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Revisiting respiratory muscle strength and pulmonary function in spinal cord injury: The effect of body positions

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Abstract

OBJECTIVES: In the subjects with high cervical spinal cord injury (SCI), The difference of respiratory muscle strength and pulmonary function according to supine and sitting position were investigated whether there are changes in the tendency.
METHODS: Twenty-three subjects with high cervical SCI and 23 subjects with low cervical and thoracic SCI were evaluated. The reference neurological level of injury for dividing the groups was fifth cervical vertebrae (C5). SCI severity was classified as motor-complete SCI. The supine and sitting forced vital capacity (FVC), percent of the predicted FVC (FVC%), maximal expiratory pressure (MEP), maximal inspiratory pressure (MIP), MEP / MIP ratio, and peak cough flow (PCF) were compared.
RESULTS: The significantly higher FVC, FVC% in the low cervical and thoracic SCI group was identified in the supine position than the sitting position. The same tendency was observed in the high cervical SCI group. In the comparison of respiratory muscle strength, higher values of supine MEP and MIP were found only in the high cervical SCI group. PCF is more positively correlated with MIP than with MEP in all groups.
CONCLUSION: We found that the supine position is more advantageous for the strong breathing and larger lung capacity in patients with high cervical SCI. The positive correlation between PCF and MIP in the patients with high cervical SCI was also confirmed. These results may be used to establish a pulmonary rehabilitation strategy for patients with high cervical SCI.

ORIGINAL ARTICLE

INTRODUCTION

Respiratory complications commonly lead to mortality in spinal cord injury (SCI) (van den Berg *et al.* 2010). These complications in patients with SCI vary in severity and frequency according to the neurological level of injury (NLI) and the American Spinal Injury Association (ASIA) Impairment Scale (Kirshblum *et al.* 2011). In the early stages of cervical SCI, flaccid paralysis and areflexia occur due to spinal shock. In this situation, atelectasis may occur due to low ventilation caused by respiratory muscle weakness and decreased consciousness (Claxton *et al.* 1998). Generally, diaphragmatic dysfunction is common in patients with high cervical cord injury whose NLI is fourth cervical vertebrae (C4) or above, and it is possible to wean the patient off the ventilator in NLI below fifth cervical vertebrae (C5) (Brown *et al.* 2006).

In patients with SCI, changes in lung function by position are also clinically important. Changes in lung capacity, respiratory muscle strength due to position changes have been reported (Terson de Paleville *et al.* 2014). In normal subjects, forced vital capacity (FVC) decreases in the supine position, but it increases in patients with tetraplegia who have no diaphragm dysfunction (Baydur *et al.* 2001). In these patients, the abdominal muscles do not contract in the sitting position; this causes a descent of the abdominal contents, which is not effective in pushing the diaphragm during exhalation (Chen *et al.* 1990). Changes in FVC in the sitting and supine positions may also be used to screen for isolated diaphragm dysfunction (Koo *et al.* 2017). When isolated paralysis of the diaphragm is present, diaphragmatic descent is disturbed by the abdominal contents in the supine position, and FVC tends to be further reduced than in the sitting position (McCool & Tzelepis 2012). Patients with SCI are expected to have various patterns of respiratory paralysis according to NLI and the ASIA Impairment Scale (AIS).

Maximal expiratory pressure (MEP) and maximal inspiratory pressure (MIP) are indicators of respiratory muscle strength and are used for early assessment the progress of respiratory muscle dysfunction in various neuromuscular diseases. Respiratory muscle strength is important not only for ventilation but also for the maintenance of upper airway patency and airway secretion removal (cough) (Park *et al.* 2010). The difference in MEP and MIP between the sitting and supine positions in normal subjects was significantly higher in the sitting position (mean difference of MIP: 8.70, MEP: 9.59) (Costa *et al.* 2015). This is because the diaphragm is restricted by the abdominal contents in the supine position, and the muscles used for the strong inspiration and expiration do not effectively contract in the supine position (Segizbaeva *et al.* 2013). The MEP / MIP ratio tends to increase as diaphragm function decreases (Koo *et al.* 2017).

