

Time Course of Respiratory Dysfunction and Motor Paralysis for 12 Weeks in Cervical Spinal Cord Injury without Bone Injury

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Abstract:

Introduction: Cervical spinal cord injury without bone injury (SCIWOBI) is a common cervical injury in the elderly population and is most likely to occur at the C3/C4 level. Respiratory dysfunction (RD) related to the damage of the spinal respiratory center, which is close to the C4 segment, is one of the greatest obstacles in improving the activities of daily living of patients with severe paralysis. We evaluated the time course of RD and motor function in cervical SCIWOBI to identify effective medical strategies.

Methods: We followed 54 patients (49 men, 5 women; mean age: 65 years old) who were treated for SCIWOBI at our medical center from 2011 to 2014. The patients were evaluated within 72 hours of injury and were monitored for at least 12 weeks. All patients began respiratory-muscle training the day after admission regardless of whether they were treated conservatively or surgically. The percent vital capacity (%VC), forced expiratory volume (FEV) in one second/forced vital capacity ratio (FEV 1.0%), and American Spinal Injury Association motor score (MS) were recorded at admission and again at weeks 4 and 12. We calculated the %VC rate of change and the MS improvement rate over the entire period.

Results: Fifty patients (92.6%) had restrictive ventilatory impairment at admission. The %VC correlated with the upper- and lower-limb MSs at admission, and the %VC and upper- and lower-limb MSs had improved by weeks 4 and 12 after the injury. The %VC rate of change was significantly correlated with the rate of improvement in lower-limb MS throughout the entire period.

Conclusions: Lung capacity decreased in SCIWOBI owing to respiratory-muscle paralysis and upper- and lower-limb motor paralyse. Lung capacity improved as the lower limbs recovered their motor function. Respiratory rehabilitation should be continued for at least 12 weeks after SCIWOBI.

Keywords:

Spinal cord injury without bone injury (SCIWOBI), respiratory dysfunction, respiratory rehabilitation

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Introduction

Respiratory dysfunction (RD) resulting from cervical spinal cord injury (SCI) is the most common cause of death following cervical SCI and contributes significantly to overall life-long morbidity and mortality compared to the general population¹⁻⁴⁾.

Cervical SCI without bone injury (SCIWOBI) is caused by hyperextension forces and is most often associated with low-energy falls in the elderly. Cervical SCIWOBI is most likely to occur at the C3/C4 level⁵⁾. The phrenic nerve re-

ceives its motor supply from C3, C4, and C5; therefore, RD in cervical SCIWOBI results from damage to the spinal respiratory center and may differ in some aspects from RD in general cervical SCI, which is a more heterogeneous disorder as regards injury levels and severity. In this study, we describe the time course of RD and motor function in cervical SCIWOBI over a period of 12 weeks and discuss appropriate medical approaches.

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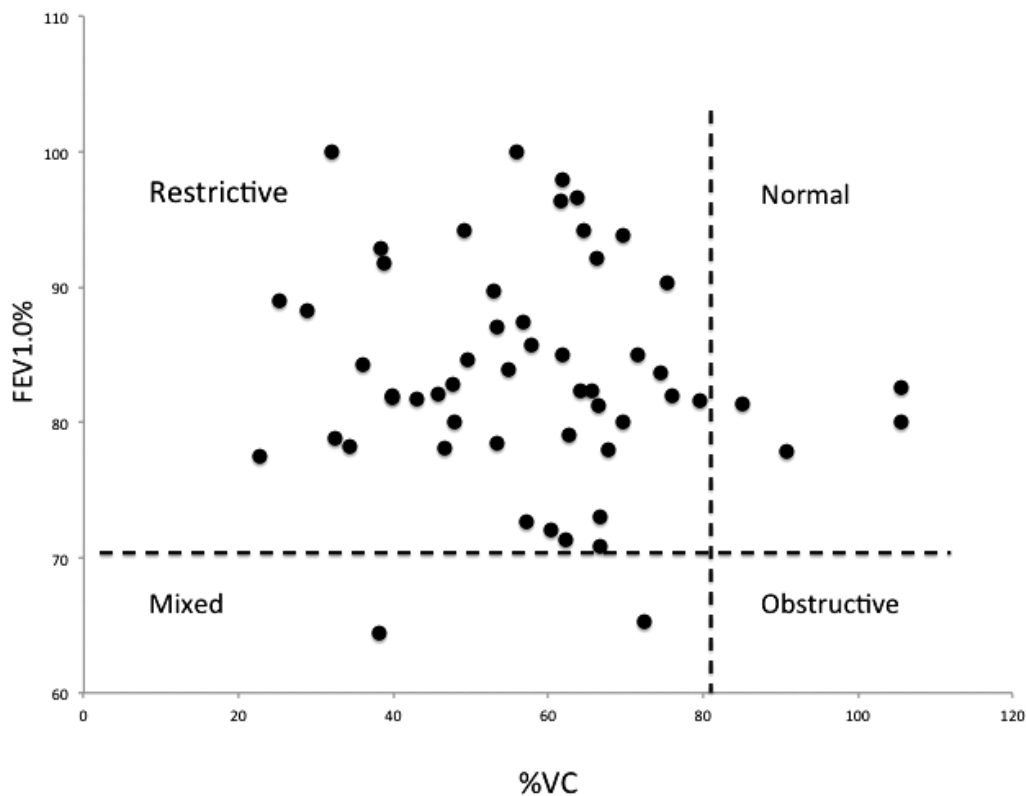


