Effectiveness of respiratory management for mechanical ventilator weaning in traumatic spinal cord injury patients with prolonged ventilation

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Case Report

Effectiveness of Respiratory Management for Mechanical Ventilator Weaning in Traumatic Spinal Cord Injury Patients with Prolonged Ventilation

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ABSTRACT

Background. Traumatic spinal cord injury is a medical condition which often results in disability and mortality. The most common lesion was cervical level, which is around 60-75% of all cases, where at this level there is a risk of respiratory problems which often require mechanical ventilation.
Case report. In the case discussed, a 28-years-old male was referred from other hospital with traumatic cervical spinal cord injury (C5-C6) ASIA score A with a history of falling from a height of 3 meters. The patient underwent decompressive laminectomy on the tenth day of onset, followed by mechanical ventilation. During treatment, the patient received pharmacological therapy, tracheostomy, acupuncture, physiotherapy, and neuromuscular electrical stimulation for ventilator weaning. The patient was hospitalized for 66 days, with mechanical ventilation duration for 32 days.
Conclusions. Factors that can influence the duration of ventilation weaning are the level and severity of spinal cord injury, time of transfer to a health facility, and complications related to ventilator installation. Multidisciplinary management, including pharmacological, physiotherapy, acupuncture, surgical, neuromuscular electrical stimulation, can increase the chances and decreasing the duration of mechanical ventilation, and reducing complications related to spinal cord injury and prolonged ventilation.
Keywords: mechanical ventilation, respiratory management, spinal cord injury, ventilation weaning

Abbreviations:

1. Regional General Hospital (RSUD)
2. Numeric Rating Scale (NRS)
3. Computed Tomography (CT)
4. Acute Kidney Injury (AKI
5. Chronic Kidney Injury (CKD)

6. Intensive Care Unit (ICU)
7. Cipto Mangunkusumo Hospital (RSCM)
8. Serum Glutamic Oxaloacetic Transaminase (SGOT)
9. Serum Glutamate Pyruvate Transaminase (SGPT)
10. Magnetic Resonance Imaging (MRI)
11. Short Tau Inversion Recovery (STIR)
12. Upper Motor Neuron (UMN)
13. American Spinal Injury Association (ASIA)
14. Open Reduction Internal Fixation (ORIF)
15. Ventilator-Associated Pneumonia (VAP)
16. Intravenous (IV)
17. Passive range of motion (PROM)
18. Neuromuscular Electrical Stimulation (NMES)
19. Nerve Conduction Velocity (NCV)
20. Sacral region skin and soft tissue infection (SSTI)
21. Drug-induced liver injury (DILI)
22. Dorsal respiratory group (DRG)
23. Ventral respiratory group (VRG)
24. Pontine respiratory group (PRG)

INTRODUCTION

Spinal cord injury is defined as damage to the spinal cord resulting in motor, sensory, and autonomic disturbances [1]. This can lead to neurological dysfunction and life-threatening conditions. The incidence of spinal cord injury is approximately 15-40 cases per 1 million people per year. The prevalence of cases in America indicates over 1 million cases, with an incidence of 40 cases per 1 million people per year. This occurrence is more common in males (81%) and often happens in the age range of 16-30 years (50% of cases). The frequently involved levels of spinal cord injury are the cervical region (60-75%), thoracic (15%), and lumbosacral (10%)[1].

The level and severity of injury are associated with the cost of care, rehabilitation, and loss of productivity [1]. In cervical injuries, it is estimated that respiratory disturbances may occur, increasing the likelihood of the need of intubation as intervention. Approximately 40% of patients with complete cervical lesions have a risk of ventilator dependence [2]. There are several management options for patients with spinal cord injuries, but those dependent on ventilators have higher mortality rates. The life expectancy for spinal cord injury patients is related to ventilator dependence, which is subsequently linked to the cost of care and the patient's quality of life [2].

There are various respiratory management options to aid in ventilator weaning, such as physiotherapy, acupuncture, neuromuscular electrical stimulation, pharmacological therapy, and surgical interventions. This case will discuss the modalities available to assess the effectiveness of ventilator weaning in patients with traumatic cervical spinal cord injuries with history of prolonged ventilator use.

CASE REPORT

A 28-year-old male was referred from the Regional General Hospital (RSUD) of Bekasi Regency (Cibitung) with complaints of weakness in all four limbs after falling seven days ago. Seven days prior, the patient fell from the roof of a house, approximately 3 meters high, while repairing the house. The patient fell in a supine position, with the back and the back of the head hitting the ground. The patient briefly lost consciousness for less than 30 minutes and then regained consciousness. The patient began to have difficulty moving all four limbs, walking with support, but still able to grasp objects. The patient also experienced neck pain rated at 5-6 on the Numeric Rating Scale (NRS), pain in the back of the head rated at 4-5 on the NRS, and swelling at the back of the head. There was no vomiting, seizures, or discharge from the ears, mouth, or nose. The patient was initially treated at home for one day.