In the previous study, pulmonary functions and MEP, MIP of the patients with cervical or thoracic SCI were analyzed in different groups, depending on whether it was motor-complete or motor-incomplete (Terson de Paleville *et al.* 2014). As mentioned, isolated paralysis of the diaphragm affects the change of lung capacity due to posture change. In the NLI of C4 or above, it can be assumed that some abnormalities of the diaphragm are present. Therefore, we can expect some changes of respiratory function according to different position in high cervical cord injuries. The purpose of this study was to determine whether there were the changes of trend in respiratory function according to supine and sitting position in patients with NLI of C4 or above. We also tried to analyze the correlation between peak cough flow (PCF), MEP and MIP in this group.

METERIAL AND METHODS

Subjects

We retrospectively enrolled SCI subjects. The subjects were recruited for the study from November 2011 to May 2017 in the Pusan National University Hospital. All 46 subjects were in the motor-complete state according to the AIS. We set the criteria for dividing the group NLI to C5. Mid-cervical lesions (at C3–C5) showed partially preserved diaphragmatic function (McCool & Tzelepis 2012). Twenty-three subjects with high cervical SCI (NLI from C2 to C4) and 23 subjects with low cervical and thoracic SCI (NLI from C5 to T6) were evaluated (Figure 1). Thereafter, the supine and sitting FVC, percent of the predicted FVC (FVC%), MEP, MIP, and PCF were measured in subjects with cervical and thoracic motor-complete SCI. Their mean ages at the time of injury were 44.5±14.2 years in the high cervical SCI group and 47.7±15.8 years in the low cervical and thoracic SCI group. We excluded subjects who were uncooperative during the test or who had a tracheostomy tube. The study was approved by the Pusan National University Hospital Institutional Review Board (IRB No. 1710-008-060).

Neurological assessment

The neurological level and severity were assessed using the AIS recommended by the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) (Kirshblum *et al.* 2011). AIS A and B constitute the motor-complete group, while AIS C and D comprise the motor-incomplete group. Sensory impairment was confirmed in the C2–S5 dermatome, using light touch and pinprick, and NLI was finally determined by the motor and sensory level. Neurological examinations were performed by two trained rehabilitation medicine physicians.

Study design

One experienced pulmonary physical therapist evaluated all subjects. All subjects underwent pulmonary function test (PFT), respiratory muscle strength test, and PCF assessment using a spirometer (MicroLab, the UK), respiratory pressure meter (MicroRPM, the UK), and peak flow meter (MircoPeak, the US), respectively. PFT was performed in the supine position and then sitting position. Predicted values of the spirometer were based on the reference equation by Choi (Choi *et al.* 2005). MIP and MEP were also measured in the supine position and then sitting position using a disposable medical mouthpiece. MIP was measured from the end of exhalation (e.g. residual volume) and MEP was measured from the end of inhalation (e.g. total lung capacity). For correct evaluation, a sharp and strong breath was required to be maintained for more than 2 seconds. MIP and MEP were assessed twice, and the higher value was recorded in both the supine and sitting positions. There was a break of 5 minutes between each evaluation for rest. PCF was measured twice with a strong cough as possible. Assisted cough was omitted because it would be difficult to quantify the help of the evaluator.

Statistical analysis

Data presented in the text and tables are reported as mean±SD. The data were grouped according to NLI. In each group, two sub-groups were created with respect to the supine and sitting positions. Statistical analysis was performed using SPSS 22.0 (IBM, Armonk, NY, USA). A p-value <0.05 was considered statistically significant. The Kolmogorov-Smirnov test was applied to identify normal distribution. In each group, the independent sample t-test was used for values assumed to follow a normal distribution and the Mann-Whitney test was used for values that were not normally distributed. For within-group comparisons, we used the paired t-test or Wilcoxon signed-rank test. The correlation between PCF and MIP and MEP was evaluated using Pearson's correlation.

