

## Case Report



# Central Hypoventilation Syndrome in Posterior Circulation Stroke Treated by Respiratory Rehabilitation: a Case Report

## OPEN ACCESS

**Received:** Dec 28, 2018

**Revised:** Mar 14, 2019

**Accepted:** Mar 22, 2019

### Correspondence to

**Seong Hoon Lim**

Department of Rehabilitation Medicine, St.  
Vincent's Hospital, College of Medicine, The  
Catholic University of Korea, 222 Banpo-daero,  
Seocho-gu, Seoul 06591, Korea.  
E-mail: seonghoon@catholic.ac.kr

**Mee-Gang Kim, Bomi Sul, Bo Young Hong, Joon Sung Kim, Seong Hoon Lim**

## HIGHLIGHTS

- Central hypoventilation syndrome is a rare and fatal condition resulting from stroke.
- Respiratory program was consisted with NMES, strengthening and aerobic exercise.
- Intensive respiratory treatment would be useful for central hypoventilation syndrome.

## Case Report



# Central Hypoventilation Syndrome in Posterior Circulation Stroke Treated by Respiratory Rehabilitation: a Case Report

Mee-Gang Kim ,<sup>1,2</sup> Bomi Sul ,<sup>1,2</sup> Bo Young Hong ,<sup>1,2</sup> Joon Sung Kim ,<sup>1,2</sup>  
Seong Hoon Lim ,<sup>1,2</sup>

<sup>1</sup>Department of Rehabilitation Medicine, The Catholic University of Korea, St. Vincent's Hospital, Suwon, Korea

<sup>2</sup>Department of Rehabilitation Medicine, College of Medicine, The Catholic University of Korea, Seoul, Korea

## OPEN ACCESS

**Received:** Dec 28, 2018

**Revised:** Mar 14, 2019

**Accepted:** Mar 22, 2019

### Correspondence to

**Seong Hoon Lim**

Department of Rehabilitation Medicine, St. Vincent's Hospital, College of Medicine, The Catholic University of Korea, 222 Banpo-daero, Seocho-gu, Seoul 06591, Korea.  
E-mail: seonghoon@catholic.ac.kr

**Copyright** © 2019. Korea Society for Neurorehabilitation

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<https://creativecommons.org/licenses/by-nc/4.0>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

### ORCID iDs

Mee-Gang Kim   
<https://orcid.org/0000-0001-7709-2079>

Bomi Sul   
<https://orcid.org/0000-0001-7166-8997>

Bo Young Hong   
<https://orcid.org/0000-0001-9290-6173>

Joon Sung Kim   
<https://orcid.org/0000-0001-7457-593X>

Seong Hoon Lim   
<https://orcid.org/0000-0002-5475-4153>

## ABSTRACT

Central hypoventilation syndrome is a rare and fatal condition resulting from various central nervous system disorders that is characterized by a failure of automatic breathing. We report a case of central hypoventilation syndrome following posterior circulation stroke whose pulmonary function was improved by respiratory rehabilitation. A 59-year-old woman with a history of hemorrhagic stroke of the bilateral cerebellum was hospitalized due to pneumonia. A portable ventilator was applied via tracheostomy, recurrent episodes of apnea and hypercapnia impeded weaning. A respiratory rehabilitation program including chest wall range of motion exercise, air stacking exercise, neuromuscular electrical stimulation (NMES) on abdominal muscles, upper extremity ergometer, locomotor training, high-frequency chest wall oscillator, mechanical insufflation, and exsufflation was employed, as spirometry showed a severe restrictive pattern. A spontaneous breathing trial was started, and a portable ventilator was applied for 8 hours, only during nighttime, to prevent sudden apneic event. After 4 weeks of treatment, follow-up spirometry showed much improved respiratory parameters. This case suggests that respiratory rehabilitation can improve pulmonary function parameters and quality of life in central hypoventilation syndrome.

**Keywords:** Stroke; Respiratory Center; Hypoventilation; Central Hypoventilation Syndrome; Respiratory Rehabilitation; Cerebellar Hemorrhage

## INTRODUCTION

Central hypoventilation syndrome is a rare condition resulting from various central nervous system disorders that is characterized by failure of automatic breathing during sleeping. Acquired central hypoventilation syndrome may develop as a result of stroke, tumor, demyelinating disease, or neurosurgical complications [1]. Central hypoventilation with brainstem stroke has been rarely reported since 1962 [2]. There is no definite consensus regarding diagnosis or treatment options, and the prognosis is usually unpredictable, although the condition is often fatal [3-5]. Also, there has been no report of respiratory rehabilitation and ventilator weaning process for central hypoventilation so far. Here, we

#### Funding

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (grant number: 2017R1E1A1A01074324).