Six days before admission to the hospital, weakness in the limbs worsened, making it difficult to move both hands and legs. The patient also had difficulty with bowel and bladder movements, and neck and head pain persisted. The patient was then taken to RSUD Cibitung for further management.

Upon arrival at the Emergency Department of RSUD Cibitung, a head CT scan revealed minimal brain bleeding and a fracture in the posterior part of the skull. Cervical and vertebral CT images showed a fracture in the neck bones. The diagnosis from RSUD Cibitung was cervical dislocation C5-C6 with tetraplegia, septic shock, Compartment syndrome of the right humerus with a closed distal humerus fracture, Acute Kidney Injury (AKI) suspected Chronic Kidney Disease (CKD), Elevated liver enzymes, and sinus bradycardia. The patient was admitted to the ICU at RSUD Cibitung and received various therapies

On the day before admission to the current hospital, the patient's complaints remained the same. The patient was referred by the neurosurgery specialist at RSUD Cibitung to RSCM for further management.

Upon arrival at the Emergency Department of RSCM, the patient had adequate contact, couldn't move all four limbs, could still move the left hand, the right hand was splinted, numbness in all extremities, inability to control bowel movements. There was no headache, vomiting, seizures, or fluid discharge from the ears and nose.

Vital signs revealed blood pressure of 90/55 mmHg, heart rate of 52 beats per minute, respiratory rate of 20 breaths per minute, and oxygen saturation of 98% on room air. No cranial nerve paresis was observed. Motor strength in the upper extremities was 1xxx|2211 (x: difficult to assess due to Humerus Fracture), while the lower extremities had a value of 0. Sensory examination revealed hypesthesia below C6, and proprioception was impaired. Autonomic examination revealed the patient had a urinary catheter and hadn't had a bowel movement for a week. There was a decrease in patellar reflex and Achilles reflex. Anal examination showed lax sphincter tone, collapsed ampulla, and negative bulbocavernosus reflex.

Initial laboratory results showed hemoglobin of 10 g/dL (reference range: 13-17 g/dL), hematocrit of 28.4% (reference range: 40-50%), leukocytes of 22,310/μL (reference range: 4,000-10,000/μL), and platelets of 464,000/μL (reference range: 150,000-410,000/μL). Liver function tests revealed SGOT of 101 U/L (reference range: 5-34 U/L) and SGPT of 150 U/L (reference range: 0-55 U/L). Electrolyte levels were sodium 133 mEq/L (reference range: 136-145 mEq/L) and potassium 5.2 mEq/L (reference range: 3.5-5.1 mEq/L).

An electrocardiogram revealed sinus bradycardia. Initial chest X-ray showed no radiological abnormalities in the heart and lungs. A non-contrast head CT scan from RSUD Cibitung on May 4, 2023 (1 day post-trauma) showed a thin subdural hematoma in the bilateral parieto-occipital area with a maximum thickness of 0.7 cm, small intracerebral bleeding in the right occipital area, and subarachnoid bleeding in the left parietal, bilateral occipital, posterior interhemispheric fissure, and tentorium cerebelli areas, along with cerebral edema. There was a cephalic hematoma in the bilateral parieto-occipital area. A linear fracture was observed in the left parieto-occipital bone and vertebra C5.

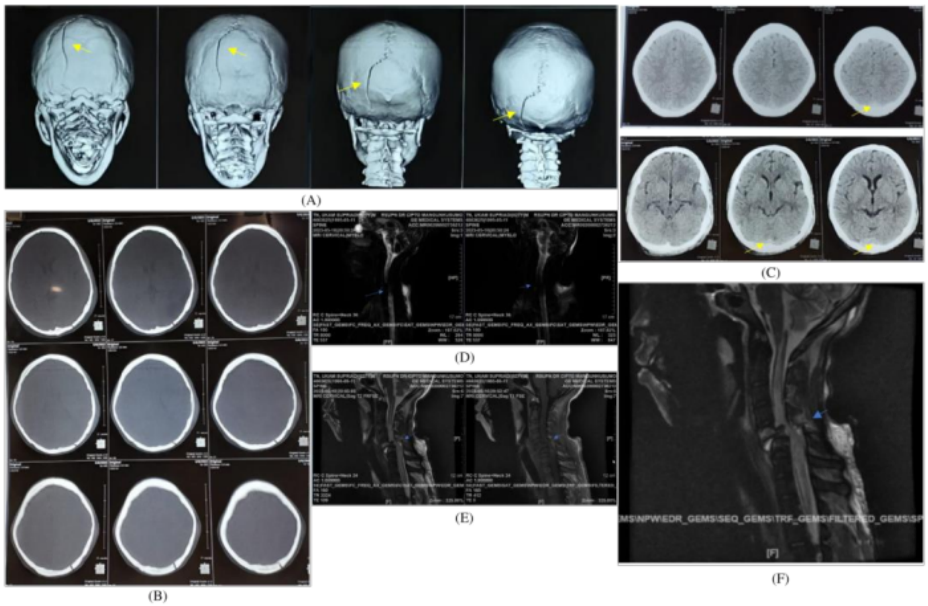

Figure 1. (A) Patient’s Head CT Scan; (B) Head CT Scan (Bone Window); (C) Head CT scan Non-Contrast; (D) Cervical Myelography; (E) Cervical MRI Sagital Section Sequences T1 and T2; (F) Cervical MRI Short Tau Inversion Recovery (STIR) Sequence, Cibitung Regent Public Hospital, May 4th 2023.