Figure 1. Pulmonary function test on admission. Restrictive ventilatory impairment was present in 50 patients (92.6%) at admission (average %VC 56.7%; average FEV 1.0%/82.0%).

Method

We evaluated the progress of 54 patients (49 men and 5 women; mean age: 65 years old; age range: 39-85 years) who were treated for cervical SCIWOB at our medical center from 2011 to 2014. The patients were evaluated within 72 hours of injury and were monitored for at least 12 weeks. The level of cervical SCI, which was determined upon admission, was at C3/C4 in 38 cases, C4/C5 in 10 cases, C5/C6 in 2 cases, and C6/C7 in 4 cases. The American Spinal Injury Association Impairment Scale (AIS)⁶ grade was A for 8 cases, B for 4 cases, C for 34 cases, and D for 8 cases. Eighteen patients had ossification of the posterior longitudinal ligament. Conservative therapy and surgical treatment were chosen in 12 cases and 42 cases, respectively. All patients were encouraged toward early mobilization starting from the second day after admission and were trained with breathing exercises to strengthen the accessory respiratory muscles and with exhalation exercises by using a device. All patients were taught stretching and squeezing techniques to prevent chest contraction. Patients with severe RD underwent diaphragm training with a 1 kg weight placed on the upper abdomen. Some patients who did not have motor paralysis or severe RD were trained with whole-body exercises for respiratory-muscle training (RMT).

The percent vital capacity (%VC), forced expiratory volume (FEV) in one second/forced vital capacity ratio (FEV 1.0%), and American Spinal Injury Association motor score⁶

(MS) were assessed upon admission and at weeks 4 and 12. The MS has a maximum score of 25 for each extremity, with a total possible score of 50 for the upper limbs and 50 for the lower limbs. A spirometer was used for respiratory measurements at admission with the patient in a supine position and at weeks 4 and 12 with the patient sitting up. We calculated the rate of change of the %VC⁷ and the improvement rate of the MS⁸ from admission to week 4, from admission to week 12, and from week 4 to week 12. Patients were assessed for restrictive ventilatory impairment (defined as 80% or less of the %VC) or obstructive ventilator impairment (defined as 70% or less of the %VC)⁹. Statistical significance was analyzed by Spearman's rank-correlation coefficient and by the Tukey-Kramer HSD test using JMP software ver. 9.0.2 (SAS Institute Inc., Cary, NC, USA). A p value < 0.05 was considered statistically significant. All patients gave their informed consent for inclusion in the study.

Results

At the time of admission, 50 (92.6%) of the 54 patients had restrictive ventilatory impairment (average %VC 56.7%; average FEV 1.0% 82.0%) (Fig. 1). The average MS was 15.2 for the upper limbs and 22.8 for the lower limbs. The %VC was correlated with the MS for the upper limb (R = 0.57) and lower limb (R = 0.56) and with the combined MS for the upper and lower limbs (Fig. 2). The %VC, lower-limb MS, and upper-limb MS all showed significant im-