RESULTS

Table 1 shows the subjects' characteristics. The A:B ratio according to the AIS category in the high cervical group and low cervical and thoracic group was 18:5 and 15:8, respectively. A high ratio of AIS A means a complete paralytic state below NLI and the patterns of respiratory paralysis according to NLI are relatively clear. The mean body mass index of each group was 22.2±3.0 kg/m^2 in the high cervical group and 23.1±4.2 kg/m^2 in the low cervical and thoracic group. The mean time after SCI was as 39.2±27.7 and 139.2±183.1 months in the high cervical group and low cervical and thoracic SCI group, respectively.

A significant difference was observed between groups in FVC% in the sitting and supine position. As expected, the higher the NLI, the smaller the predicted lung capacity. Significant within-group differences, with respect to position, were observed in all comparisons (Table 2). The significantly higher FVC, FVC% in the low cervical and thoracic SCI group were identified in the supine position than the sitting position. In the high cervical SCI group, which was expected to show different pattern due to the possibility of the diaphragm dysfunction, the supine FVC and FVC% were also higher.

MEP and MIP were compared between groups and significant difference in MEP was found. MEP was higher in the low cervical and thoracic SCI groups in the inter-group comparisons. However, in the case of MIP, there was no significant difference between the two groups. In within-group comparisons of the values according to the position, higher values of supine MEP and MIP were found only in the high cervical SCI group. When PCF was compared between groups, a

Tab. 1. Subjects' characteristics.

	High cervical SCI group (n=23)	Low cervical and thoracic SCI group (n=23)
Sex (Male:Female)	20:3	17:7
AIS category (A:B)	18:5	15:8
Age (years)	44.5±14.2	47.7±15.8
Body mass index (kg/m^2)	22.2±3.0	23.1±4.2
Time after SCI (months)	39.2±27.7	139.2±183.1

Abbreviations: AIS, ASIA Impairment Scale; SCI, spinal cord injury
High cervical SCI group = C2–4, motor complete
Low cervical and thoracic SCI group = C5–T6, motor complete
Values are mean ± SD

Tab. 2. Mean FVC, FVC% in the supine and sitting position.

		High cervical SCI group (n=23)	*p*-value	Low cervical and thoracic SCI group (n=23)	*p*-value
FVC (L)	sitting position	1.27±0.69 †	<0.001	1.73±0.91 †	0.003
	supine position	1.73±0.82		2.07±1.01	
FVC%	sitting position *(*p*=0.048)	29.49±12.90 †	<0.001	43.48±17.64 †	0.002
	supine position *(*p*=0.004)	40.30±15.57		51.12±19.44	

Abbreviations: FVC, forced vital capacity; † Significant difference compared with the supine position in the same group (paired t-test); * Significant difference between groups (independent sample t-test); Values are mean ± SD