#### Conflict of Interest

The authors have no potential conflicts of interest to disclose.

report the case of a patient with recurrent hypoventilation after posterior circulation stroke that was improved by comprehensive respiratory rehabilitation.

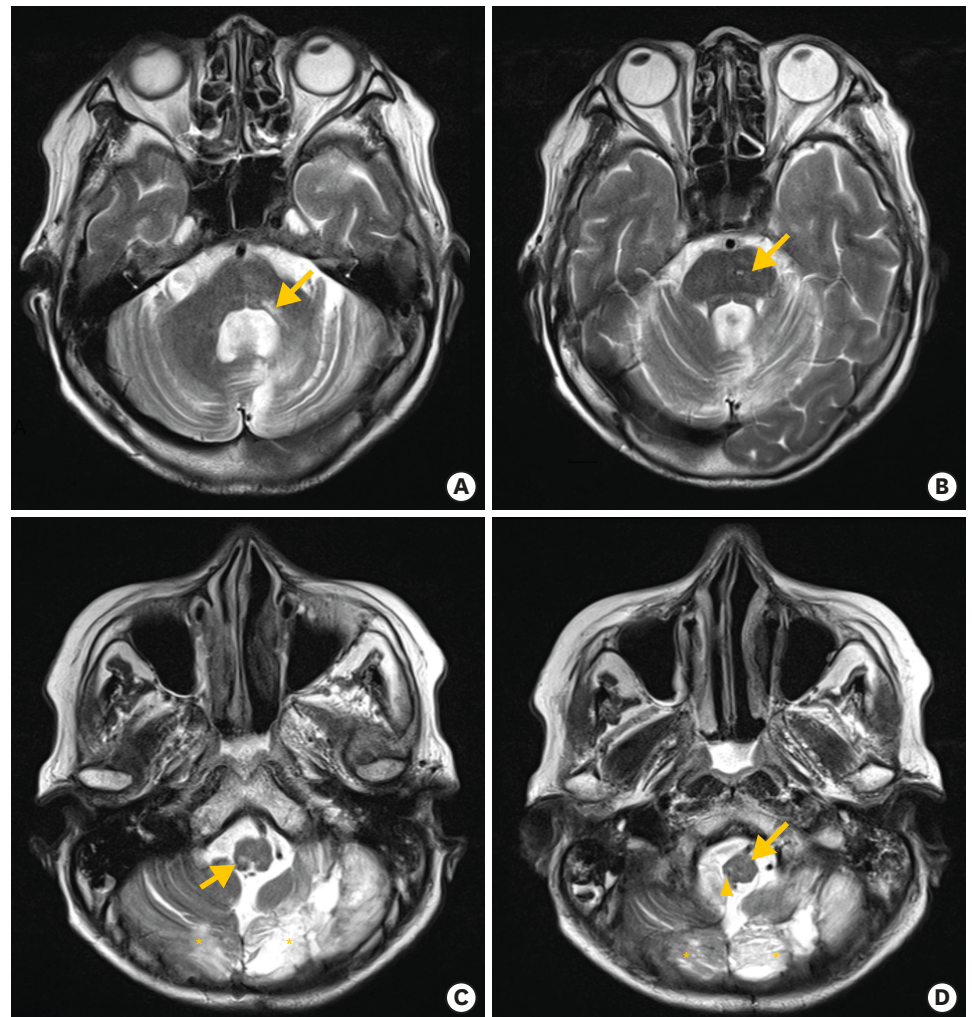
## CASE REPORT

A 59-year-old woman visited the emergency department for dyspnea, hypoxia, and fever. The patient had a history of bilateral cerebellar hemorrhage 5 months previously, and underwent a craniotomy and a tracheostomy. She had been hospitalized for stroke and recurrent pneumonia at another hospital. The patient had been recommended to use portable ventilator, but has not been using it for more than 3 months. She was diagnosed with aspiration pneumonia and treated in the intensive care unit with mechanical ventilation. On the 11th day of hospitalization, ventilator weaning was attempted. The patient had maintained tolerable state on oxygen (O<sub>2</sub>) support of 2 L/min for 2 days, but on the 3rd day of weaning the blood gas study revealed mild respiratory acidosis and carbon dioxide (CO<sub>2</sub>) retention as a pH of 7.34, pCO<sub>2</sub> of 85.2 mmHg and pO<sub>2</sub> of 101.6 mmHg. The phenomenon was thought to be oxygen-induced hypercapnia and O<sub>2</sub> was tapered to 0.5 L/min. On the 5th day of weaning, the patient was found apneic and in stupor. The blood gas study showed respiratory acidosis and severe hypercapnia, a pH of 7.33, and pCO<sub>2</sub> of 97.8 mmHg. The mechanical ventilator was applied again, and spontaneous breathing was not detected by the ventilator for a day.