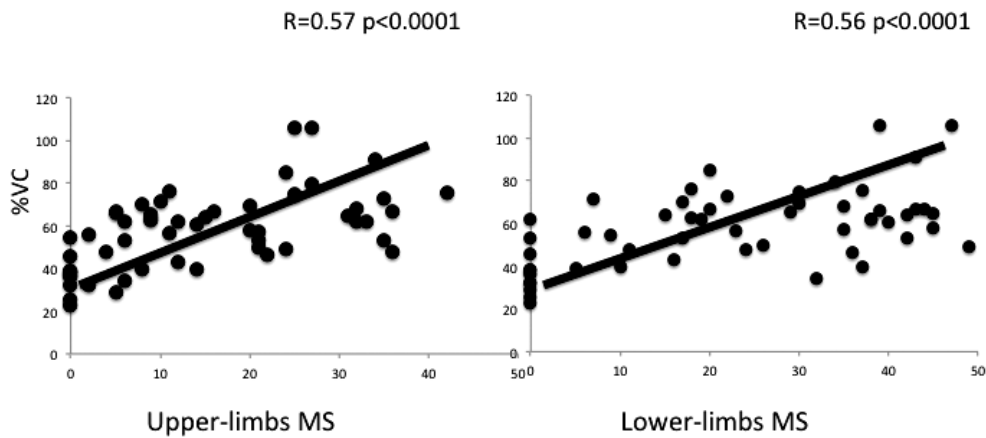


Figure 2. Correlation between upper- and lower-limb MSs and the %VC at admission. The %VC was correlated with the MS of the upper limb (R=0.57) and lower limb (R=0.56).

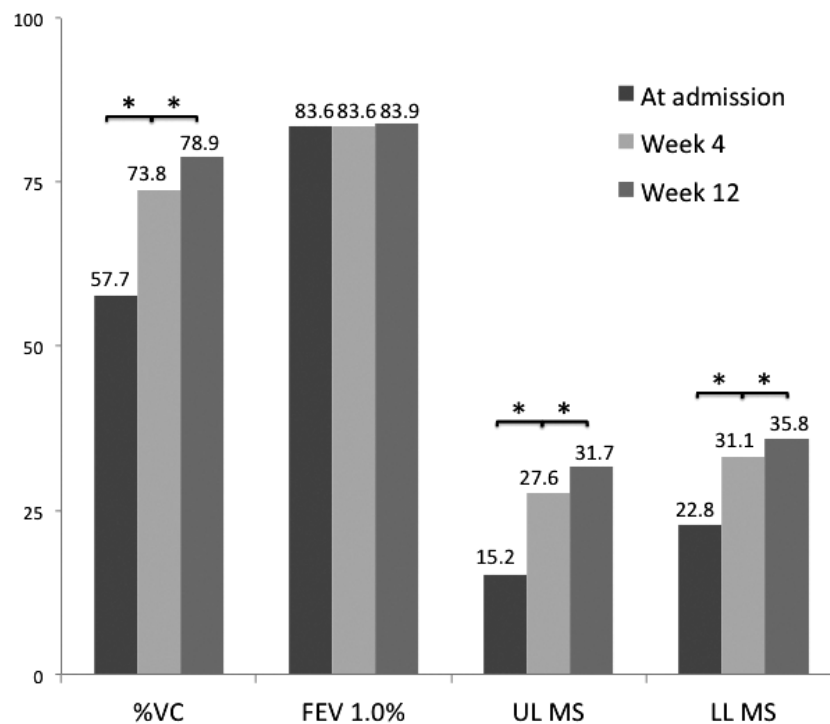


Figure 3. Changes in %VC, FEV 1.0%, and upper- and lower-limb MSs over time.

The MS of the upper and lower limbs and the %VC had significantly improved by weeks 4 and 12; *P<0.01. UL MS, upper-limb MS (50 points possible); LL MS, lower-limb MS (50 points possible).

improvements at 4 and 12 weeks (Fig. 3). At 12 weeks, 26 patients (48.1%) still had restrictive impairment (average %VC 78.9%; average FEV 1.0%/83.9%) (Fig. 4). The improvement rates for the %VC, upper-limb MS, and lower-limb MS were 32.1%, 39.1%, and 47.8% from week 0 to week 4, respectively; 7.8%, 21.3%, and 12.0% from week 4 to week 12, respectively; and 41.2%, 51.8%, and 60.3% from week 0 to week 12, respectively. The %VC rate of change was significantly correlated with the improvement rate of the lower-limb MS (but not the upper-limb MS) over the entire period (Table 1). We then divided the patients into elder (≥

75 years old) and younger (≤74) groups and compared their improvements in respiratory function and upper- and lower-limb MSs. In the elder group, neither upper- nor lower-limb MS improvement was correlated with the improvement of respiratory function (R = -0.05). In the younger group, only lower-limb MS improvement was correlated with the improvement of respiratory function (R = 0.3226), as observed in the entire patient group.

