism, several cough assisting methods for patients with respiratory muscle weakness have been suggested, such as respiratory muscle training,¹⁴ functional electrical

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stimulation of the abdominal muscles,^{6,15,16} and manual assist coughing following the maximum insufflation.^{15,17,18} As is known in the cough mechanism and assisted coughing techniques, the expiratory muscles play the most basic and important role in producing a functional cough flow. Therefore, there is a great deal of interest and research on the correlation between the expiratory muscle strength and cough. Although the expiratory muscle function plays an important role in an effective cough, the lung volume attained prior to a contraction of the expiratory muscle also plays an important role during cough.^{17,19} The function of the inspiratory muscles is essential in the inspiratory phase of cough. However, there is no report on the correlation between coughing and the inspiratory muscle strength.

Therefore, this study investigated the relationships of the voluntary cough capacity, the assisted cough techniques, and the inspiratory muscle strength as well as the expiratory muscle strength.

Methods

The sample consisted of 40 patients with a traumatic SCI at the cervical level, who were admitted to an inpatient rehabilitation program. All the subjects had sustained complete motor injuries, as defined by the American Spinal Injury Association criteria.²⁰ This study excluded those patients who had concomitant intrinsic lung disease or an indwelling tracheostomy tube, and who were unable to cooperate because of a mental or physical problem. Informed consent was obtained from each patient, and the medical ethical committee at this hospital approved this study.

The vital capacity (VC) was measured in the sitting and supine position, and the maximum insufflation capacity (MIC) was measured in the sitting position using a Micro spirometer (Micro Medical Ltd, Rochester, Kent, UK). For measuring the MIC, the patient was asked to take a deep breath and then hold it. A volume of air was then delivered via an oro-nasal interface by using a manual resuscitator bag. The patient added this air to what was already in the lungs and held it with the glottis closed. The process was repeated until no more air could be held, and the lungs and chest wall were fully expanded. The maximum-stacked volume of air was measured by having the patient blow the entire volume through a spirometer. This process was repeated at least three times and the highest value was selected as the MIC.

The maximum respiratory pressure reflecting the strength of the respiratory muscles was measured using a P_{\max} mouth pressure monitor (Morgan Medical Ltd, Rainham, Kent, UK) in the sitting position. In order to measure the maximum expiratory pressure (MEP), the subject performed a maximum expiratory effort after a maximum inspiration. The maximum inspiratory pressure (MIP) was measured by exerting the maximum inspiratory effort after the maximum expiration. The pressures measured should be maintained for at least 1 s.

The highest positive value for the MEP and the lowest negative value for the MIP in three or more attempts were chosen. The absolute value of the MIP was used to analyze the data.

The peak cough flows (PCFs) were measured using the Assess[®] Peak Flow Meter (Health Scan Products Inc., Cedar Grove, NJ, USA). The unassisted peak cough flow (UPCF) was measured by having the person cough as forcefully as possible through the peak flow meter. The assisted PCF under three different conditions were evaluated. In order to measure the volume assisted peak cough flow (VPCF), which assists the inspiratory phase of a cough, the patients were insufflated to the MIC and then coughed as forcefully as possible. The manual assisted peak cough flow (MPCF), which assists the expiratory muscle function, was measured while the abdominal thrust was timed to the glottic opening. Both techniques were carried out simultaneously in the combined assisted cough technique as the combined peak cough flow (CPCF). This consisted of manual abdominal compression during the expulsive phase of the maximum voluntary cough after insufflating to the MIC. The PCFs under four different conditions were compared. The highest value in at least three trials was used in each test, and the correlation between the MIP, MEP and PCFs under each condition was evaluated.

A paired *t*-test was used for the comparisons between the VC and the MIC and a repeated measure analysis of the variance was used for the comparisons between the UPCF and each assisted PCF. The relationship between the maximum respiratory pressures and the PCFs was analyzed through the correlation coefficient. All the data were analyzed using SPSS 11.0 for windows.

Results

In total, 40 cervical SCI patients (34 men and six women) were involved. The mean age was 35.1 ± 4.7 years old, the mean height was 173.4 ± 6.4 cm, and the mean weight was 63.4 ± 9.8 kg. The duration between the injury and the pulmonary function test was 6.1 ± 4.7 months. Figure 1 shows the distribution of the neurological level of injury.