A week later, the patient was transferred to the department of rehabilitation medicine for respiratory rehabilitation. On neurologic examination, there was a mild ocular skew deviation without specific oculomotor palsies. There was moderate ataxia of the trunk and both extremities. Motor examination revealed Medical Research Council (MRC) grade 3 weakness of the left upper extremity and MRC grade 2 weakness of the right lower extremity. Deep tendon reflexes were increased at the right extremity, and Hoffman's sign was present in the right hand. The patient could maintain static sitting position, but standing was unable due to trunk ataxia and weakness of the right lower extremity. The patient's initial Glasgow Coma Scale (GCS) score was 14 (eye response 4, verbal response 4, motor response 6). The National Institutes of Health Stroke Scale (NIHSS) score was 12. The Korean Mini-Mental Status Examination (K-MMSE) score of the patient was 20, with impairments in orientation, attention, language, and visuospatial domains. Voice and speech could not be evaluated because of the tracheostomy, but the patient could make a simple conversation by body language and follow 3-step commands. On speech-language evaluation, the oral motor function task showed generally poor movement, and severely impaired speech intelligibility and dysphonia. The patient's Aphasia Quotient assessed by the Korean version Western Aphasia Battery was 84.6 and there was no definite difficulty with daily conversation. All nutrition was supplied through the nasogastric tube, as the Videofluoroscopic Swallowing Studies showed a massive amount of silent aspiration without opening of upper esophageal sphincter or laryngeal elevation (Videofluoroscopic Dysphagia Scale [VDS] score 87, Penetration-aspiration Scale score 8, Dysphagia Outcome and Severity Scale 1). The modified Barthel index of the patient was scored 7, as she was totally dependent in all activities of daily living, except for dressing and bowel control. Portable ventilator support was applied via the tracheostomy tube and kept for 24 hours.

The initial computed tomography (CT) scan of the brain which was taken 5 months ago showed about 18.7 mL of hematoma, in the left cerebellar hemisphere. The neurologic examination of the patients highly suggested the brainstem lesion but there were no obvious brainstem lesions on follow-up CT scans of the brain, which were last taken 2 months

ago. Thus, we did the brain magnetic resonance imaging (MRI) to identify the unknown lesions. The T2-weighted brain MRI showed encephalomalacic changes in both cerebellar hemispheres, the left middle cerebellar peduncle, left pons, and the left anterior and right lateral medulla (Fig. 1). As there were no acute lesions shown in diffusion-weighted imaging and apparent diffusion coefficient map of the brain MRI, these brainstem lesions were thought to be degenerations following cerebellar hemorrhage. The initial spirometry was done through the tracheostomy tube in 90-degree sitting position in wheelchair, and the connection site between the tube and the spirometry was carefully sealed by gauze and sealing tape and the examiner's hands to prevent air leakage (Vmax 22; CareFusion, San Diego, CA, USA). The spirometry demonstrated forced vital capacity (FVC) of 950 mL (35% of the reference), forced expiratory volume in 1 second ( $FEV_1$ ) of 920 mL (46% of the reference), and  $FEV_1/FVC$  of 97%. An electrodiagnostic study was done to rule out any possibilities of other neuromuscular diseases such as myopathy or motor neuron disease. There were no clear evidences of such diseases, except for bilateral median entrapment neuropathies around the wrist. Hematologic and coagulation profile, electrolytes, renal functions, liver functions,



**Fig. 1.** T2-weighted brain MRI showing encephalomalacic changes in both cerebellar hemispheres. The left middle cerebellar peduncle (arrow, A), left pons (arrow, B), left anterior (arrow, D), and right lateral medulla (arrowhead, D).

MRI, magnetic resonance imaging.

\*Cerebellar hemispheres.

and thyroid functions were unremarkable. The CT scan of lung and mediastinum showed no evidence of structural abnormalities of lung and heart. The echocardiogram and 24-hour Holter monitoring revealed no significant abnormalities. Based on the clinical manifestation (recurrent apnea during sleeping) and brain imaging, we considered the patient has the central hypoventilation due to brainstem lesion.

As there is no standardized protocol for respiratory rehabilitation of specific brain lesion, we applied strategies for active respiratory rehabilitation programs that have been used and proven effective in patients with chronic obstructive pulmonary disease or neuromuscular diseases including cervical spinal cord injury. A daily respiratory rehabilitation program including neuromuscular electrical stimulation (NMES) of the abdominal muscles, air-stacking exercise via tracheostomy tube, mechanical insufflation-exsufflation (MIE), chest wall range of motion (ROM) exercise, upper extremity ergometer, locomotor training such as wheelchair propulsion, and high-frequency chest wall oscillator was applied (Table 1).