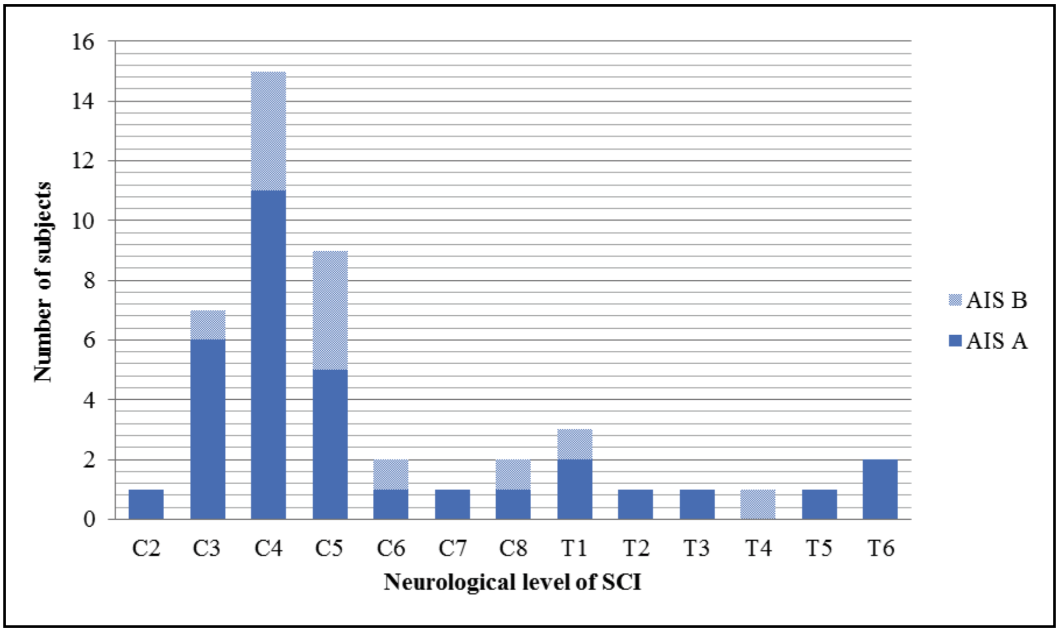

Fig. 1. The number of subjects with motor complete SCI at different neurological level of injuries.

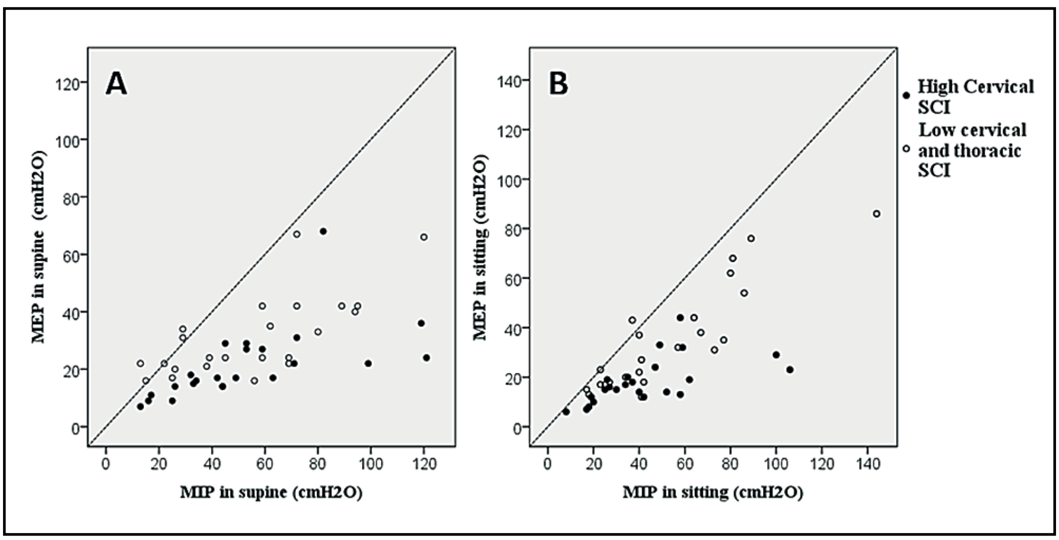

Fig. 2. The relationship between MIP and MEP of each group in supine position (A), in sitting position (B). Each point represents value from a single subject.

Tab. 3. Mean MEP, MIP, MEP/MIP ratio, and PCF in the sitting and supine position.

	MEP (cmH_2O)		MIP (cmH_2O)	
	sitting position †	supine position †	sitting position	supine position
High cervical SCI group (n=23)	18.26±9.21 *	21.43±12.77	42.13±24.55 *	52.7±30.23
Low cervical and thoracic SCI group (n=23)	35.13±21.20	31.57±14.16	53.30±30.62	55.52±28.89
	MEP/MIP ratio		**PCF (L/min)**	
	sitting position †	supine position †	sitting position †	supine position †
High cervical SCI group (n=23)	0.48±0.17	0.45±0.15	157.86±73.56	163.81±74.95
Low cervical and thoracic SCI group (n=23)	0.68±0.20	0.68±0.34	221.74±107.30	214.78±98.30

Abbreviations: MEP, Maximal Inspiratory Pressure; MIP, Maximal Inspiratory Pressure; PCF, Peak Cough Flow; * Significant difference compared with supine position in the same group, *p*<0.05 (Paired T test); † Significant difference between groups, *p*<0.05 (Independent sample T -test) significant higher values were found in the low cervical and thoracic groups. In PCF, there were no significant within-group differences with respect to position (Table 3).