The mean values of the VCs in the sitting position, the VCs in the supine position and the MICs were 1935 ± 586 ml ($47.8 \pm 14.3\%$ of predicted normal value^{21,22}), 2527 ± 525 ml ($61.3 \pm 12.0\%$ of predicted normal value^{21,22}) and 2550 ± 667 ml, respectively. The mean value of MIC was higher than that of the VCs in the sitting position ($P < 0.001$).

The mean values of the MIPs and the MEPs were 64 ± 24 cm H₂O ($51.2 \pm 19.1\%$ of predicted normal value²³) and 36 ± 24 cm H₂O ($15.4 \pm 10.3\%$ of predicted normal value²³), respectively.

The mean PCFs under the different conditions were: UPCF, 228 ± 79 l/min; VPCF, 277 ± 72 l/min; MPCF, 324 ± 77 l/min; CPCF, 362 ± 82 l/min. All three assisted cough methods showed significantly higher values than with the unassisted method (VPCF, $F = 115.01$; MPCF, $F = 187.39$; CPCF, $F = 250.82$) ($P < 0.001$). The MPCF

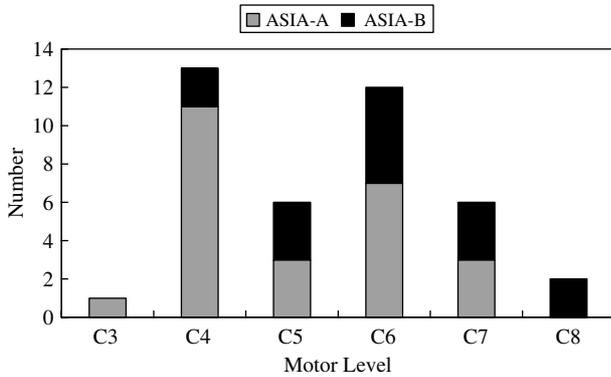


Figure 1 Distribution of injury level and ASIA impairment scale of patients. ASIA, American Spinal Injury Association

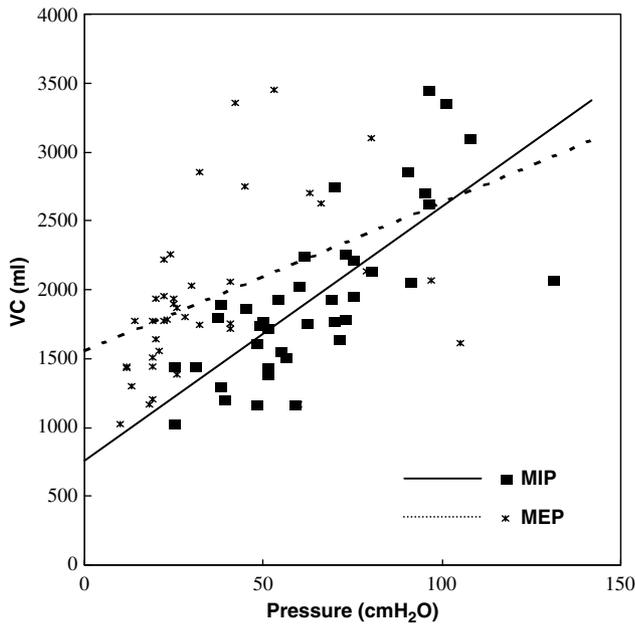


Figure 2 Relationships between the MIP, MEP and VC. Both absolute value of the MIP ($R=0.749$, $P<0.001$) and the MEP ($R=0.438$, $P<0.005$) correlated significantly with the VC. MIP, maximal inspiratory pressure; MEP, maximal expiratory pressure; VC, vital capacity

significantly exceeded the VPCF ($F = 65.74$) ($P<0.001$), and the CPCF significantly exceeded the VPCF ($F = 157.77$) and the MPCF ($F = 120.45$) ($P<0.001$).

The VC correlated with the voluntary cough capacity (UPCF) ($R = 0.583$, $P<0.001$) and the MIP ($R = 0.749$, $P<0.001$) correlated more significantly with the VC than the MEP ($R = 0.438$, $P<0.005$) (Figure 2).