**Table 1.** The respiratory rehabilitation protocols for the patient and their expected effects

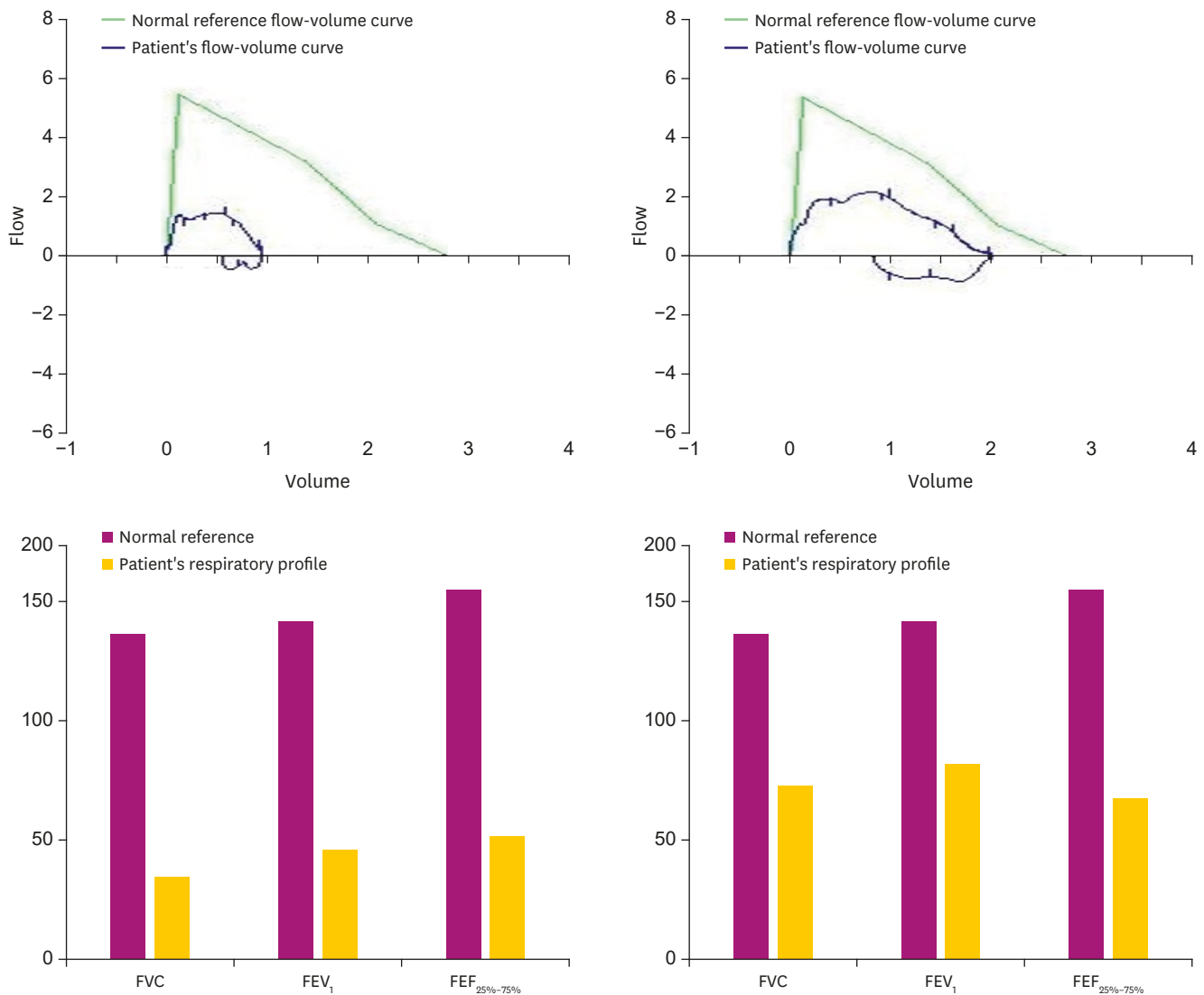
Respiratory rehabilitation	Protocol	Expected effects	Reference
Chest wall range of motion exercise	<ul style="list-style-type: none"> <li>- Five-minute warm-up stretching of intercostalis, pectoralis, sternocleidomastoid muscles</li> <li>- Bilateral sides of muscles are gently stretched with manual assist of physiotherapist</li> <li>- Five minutes</li> <li>- Once a day</li> <li>- Five days a week</li> </ul>	<p>Increased range of motion of thorax</p> <p>Decreased respiratory muscles fatigue</p>	Putt et al. (2008)
Air stacking exercises	<ul style="list-style-type: none"> <li>- Two times of additional air infusion after maximal inhalation and holding breath for 2 seconds</li> <li>- Ten times per session</li> <li>- Once a day</li> <li>- Five days a week</li> </ul>	<p>Increased range of motion of thorax</p> <p>Improvement of FVC</p>	Na et al. (2014)
Functional electrical stimulation of the abdominal muscles	<ul style="list-style-type: none"> <li>- Active electrodes on bilateral rectus abdominis muscles</li> <li>- Intensity: 50 mA</li> <li>- Frequency: 50 Hz</li> <li>- Fifteen minutes</li> <li>- Once a day</li> <li>- Five days a week</li> </ul>	<p>Improvement of abdominal muscle strength</p> <p>Improvement of FEV<sub>1</sub></p>	<p>McLachlan et al. (2013)</p> <p>McCaughey et al. (2016)</p> <p>Na et al. (2014)</p>
Upper extremities ergometer	<ul style="list-style-type: none"> <li>- Proprioceptive Neuromuscular Facilitation</li> <li>- Maximal weight</li> <li>- Revolutions per minutes</li> <li>- Twenty minutes</li> <li>- Once a day</li> <li>- Three times a week</li> </ul>	<p>Improvement of FVC and FEV<sub>1</sub></p>	<p>Sutbeyaz et al. (2005)</p> <p>McKeough et al. (2012)</p>
Locomotor training	<ul style="list-style-type: none"> <li>- Wheelchair propulsion with both hands</li> <li>- Start at 1.0 km/h, increased up to 1.5 km/h</li> <li>- Ten minutes</li> <li>- Once a day</li> <li>- Five days a week</li> </ul>	Improvement of FVC	Tiftik et al. (2015)
High-flow chest wall oscillator	<ul style="list-style-type: none"> <li>- Pressure setting 6</li> <li>- Twelve Hz</li> <li>- Ten minutes</li> <li>- Once a day</li> <li>- Five days a week</li> </ul>	Improvement of airway secretion elimination	<p>Huang et al. (2016)</p> <p>Darbee et al. (2005)</p>
Mechanical insufflation-exsufflation	<ul style="list-style-type: none"> <li>- Insufflation pressure of +30 cmH<sub>2</sub>O</li> <li>- Exsufflation pressure of -30 cmH<sub>2</sub>O</li> <li>- Five positive-to-negative pressure per session, followed by 20 seconds of normal breathing</li> <li>- Five session a day</li> <li>- Five days a week</li> </ul>	Improvement of airway secretion elimination	Vianello et al. (2005)