These observations indicated that lung capacity decreases in cervical SCIWOB patients because of the paralysis of the respiratory muscles on the same level as the motor pa-

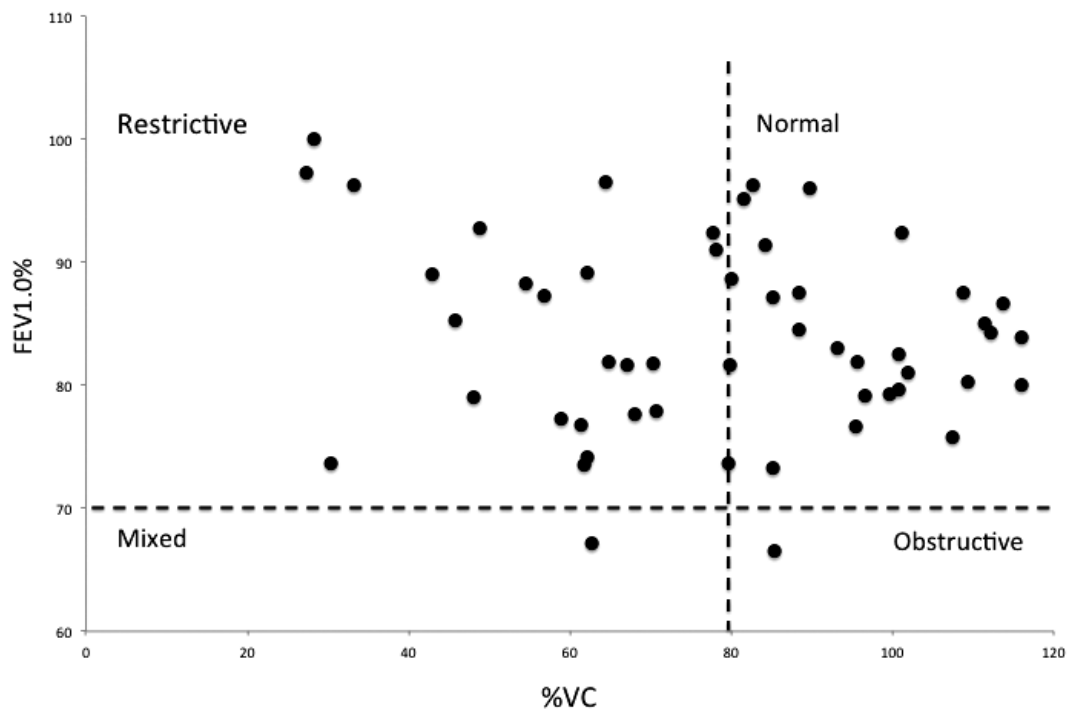


Figure 4. Pulmonary function test at week 12. Restrictive ventilator impairment was still present in 26 patients (48.1%) at 12 weeks after injury.

Table 1. Correlation Coefficient between the Rate of Change of the %VC and the Improvement Rate of the MS from Admission to Week 4, from Admission to Week 12, and from Week 4 to Week 12.

	Correlation coefficient	P value
MS (Upper limbs)		
Period (weeks)		
0-4	0.1916	0.1651
0-12	0.2059	0.1353
4-12	0.2395	0.0811
MS (Lower limbs)		
Period (weeks)		
0-4	0.1896	0.1697
0-12	0.3054	0.0247*
4-12	0.3614	0.0073*

Abbreviations: VC, Vital Capacity; MS, American Spinal Injury Association motor score; the period is weeks postadmission (0 is at admission) *p<0.05

ralysis of the upper and lower limbs. Lung capacity is likely to improve as patients recover motor function in their lower limbs. None of the patients in this study were placed on mechanical ventilation or had a tracheotomy.