The MEP correlated with the voluntary cough capacity (UPCF) as expected ($R = 0.495$, $P<0.001$) (Figure 3). Positive correlations between the MEP and the three different assisted cough methods were also evident (between MEP and VPCF, $R = 0.556$, $P<0.001$; between MEP and MPCF, $R = 0.349$, $P<0.05$; between

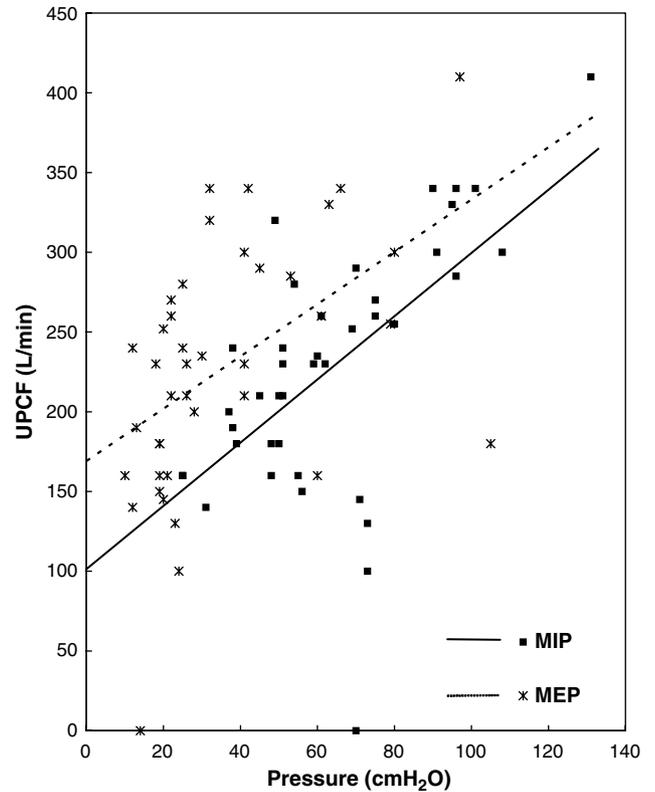


Figure 3 Relationships between the MIP, the MEP and the UPCF. Both absolute value of the MIP ($R = 0.599$, $P<0.001$) and the MEP ($R = 0.495$, $P<0.001$) correlated significantly with the UPCF. MIP, maximal inspiratory pressure; MEP, maximal expiratory pressure; UPCF, unassisted peak cough flow

MEP and CPCF, $R = 0.335$, $P<0.05$) (Figures 4–6). Regarding the relationship between the absolute value of the MIP and the PCFs, the MIP showed a better correlation with both the UPCF and all of the three assisted PCFs than the MEP (between MIP and UPCF, $R = 0.599$, $P<0.001$; between MIP and VPCF, $R = 0.636$, $P<0.001$; between MIP and MPCF, $R = 0.551$, $P<0.001$; between MIP and CPCF, $R = 0.493$, $P<0.001$) (Figures 3–6).

Discussion

In those patients with a cervical or high thoracic SCI, VC can be reduced by 30–50%, the functional residual capacity can be reduced by approximately 25%, and the expiratory reserve volume can be reduced by as much as 75%. These findings reflect the loss of the abdominal and chest wall muscle strength and control, which results from the SCI.²⁴ The impairment of the pulmonary function as a result of a weakness in the respiratory muscles may lead to an ineffective cough, atelectasis and other respiratory complications.²⁵ DeVivo and Ivic²⁶ reported that the overall 1-year survival rate of the ventilator-dependent persons with an SCI was 25.4%, while the 15-year survival rate was 16.8%, and the