FVC, forced vital capacity; FEV<sub>1</sub>, forced expiratory volume in 1 second.



1. Chest wall ROM exercise: before starting active respiratory rehabilitation, 5-minute warm-up stretching of intercostalis, pectoralis, sternocleidomastoid muscles was done. Because the patient's dynamic sitting balance was poor, this stretching exercise was done with manual assist of a physiotherapist. 5 minutes per session, once a day, 5 days a week [6].
2. Air stacking exercise: the patient was encouraged to inhale as much air as she can, and then therapist infused additional air two times by bagging (M.O.W. Silicone resuscitators MR010; MOW Medical, Wonju, Korea) via tracheostomy. The patient holds the breath for 2 seconds and then started to exhale. 10 times per session, once a day, 5 days a week. This exercise was done in a supine position on the first week, and then changed to a sitting position [7].
3. NMES on abdominal muscles: active electrodes were placed on the bilateral rectus abdominis muscles (Microstim; MEDEL, Hamburg, Germany). The patient was encouraged to exhale during the stimulation. 50 mA of intensity, 50 Hz of frequency, for 15 minutes, once a day, 5 days a week, in a sitting position [7-9].
4. Upper extremity ergometer: arm crank exercise was performed at 60% of the peak work rate. Intensity was progressed maintaining symptom scores at a moderate level of 3 on the modified Borg scale. For 15 minutes, 3 times a week (Isokinetic upper body ergometer, PRO1000 seated upper body; SCIFIT, Tulsa, OK, USA) [10,11].
5. Locomotor training: wheelchair propulsion with both upper extremities, started at 1.0 km/h, increased up to 1.5 km/h. For 10 minutes, twice a day, started with 3 days a week and increased to 5 days a week [12].
6. High-frequency chest wall oscillator: vest pressure setting 6 (The Vest; Hill-Rom, Chicago, IL, USA), 12 Hz of frequency, for 15 minutes, once a day, 5 days a week, in a sitting position [13,14].
7. MIE: insufflation and exsufflation pressures of +30/-30 cmH<sub>2</sub>O were applied via tracheostomy (Cough & Suction, CNS-100; Sungdo MC, Siheung, Korea), and changed to oronasal mask after the removal of the tracheostomy. Five positive-to-negative pressure cycles per session, followed by 20 seconds of normal breathing. Total 5 session per day, 5 days a week, in a sitting position [15].