Discussion

Most patients in this study had restrictive ventilatory impairment when first evaluated for cervical SCIWOB; this finding is consistent with observations in patients with cervi-

cal SCI in general¹⁰. Studies have reported a %VC improvement of 15% to 30% in cervical SCI¹¹⁻¹⁴. In the present study, the %VC improvement rate of cervical SCIWOB was 41.2% for the entire 12-week period, and most patients showed good improvement in RD throughout this period.

Various interventions for cervical SCI have been described in the literature, including RMT to improve respiratory function^{11,22}. In the present study, all patients were encouraged to pursue early mobilization starting from the day after admission. All patients were trained in breathing to strengthen their accessory respiratory muscles, such as the sternocleidomastoid, trapezius, and scalene muscles, which receive motor innervations from C2-C3, C2-C4, and C4-C6, respectively. These muscles can be trained by placing a load on the muscle, similar to limb training. Some studies have reported that expiratory-muscle resistance training improves respiratory-muscle performance^{11,18,19}; thus, we used a rehabilitation program that includes exhalation training with a device called a “party horn,” which can easily be used at the bedside at any time. Patients were also trained to stretch the chest wall to prevent chest contraction because the flaccid paralysis of the thoracic intercostals causes paradoxical chest wall contraction rather than expansion during diaphragm activity, thus reducing ventilator efficiency²³⁻²⁶. Patients undergo respiratory training in a room set aside for this purpose for approximately three hours in the morning and three hours in the afternoon for five days a week depending on the patient’s condition. In their free time, patients continue with party horn training or weight loading on the upper abdomen according to their particular needs. Considering that RD can continue to improve through week 12, it is neces-

sary to continue respiratory training up to this period.

A patient's overall respiratory outcome is still largely affected by the neurologic level and severity of the injury. Upper cervical and functionally complete cervical SCI patients suffer the highest morbidity and mortality rates²⁷⁻²⁹). In the current study, the absolute value of the %VC of our patients at 12 weeks was significantly lower than that at 0 weeks; this finding is in accordance with the neurological level of injury (NLI) and AIS (data not shown). However, the %VC rate of change over the entire period was not significantly correlated with the NLI or AIS (data not shown). We also investigated the relationship between age and RD. The absolute value of the %VC at 12 weeks was significantly lower in older patients, and the %VC rate of change over the entire period was also significantly correlated with age (data not shown). These results suggested that we should still apply RMT to improve respiratory function regardless of a patient's age, NLI, or AIS at injury because all patients have the potential to improve even if they suffer from complete paralysis or from an injury at a high cervical spinal level. However, we note that elderly patients with incomplete paralysis and a lower cervical cord injury level may improve more slowly than expected before starting RMT.

A reduction in %VC of 20%-50% in cervical SCI causes inefficient ventilation and markedly impairs the ability to cough²³). Patients with a %VC less than 25% are likely to develop respiratory failure and require ventilator support³⁰). In the present study, 4 patients still had a %VC < 40% at the end of 12 weeks. Although respiratory training may have helped these patients stay off mechanical ventilation at least through week 12, these patients are likely to face a life-long struggle with RD because of the impairment of the cough-mediated clearance of airways, thus leading to atelectasis, infection, and compromised respiratory function. Given these challenges, cervical SCIWOBi patients with RD will benefit greatly from persistent interventions, such as RMT, and from proper bedside care that improves respiratory function and prevents or alleviates these conditions. Considering that lung capacity improved as patients recovered motor function in their lower limbs, evaluating lower-limb MS may be a good way to assess RD improvement. We speculate that the lack of correlation between lower-limb MS and respiratory function improvement in the elder group was due to individual differences in the patients' motor disorder history, RD, and muscle strength. Further investigations are needed to elucidate the effects of these factors. This study followed cervical SCIWOBi patients for 12 weeks, but longer follow-up studies are necessary to investigate the long-term recovery and prognosis for cervical SCIWOBi.

Conclusions

Restrictive ventilatory impairment was present in 92.6% of cervical SCIWOBi patients at the initial evaluation. Although the %VC, upper-limb MS, and lower-limb MS showed improvements at 4 and 12 weeks, restrictive impair-

ment was still present in 48.1% of patients at week 12. Lung capacity improved as patients, particularly in the younger group, recovered lower-limb motor function throughout the 12-week period.

Conflicts of Interest: The authors declare that there are no relevant conflicts of interest.

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Author Contributions: Chikara Ushiku wrote and prepared the manuscript, and all of the authors participated in the study design. All authors reviewed and approved the final version of the manuscript.

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