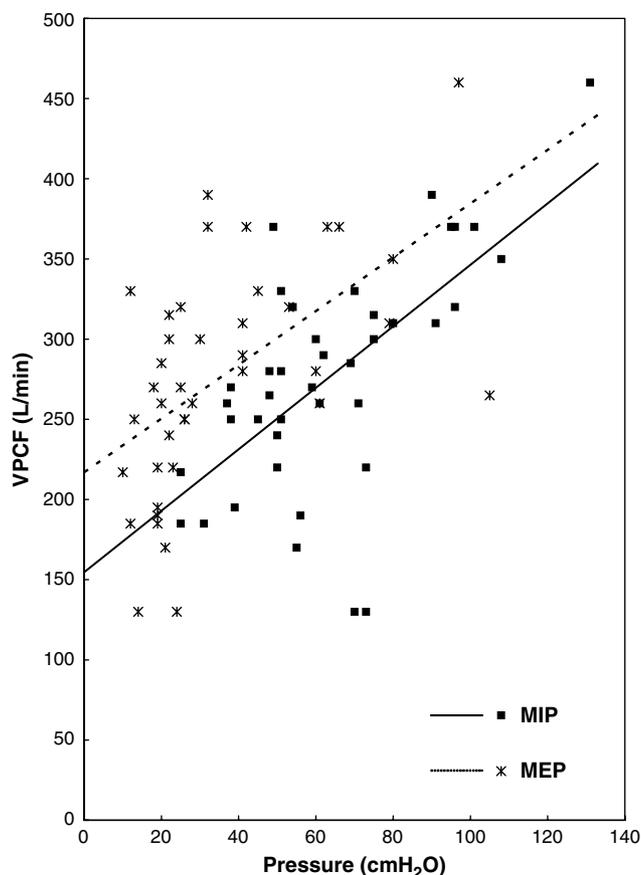


Figure 4 Relationships between the MIP, MEP and VPCF. Both absolute value of the MIP ($R=0.636$, $P<0.001$) and the MEP ($R=0.556$, $P<0.001$) correlated significantly with the VPCF. MIP, maximal inspiratory pressure; MEP, maximal expiratory pressure; VPCF, volume assisted peak cough flow

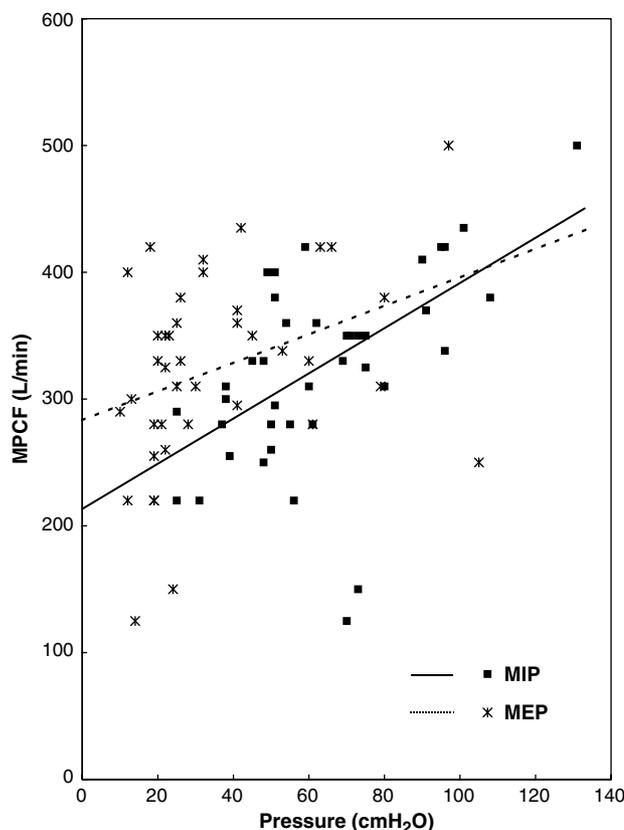


Figure 5 Relationships between the MIP, MEP and MPCF. Both absolute value of the MIP ($R=0.551$, $P<0.001$) and the MEP ($R=0.349$, $P<0.05$) correlated significantly with the MPCF. MIP, maximal inspiratory pressure; MEP, maximal expiratory pressure; MPCF, manual assisted peak cough flow

leading cause of death was respiratory complications, particularly pneumonia. Therefore, in order to minimize the number of respiratory complications, it is important to understand the physiological changes in the respiratory system in patients with an SCI.

It has been reported that the VC of cervical SCI patients in the sitting position ranged from 52 to 57% of the predicted.^{27,28} In this study, similar results (the sitting value of the VC 1935 ± 586 ml, $47.8 \pm 14.3\%$ of predicted) were observed and the supine values of the VC (2527 ± 525 ml, $61.3 \pm 12.0\%$ of predicted) were larger compared with the sitting value ($P<0.001$). When persons with a cervical SCI assume an upright posture, the abdominal contents are shifted caudally due to gravitational forces and the lack of an abdominal muscle tone. This caudal shift shortens the diaphragmatic muscle fiber length reducing the trans-diaphragmatic pressure, which decreases the zone of apposition of the diaphragm with the lower rib cage, and increases the radius of the curvature of the diaphragm. There all contribute to a reduction in the tangential tension developed by the diaphragm according to La Place's law, and eventually cause a reduction in the VC.²⁹

For a cough to be effective, three actions of a normal cough (inspiration, compression, and expulsion) should properly be operated.¹² In the inspiration phase, normal subjects increase the precough tidal volumes to approximately 85–90% of their inspiratory capacity and have a total cough volume of 2.3 ± 0.51 so as to obtain the optimal PCFs.³⁰ During the compression phase, an expiratory force against a closed glottis results in a rapid rise in the pleural and alveolar pressures.^{12,13} The contraction of the expiratory muscles with the glottis open strongly expels air from the lungs in the expulsion phase.^{12,13} When any of these phases are in an abnormal state, coughing becomes ineffective. If the sufficient amount of air cannot be voluntarily inspired due to weakness of the inspiratory muscles, the cough capacity is diminished despite the normal contraction of the expiratory muscles.¹⁰ The glottis plays a crucial role in the compression phase, and its function is considerably impaired in amyotrophic lateral sclerosis due to bulbar muscle involvement.³¹ However, it is not an issue in SCI patients. The expiratory muscle plays an important role in the compression and expulsive phases, and a weakness in it reduces the effectiveness of cough.^{12,13}