After 4 weeks of rehabilitation, follow-up spirometry showed improved respiratory parameters (Fig. 2); FVC increased to 1,990 mL (73% of reference), FEV<sub>1</sub> increased to 1,650 mL (82% of reference), and FEV<sub>1</sub>/FVC was 83% (Table 2). Ventilator weaning with spontaneous breathing trial was attempted. Ventilator-free time was gradually prolonged as blood gas analysis showed no hypercapnia; pCO<sub>2</sub> was maintained from 32 to 39 mmHg. The patient could sustain tolerable breathing, but after 60 hours of ventilator cessation, she experienced sudden dyspnea and drowsiness. Consequently, ventilation support was continued for 8 hours only during sleeping to prevent a sudden apneic event. The non-fenestrated cuffed tracheostomy tube was changed to a fenestrated cuffed tube, which was kept plugged during daytime so that the patient could speak. Air stacking exercise and MIE was applied via oronasal mask with tracheostomy kept plugged. After 4 weeks of rehabilitation, motor power improved from MRC grade 3 to 4 in the left upper extremity and from MRC grade 2 to 3 in the right lower extremity. Static standing balance was improved to fair grade, and the patient could walk short distance with maximal assist. Follow-up GCS score was 15, NIHSS score was 7. The K-MMSE score and the VDS score have not been changed. The modified Barthel Index score was improved from 7 to 25. On the 55th hospital day, she was transferred to a rehabilitation hospital.



**Fig. 2.** Changes in spirometry before (left) and after (right) 4 weeks of a respiratory rehabilitation program. FVC, forced vital capacity; FEV<sub>1</sub>, forced expiratory volume in 1 second; FEF<sub>25%-75%</sub>, forced expiratory flow at 25%-75%.

**Table 2.** Changes in pulmonary function test parameters after 4 weeks of respiratory rehabilitation

Variables	Initial study (January 3rd, 2017)		Follow-up study (January 31st, 2017)	
	Pre	%Ref	Pre	%Ref
Spirometry				
FVC (L)	0.95	35	1.99	74
FEV <sub>1</sub> (L)	0.92	46	1.65	82
FEV <sub>1</sub> /FVC (%)	97	-	83	-
PEF (L/sec)	1.40	26	2.15	40

FVC, forced vital capacity; FEV<sub>1</sub>, forced expiratory volume in 1 second; PEF, peak expiratory flow; Pre, before using bronchodilator; %Ref, percentage of the reference value.

## DISCUSSION

Central hypoventilation syndrome caused by cerebellar and brainstem stroke may have poor prognosis. Our case demonstrated that respiratory rehabilitation can contribute to favorable outcomes, with improved pulmonary function parameters and ventilator weaning, which had

not been described in previous case reports [5,16]. Moreover, we provided herein a detailed description of respiratory rehabilitation for future public use.

Central hypoventilation syndrome can be caused by posterior circulation stroke, and consensus on the diagnostic criteria and therapeutic options is lacking. The pathophysiology is thought to be loss of automatic and/or voluntary breathing by selective lesions involving interconnected respiratory groups in the brainstem; the pontine respiratory group, the dorsal respiratory group, and the ventral respiratory group [5,17]. The abnormal periodic breathing with apnea is regarded as sequelae of extensive cerebrovascular accidents and regularly found immediately after stroke, then markedly declines 3 and 6 months into recovery [3,17]. The prevalence of automatic breathing failure after stroke has not been estimated so far, although some cases in medullary lesions have been reported [2,4,5,16,18-26]. The prognosis was usually poor with recurrent apneic event followed by re-intubation, and ended with death because of respiratory arrest, pneumonia, and sepsis [19,20,23,24,26]. Some authors have suggested that polysomnography, overnight oximetry monitoring, or end tidal CO<sub>2</sub> monitoring would help in detecting the events of central sleep apnea [5,16]. In 2012, the American Academy of Sleep Medicine (AASM) Sleep Apnea Definitions Task Force reviewed rules for scoring respiratory events [27]. The task force made recommendations concerning recommended and alternative sensors for the detection of apnea and hypopnea during polysomnography. The major limitation of this report is that the polysomnography or overnight end-tidal pCO<sub>2</sub> monitoring were not evaluated. However, the clinical manifestation showed recurrent apneic events during the late phase of sleep, which were detected by ventilator alarm (which is recommended sensors for apnea by AASM manual). Previous case reports of central hypoventilation syndrome have not done the polysomnography and the diagnosis was based on the clinical manifestation. Although it is currently not covered by national insurance service, we suggest the polysomnography to prove and precisely diagnose sleep disordered breathing, if possible.