As shown in Table 3 and Figure 2, the MEP/MIP ratio was relatively higher in the low cervical and thoracic SCI group than in the high cervical SCI group; however, there was no significant within-group difference in this ratio with respect to position in the same group. Spearman's rank correlation revealed that the value of MEP / MIP tended to increase with decreasing neurological level (correlation coefficient =0.316, p=0.033, supine position; correlation coefficient =0.511, p<0.001, sitting position), which means that the higher the NLI, the more predominantly the MEP value decreases. A significant positive correlation was noted between PCF, MEP, and MIP for all values. Position-related differences were not consistent and MIP showed a more positive correlation with PCF than did MEP, in all groups (Table 4).

DISCUSSION

The diaphragm is the main muscle of respiration in humans. The diaphragm is controlled by a phrenic nerve originating from C3–5 and is responsible for more than 70% of inspiration in quiet breathing (Al-Bilbeisi & Mc 2000). Expiration in quiet breathing is usually passively caused by the elastic recoil force of the lung and chest wall (Colebatch *et al.* 1979). In the case of SCI below C5, the diaphragm function will be maintained, so that the main problem might be limited coughing due to weakness of abdominal muscles and chest wall instability. According to the respiratory physiology, if the NLI is above C5, there will be additional problem in inspiration. As a result, about 36% of patients with the NLI above C6 require long-term mechanical ventilator support (Wicks & Menter 1986).

In this study, FVC% value was significantly lower in the case of the high cervical SCI group than lower cervical and thoracic SCI group (Table 2). It is already well known that the higher the neurological level, the more severe respiratory failure. Also, when comparing the position in the within group, a larger FVC value was found in all groups in the supine position than the sitting position. In the low cervical and thoracic group, the same trend was observed in a study of motor-complete cervical SCI patients with C6–8 NLI as expected (Park *et al.* 2010). We hypothesized that there would be a change in the tendency of respiratory function in subjects with high cervical SCI due to diaphragmatic dysfunction. The diaphragmatic descent was thought to be disturbed by the abdominal contents during maximal inspiration. In normal subjects, it was also confirmed that the FVC value decreased at the supine position by this effect (Blair & Hickam 1955). This tendency is more evident in patients with paralysis of the diaphragm (Davis *et al.* 1976). Therefore, FVC was supposed to be lower in the supine position than in the diaphragm preserved SCI group. However, the same trend was observed in the high cervical SCI group of this study. Therefore, we can assume that the change of FVC according to the position does not have a great effect even in the high cervical SCI group.

Position-related differences in MEP and MIP have been shown in healthy persons (Costa *et al.* 2015). On average, MEP is higher than the MIP and both MEP and MIP are higher in the sitting position than in the supine position. This is thought to be due to the abdominal contents exerting a burden on breathing effort when measured in the supine position (Costa *et al.* 2015). However, as seen in this study, MIP is generally higher than MEP in motor-complete SCI subjects with respiratory muscle weakness (Terson de Paleville *et al.* 2014). In the high cervical SCI group, the supine MEP and MIP values were significantly higher than the sitting's, but there was no significant position-related difference in low cervical and thoracic SCI groups. When the diaphragm is paralyzed, it is thought that MIP will be decreased in the supine position because of the abdominal contents. However, the opposite was noted in this study. It is presumed that the influence of other respiratory muscles, such as the neck accessory muscles is greater during the test than the effect of partial diaphragmatic paralysis. Further studies are required that applies the surface electromyography for the activation of the accessory muscles during the test.

In this study, MEP was found to be significantly different between groups, but there was no significant difference in MIP between groups (Table 3). The significantly lower MEP value was identified in the high cervical SCI group. This means that the decrease of MEP is more prevalent than MIP even if the group is above C5. This suggests that the diaphragm and accessory

Tab. 4. Correlation PCF with MIP, MEP.