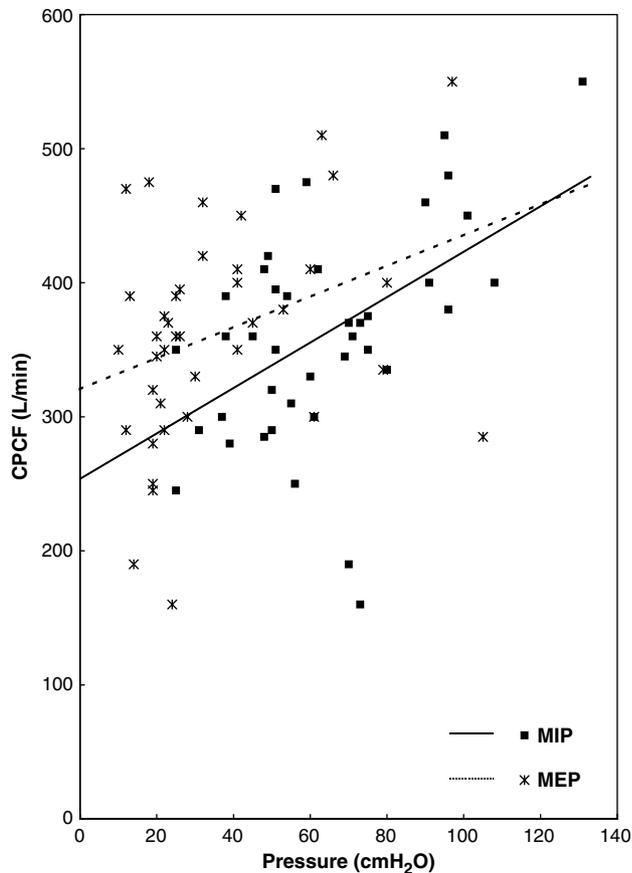


Figure 6 Relationships between the MIP, MEP and CCPF. Both absolute value of the MIP ($R=0.493$, $P<0.001$) and the MEP ($R=0.335$, $P<0.05$) correlated significantly with the CCPF. MIP, maximal inspiratory pressure; MEP, maximal expiratory pressure; CCPF, combined peak cough flow

The respiratory expiration action of the chest and abdomen in cervical SCI patients is primarily a passive action, which is dependent upon the recoil of the inflated chest due to paralysis of the intercostal and abdominal muscles, and these impairments in the active expiratory pressures results in an ineffective cough and a reduced ability to clear the respiratory tract secretions.³² Therefore, expiratory-phase assist techniques such as a quad-cough, expiratory muscle-training exercises and functional electrical stimulation of the abdominal muscles have been used to produce an effective cough for clearing the respiratory tract secretions and have shown their effectiveness in increasing the cough flow and the MEP.^{6,14–17}

Another method for improving the cough capacity is to increase the insufflation volume. In order to achieve the maximum expiratory flow during a cough requires a lung insufflation of 85–90% of the inspiratory capacity.³⁰ In SCI patients, an inspiratory muscle weakness limits the precough volumes needed to produce effective PCFs. Therefore, delivering additional air volume after taking a deep breath can make increase the cough

capacity in SCI patients.^{18,33} This study also revealed that the MIC was larger than the VC ($P<0.001$), which explains why the measured VPCF was larger than the UPCF. Despite this theoretical background, abdominal compression to assist only the expiratory phase is mainly used in SCI patients to improve the cough capacity.

The maximum respiratory pressure, which is a useful marker of respiratory muscle weakness, is more sensitive for detecting weakness in the respiratory muscles than the pulmonary volumes.³⁴ In patients with neuromuscular diseases, it is known that the most sensitive indicator of a respiratory impairment is the MEP.³² Therefore, a decline in the MEP correlates with the voluntary cough capacity (UPCF), as shown in this study and other reports.¹³ Although the MIP, which reflects the strength of all the inspiratory muscles, is expected to affect the inspiratory phase of a cough, there is no study on the relationship between the VC, the cough capacity and the MIP. Therefore, the correlation between VC, cough capacity and MIP was examined, and it was found that the UPCF had a more significant correlation with the MIP ($R=0.599$) than the MEP ($R=0.495$) (Figure 3). The positive correlation between the MIP and the three different assisted cough methods were also more significant than the MEP (Figures 4–6).