Respiratory rehabilitation is a comprehensive intervention based on thorough patient assessment, followed by patient-tailored exercise training, education, and behavior change [17]. One strategy with demonstrated therapeutic potential is the use of treatments that increase neural and muscular activity which may contribute to direct stimulation of respiratory circuitry and promote plasticity [12,18]. There has been no structured protocol for respiratory rehabilitation in hypoventilation caused by brainstem stroke. In this case report, we constituted respiratory rehabilitation program with widely used strategies for chronic pulmonary diseases and other neuromuscular diseases. We designed the protocol to increase chest wall mobility (chest wall ROM exercise [6], air stacking exercise [7]), improve vital capacity (air stacking exercise [7], upper extremity ergometer [10], locomotor training [12]), strengthen expiratory muscles (NMES on abdominal muscle [7-9], upper extremity ergometer [10,11]), and eliminate airway secretion (MIE [15], high-flow chest wall oscillator [13,14]). The effectiveness of individual strategies of respiratory rehabilitation in central hypoventilation syndrome may be difficult to prove by clinical trials due to its rarity. Nevertheless, we suggest that strategies to enhance neuroplasticity in cervical spinal cord injuries may also be beneficial in central hypoventilation caused by brainstem lesions, as both diseases can compromise the projections of respiratory circuits arising from the brainstem.

In conclusion, patients with posterior circulation stroke can present automatic breathing failure and should be carefully monitored for sudden apnea, especially during sleep. Respiratory rehabilitation and ventilator support regarding the individual's specific



condition can result in a good prognosis and improved activities of daily living in central hypoventilation syndrome.

## REFERENCES

1. Zaidi S, Gandhi J, Vatsia S, Smith NL, Khan SA. Congenital central hypoventilation syndrome: an overview of etiopathogenesis, associated pathologies, clinical presentation, and management. *Auton Neurosci* 2018;210:1-9.  
[PUBMED](#) | [CROSSREF](#)
2. Severinghaus JW, Mitchell RA. Ondine's curse - failure of respiratory center automaticity while awake. *Clin Res* 1962;10:122.
3. Randerath W, Verbraecken J, Andreas S, Arzt M, Bloch KE, Brack T, Buyse B, De Backer W, Eckert DJ, Grote L, Hagmeyer L, Hedner J, Jennum P, La Rovere MT, Miltz C, McNicholas WT, Montserrat J, Naughton M, Pepin JL, Pevernagie D, Sanner B, Testelmans D, Tonia T, Vrijsen B, Wijkstra P, Levy P. Definition, discrimination, diagnosis and treatment of central breathing disturbances during sleep. *Eur Respir J* 2017;49:1600959.  
[PUBMED](#) | [CROSSREF](#)
4. Mishina M, Ohkubo S, Kamiya N, Abe A, Suda S, Sakamaki M, Kominami S, Mizunari T, Kobayashi S, Katayama Y. Efficacy of tracheostomy for central alveolar hypoventilation syndrome caused by lateral medullary infarction. *J Nippon Med Sch* 2014;81:276-284.  
[PUBMED](#) | [CROSSREF](#)
5. Mendoza M, Latorre JG. Pearls and oysters: reversible Ondine's curse in a case of lateral medullary infarction. *Neurology* 2013;80:e13-e16.  
[PUBMED](#) | [CROSSREF](#)
6. Putt MT, Watson M, Seale H, Paratz JD. Muscle stretching technique increases vital capacity and range of motion in patients with chronic obstructive pulmonary disease. *Arch Phys Med Rehabil* 2008;89:1103-1107.  
[PUBMED](#) | [CROSSREF](#)
7. Na EH, Han SJ, Yoon TS. Effect of active pulmonary rehabilitation on pulmonary function in patients with brain lesion. *NeuroRehabilitation* 2014;35:459-466.  
[PUBMED](#) | [CROSSREF](#)
8. McCaughey EJ, Borotkanics RJ, Gollee H, Folz RJ, McLachlan AJ. Abdominal functional electrical stimulation to improve respiratory function after spinal cord injury: a systematic review and meta-analysis. *Spinal Cord* 2016;54:754.  
[PUBMED](#) | [CROSSREF](#)
9. McLachlan AJ, McLean AN, Allan DB, Gollee H. Changes in pulmonary function measures following a passive abdominal functional electrical stimulation training program. *J Spinal Cord Med* 2013;36:97-103.  
[PUBMED](#) | [CROSSREF](#)
10. Sutbeyaz ST, Koseoglu BF, Gokkaya NK. The combined effects of controlled breathing techniques and ventilatory and upper extremity muscle exercise on cardiopulmonary responses in patients with spinal cord injury. *Int J Rehabil Res* 2005;28:273-276.  
[PUBMED](#) | [CROSSREF](#)
11. McKeough ZJ, Bye PT, Alison JA. Arm exercise training in chronic obstructive pulmonary disease: a randomised controlled trial. *Chron Respir Dis* 2012;9:153-162.  
[PUBMED](#) | [CROSSREF](#)
12. Tiftik T, Gökaya NK, Malas FU, Tunç H, Yalçın S, Ekiz T, Erden E, Akkuş S. Does locomotor training improve pulmonary function in patients with spinal cord injury? *Spinal Cord* 2015;53:467-470.  
[PUBMED](#) | [CROSSREF](#)
13. Huang WC, Wu PC, Chen CJ, Cheng YH, Shih SJ, Chen HC, Wu CL. High-frequency chest wall oscillation in prolonged mechanical ventilation patients: a randomized controlled trial. *Clin Respir J* 2016;10:272-281.  
[PUBMED](#) | [CROSSREF](#)
14. Darbee JC, Kanga JF, Ohtake PJ. Physiologic evidence for high-frequency chest wall oscillation and positive expiratory pressure breathing in hospitalized subjects with cystic fibrosis. *Phys Ther* 2005;85:1278-1289.  
[PUBMED](#) | [CROSSREF](#)
15. Vianello A, Corrado A, Arcaro G, Gallan F, Ori C, Minuzzo M, Bevilacqua M. Mechanical insufflation-exsufflation improves outcomes for neuromuscular disease patients with respiratory tract infections. *Am J Phys Med Rehabil* 2005;84:83-88.  
[PUBMED](#) | [CROSSREF](#)