		High Cervical SCI		Low Cervical and Thoracic SCI	
		MEP in seated	**MIP in seated**	**MEP in seated**	**MIP in seated**
PCF in seated	r	0.586**	0.753**	0.795**	0.817**
		MEP in supine	MIP in supine	MEP in supine	MIP in supine
PCF in supine	r	0.686**	0.782**	0.675**	0.813**

Abbreviations: MEP, maximal expiratory pressure; MIP, maximal inspiratory pressure; PCF, peak cough flow; SCI, spinal cord injury
** p<0.01

inspiratory neck muscles will be spared to some degree in subjects with high motor-complete tetraplegia; however, the expiratory muscles will be more paralyzed in these subjects than in subjects with low tetraplegia or paraplegia.

The MEP/MIP ratio is used as a good indicator to simply identify patterns of respiratory muscle weakness in various neuromuscular diseases. Compared with MEP/MIP in neuromuscular disease, MEP was higher than MIP, and the same pattern is noted in normal subjects. However, when analyzed by disease, myotonic dystrophy shows a greater decrease in MEP and myasthenia gravis shows a greater decrease in MIP (Fregonezi *et al.* 2015). In this study, the mean MEP/MIP ratio was less than 1 in all groups and was significantly lower in the high cervical SCI group than in the low cervical and thoracic SCI group (Table 3, Figure 2). In other words, the high cervical SCI group can be presumed to demonstrate more severe paralysis of the expiratory muscles compared to the inspiratory muscles.

PCF was significantly lower in the high cervical SCI group. As expected, the decreased PCF means that assist techniques are needed for sputum removal (Gauld & Boynton 2005). It has been reported that PCF is more correlated with MIP than with MEP (Park *et al.* 2010). This means that the ability to inhale the proper amount of air is more important to the coughing ability. In this study, we also attempted to analyze the correlation between each group and position. The results were similar to that of the previous study (Park *et al.* 2010), and the positive correlations with PCF and MIP were greater in the low cervical and thoracic groups (Table 4).

A statistical power analysis was performed using"G Power" software (www.gpower.hhu.de; UCLA, Los Angeles, CA). According to the analysis, about 34 samples were required, but the subject data could not be collected due to the limitation of the single center retrospective study. Because the sample size was small, some values were not normally distributed. The major limitation of this study was inability to enroll all subjects with high cervical SCI above C5. Tracheostomy and continuous mechanical ventilator use are often needed for subjects with high cervical SCI above C5 (Claxton *et al.* 1998). In other words, when there is complete paralysis of the respiratory muscles, a series of respiratory evaluations cannot be performed properly. Therefore, this study did not confirm the effect of complete diaphragmatic paralysis on PFT. In addition, there was no accurate evaluation of the degree of abdominal paralysis in this study. Based on the AIS, we evaluated the key muscles and enrolled only subjects with motor-complete SCI. Therefore, we could not confirm the degree of paralysis of the abdominal muscles. In our next study, we hope to perform additional analysis via the quantitative evaluation of abdominal muscles and accessory respiratory muscles using multichannel surface electromyography during PFT. Because of demographic heterogeneity, a large difference between the groups in parameters such as the time after SCI was noted.

In this study, we have confirmed the trend of FVC, MIP, MEP, and PCF values in high tetraplegia subjects in different positions. SCI patients with C4 or higher NLI were examined to see if there were any differences in lung volume, MEP, and MIP according to different positions due to the possibility of diaphragmatic dysfunction or other factors. As expected, a lower mean FVC% and a lower MEP and PCF in the sitting and supine position were observed in subjects with high cervical SCI compared to subjects with low cervical and thoracic SCI. However, within-group, and based on the position-related differences, FVC showed the same tendency in the high cervical SCI group and low cervical and thoracic SCI group. In subjects with high tetraplegia, the mean MEP and MIP was measured lower in the sitting position than supine position.

We found that the supine position is more advantageous for the strong breathing and larger lung capacity in patients with high cervical SCI. The positive correlation between PCF and MIP in the patients with high cervical SCI was also confirmed. These results may be used to establish a pulmonary rehabilitation strategy for patients with high cervical SCI.

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