In this study, the VC ($R=0.583$) showed more a significant positive correlation with the voluntary cough capacity (UPCF) than the MEP ($R=0.495$). In addition, the absolute value of the MIP ($R=0.749$) showed a more significant positive correlation with the VC than the MEP ($R=0.438$). That is, it is possible that a stronger inspiratory muscle will result in a larger precough inspiratory volume. This might explain why the MIP showed a more significant correlation with the UPCF than the MEP, which also means that the inspiratory function had a more significant influence on the cough capacity in the patients with a motor complete cervical SCI than the expiratory function.

It is known that the MIP is relatively preserved in patients with neuromuscular disease until they become old, and the MEP has been emphasized as a sensitive marker of the respiratory muscle deterioration.¹³ However, these opinions are based on studies that were performed on patients with chronic progressive disease such as muscular dystrophy, spinal muscular atrophy, etc. Therefore, the MEP might not be a more sensitive marker of the respiratory muscle deterioration in patients with a traumatic SCI in whom both the inspiratory and expiratory dysfunction develop simultaneously due to respiratory muscle paralysis injuries.

Deep inspiration expands the more distal airways, improves the expiratory muscle function, and increases the pulmonary recoil pressure of the respiratory system.^{35–37} Forced expiration during coughing normally begins with maximum inflation of the lungs, that is, greater expiratory pressures, and flows can be produced at high lung volumes by optimizing the length–tension relationship of the expiratory muscles.^{36,37} Therefore, the cough flow is reduced as a result

of inspiratory muscle weakness as well as expiratory muscle weakness.^{13,37} As the strength of the inspiratory muscle declines, the patients lose their ability to take spontaneous periodic deep breaths, which normally stimulates surfactant production and distribution, and reopens the collapsed peripheral airways.³⁸ Without deep insufflations, these patients first develop microatelectasis, and a long-term inability to take deep breaths or chronic hypo-inflation results in a permanent pulmonary restriction. Therefore, decreased pulmonary compliance results initially in microatelectasis, and ultimately in increased stiffness of the chest wall and the lung tissues themselves.²⁸ An effective cough relies on the generation of sufficient dynamic airway compression to produce a high airflow velocity. In contrast, the diminished lung compliance may limit the dynamic airway compression, which might be another factor that causes weak coughing.¹⁰ These various factors are correlated with the MIP and can affect the cough capacity.

An assisted coughing method to help the expiratory muscles only may not be enough to induce a strong cough flow in SCI patients accompanied with reduced a precough inspiration volume due to weakness of the inspiratory muscles. Therefore, both manual compression and mechanical insufflation is believed to assist the expectoration of secretions in patients with respiratory muscle weakness. As shown in this present study, patients can achieve the highest cough flow using the CPCF technique. This result together with the relationship between the maximum respiratory pressures and the two different assisted cough methods suggest that both the MEP and MIP, which are the markers of the respiratory muscle weakness, should be considered in a study of the cough effectiveness.

However, most patients were in the acute phase after injury, which means that the duration between the injury and the pulmonary function tests was within 1 year in 37 of the 40 subjects. Therefore, long-term studies will be required to demonstrate the relationship between the respiratory muscle strength and the cough capacity in the chronic phase. In addition, the interaction between spasticity and voluntary motor control of the respiratory muscle may have affected the findings of this study. However, the potential effect of this problem was not examined in this study. In addition, note the sample size was relatively small, which might have masked or skewed some of the important statistical trends. Accordingly, a larger study with subjects subdivided according to the neurological level of injury, age, the presence of spasticity, and the duration of injury, will need to be performed in order to clarify the influence of the respiratory muscle strength on the cough capacity of patients with SCI.

Conclusions

A reduced cough capacity due to respiratory muscle weakness is one of the main causes of morbidity and mortality in SCI. These factors that affect a cough

should thoroughly be analyzed in order to effectively assist a weakened cough. As shown in the results of this study, the MIP showed a more significant correlation with the voluntary or assisted cough capacity than the MEP. Therefore, an evaluation and improvement in the inspiratory muscle strength should be considered in those patients with a motor complete cervical SCI rather than just to manage the expiratory function.

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