16. Tanaka K, Kanamaru H, Morikawa A, Kawaguchi K. Central hypoventilation syndrome complicated with lateral medullary infarction after endovascular treatment of the vertebral artery dissecting aneurysm: a case report. *NMC Case Rep J* 2016;3:133-136.  
[PUBMED](#) | [CROSSREF](#)
17. Lipford MC, Park JG, Ramar K. Sleep-disordered breathing and stroke: therapeutic approaches. *Curr Neurol Neurosci Rep* 2014;14:431.  
[PUBMED](#) | [CROSSREF](#)
18. de Gea-García JH, Villegas-Martínez I, Fernández-Vivas M, Sanmartín-Monzó JL, Jara-Rubio R, Martínez-Fresneda M. Weaning failure in mechanical ventilation. Ondine's curse: a clinical case and review. *Med Intensiva* 2010;34:282-285.  
[PUBMED](#) | [CROSSREF](#)
19. Devereaux MW, Keane JR, Davis RL. Automatic respiratory failure associated with infarction of the medulla. Report of two cases with pathologic study of one. *Arch Neurol* 1973;29:46-52.  
[PUBMED](#) | [CROSSREF](#)
20. Heckmann JG, Ernst S. Central alveolar hypoventilation (Ondine's curse) caused by megadolichobasilar artery. *J Stroke Cerebrovasc Dis* 2014;23:390-392.  
[PUBMED](#) | [CROSSREF](#)
21. Li D, Hao SY, Lou XH, Tang J, Xiao XR, Wu Z, Zhang LW, Zhang JT. Apnea as an uncommon preoperative manifestation of medulla cavernous malformation: surgical treatment and literature review. *Br J Neurosurg* 2014;28:335-339.  
[PUBMED](#) | [CROSSREF](#)
22. Liu Z, He Y, Li S, Wu L, Jiao Q. Brainstem tethering with Ondine's curse. *World Neurosurg* 2011;76:592.e11-592.e14.  
[PUBMED](#) | [CROSSREF](#)
23. Pedroso JL, Baiense RF, Scalzaretto AP, Neto PB, Teixeira de Gois AF, Ferraz ME. Ondine's curse after brainstem infarction. *Neurol India* 2009;57:206-207.  
[PUBMED](#) | [CROSSREF](#)
24. Schestatsky P, Fernandes LN. Acquired Ondine's curse: case report. *Arq Neuropsiquiatr* 2004;62:523-527.  
[PUBMED](#) | [CROSSREF](#)
25. Sivakumar K, Garcha M, Mehta D, Leary MC, Yacoub HA. Central hypoventilation: a rare complication of Wallenberg syndrome. *Case Rep Neurol Med* 2018;2018:4894820.  
[PUBMED](#) | [CROSSREF](#)
26. Terao S, Miura N, Osano Y, Noda A, Sobue G. Rapidly progressive fatal respiratory failure (Ondine's curse) in the lateral medullary syndrome. *J Stroke Cerebrovasc Dis* 2004;13:41-44.  
[PUBMED](#) | [CROSSREF](#)
27. Berry RB, Chediak A, Brown LK, Finder J, Gozal D, Iber C, Kushida CA, Morgenthaler T, Rowley JA, Davidson-Ward SL; NPPV Titration Task Force of the American Academy of Sleep Medicine. Best clinical practices for the sleep center adjustment of noninvasive positive pressure ventilation (NPPV) in stable chronic alveolar hypoventilation syndromes. *J Clin Sleep Med* 2010;6:491-509.  
[PUBMED](#)