The patient underwent cervical magnetic resonance imaging (MRI) at RSCM on May 11, 2023, revealing the presence of posterior fragment fractures causing severe stenosis of the spinal canal at that level and spinal cord edema extending from C3 to C7. Additionally, there was a fracture on the anterior side of the superior endplate of the C6 vertebra and bone marrow edema in the vertebral bodies of C5 and C6. Based on the patient's medical history, initial physical examination, and supporting tests, the following diagnoses were obtained:Upper Motor Neuron (UMN) tetraparesis, C6 and below hipesthesia, anesthesia from T11down, urinary and fecal retention due to traumatic spinal cord injury, (American Spinal Injury Association) ASIA score grade A, with severe canal stenosis and burst fracture of C5, spondylolisthesis C5-6.

- Traumatic intracranial bleeding in the right occipital region, traumatic subdural bleeding, bilateral parieto-occipital traumatic subarachnoid bleeding.
- Neurogenic shock with dopamine and norepinephrine.
- Linear fracture of the occipital bone.
- Compartment syndrome of the right humerus due to a closed 1/3 distal humerus fracture.

The patient was then planned for consciousness and neurologic deficit observation, maintaining a target systolic blood pressure >90 mmHg, neurosurgical decompression and stabilization, and orthopedic management of the humerus fracture. The patient was treated for 66 days, and the treatment progression is described in (Figure 1).

On the second day of treatment, the patient's blood pressure tended to decrease with bradycardia. Norepinephrine and dopamine were administered. On the third day, the patient underwent laminectomy for decompression and stabilization of the cervical vertebrae, followed by debridement and open reduction internal fixation (ORIF) of the right humerus. After the procedures, the patient was sedated, placed on mechanical ventilation, and given antibiotics.

On the fifth day of treatment, the patient was noted to have a fever (38°C) and a cough. A chest X-ray revealed suspected infiltrate in the lower left lung field, suggestive of pneumonia. The patient was then consulted with the pulmonary department, and blood and sputum cultures were performed, followed by antibiotic administration. During treatment, the patient experienced ventilator-associated pneumonia (VAP) and pressure ulcers. Sputum culture results showed moderate gram-negative rods, leukocytes >50/low power field, epithelium 20-25/low power field, with Acinetobacter sp. isolated. Definitive antibiotic therapy included tigecycline 2x50 mg IV for 7 days, ampicillin-sulbactam 4x1.5 g for 14 days, amikacin 1x1g IV for 10 days, and empirical antibiotics mycamine 1x100 mg IV for 6 days, meropenem 3x2g IV for 14 days, ceftriaxone 2x1g IV for 7 days, and gentamicin 1x80 mg IV for 7 days.

On the 9th day of treatment, the patient started physiotherapy by medical rehabilitation with the regimen positioning bed reclining 30 degrees, according to the patient's tolerance, gradually increasing, passive range of motion (PROM) for both upper and lower extremities bilaterally, chest therapy, periodic cough assist, and electrical stimulation on bilateral quadriceps in a supine position.

On the 13th day of treatment, the patient was consulted for acupuncture therapy to aid in ventilator weaning. The acupuncture needles were retained for 30 minutes, then removed with the following regimen:

- Manual acupuncture on LU1, ST25 bilaterally, CV17.
- Manual acupuncture on LU10, PC6, LU7 on the left.
- Manual acupuncture on ST36, ST40, KI3, LR3 bilaterally.
- Manual acupuncture on BL2, ST18, bilateral GV20, EXHN3, CV14.
- Manual acupuncture on SP5 and SP17, 0.5 bilaterally.
- Manual acupuncture on YNSA basic point D, E on the left, and Ypsilon, lung, kidney on the left.

The patient also began transcranial direct stimulation and neuromuscular electrical stimulation (NMES), along with diaphragm muscle taping on the 20th day of treatment. NMES was performed on bilateral pectoralis and flank muscles. During ventilator weaning therapy, nerve conduction velocity (NCV) examination of the phrenic nerve on June 5, 2023 (day 26 of treatment) showed results within normal limits.

On the 34th day of treatment, the mechanical ventilator was gradually removed and replaced with oxygen administration via a simple mask. Upon evaluation, the patient's ventilator-associated pneumonia had improved, and the patient began transitioning to a step-down room.

The patient's hospitalization lasted for 66 days, with mechanical ventilator placement for approximately 32 days. Post-treatment, there was improvement in the patient's motor and sensory condition. The patient was discharged in a bedridden condition. The treatment progression is described in the following figure.

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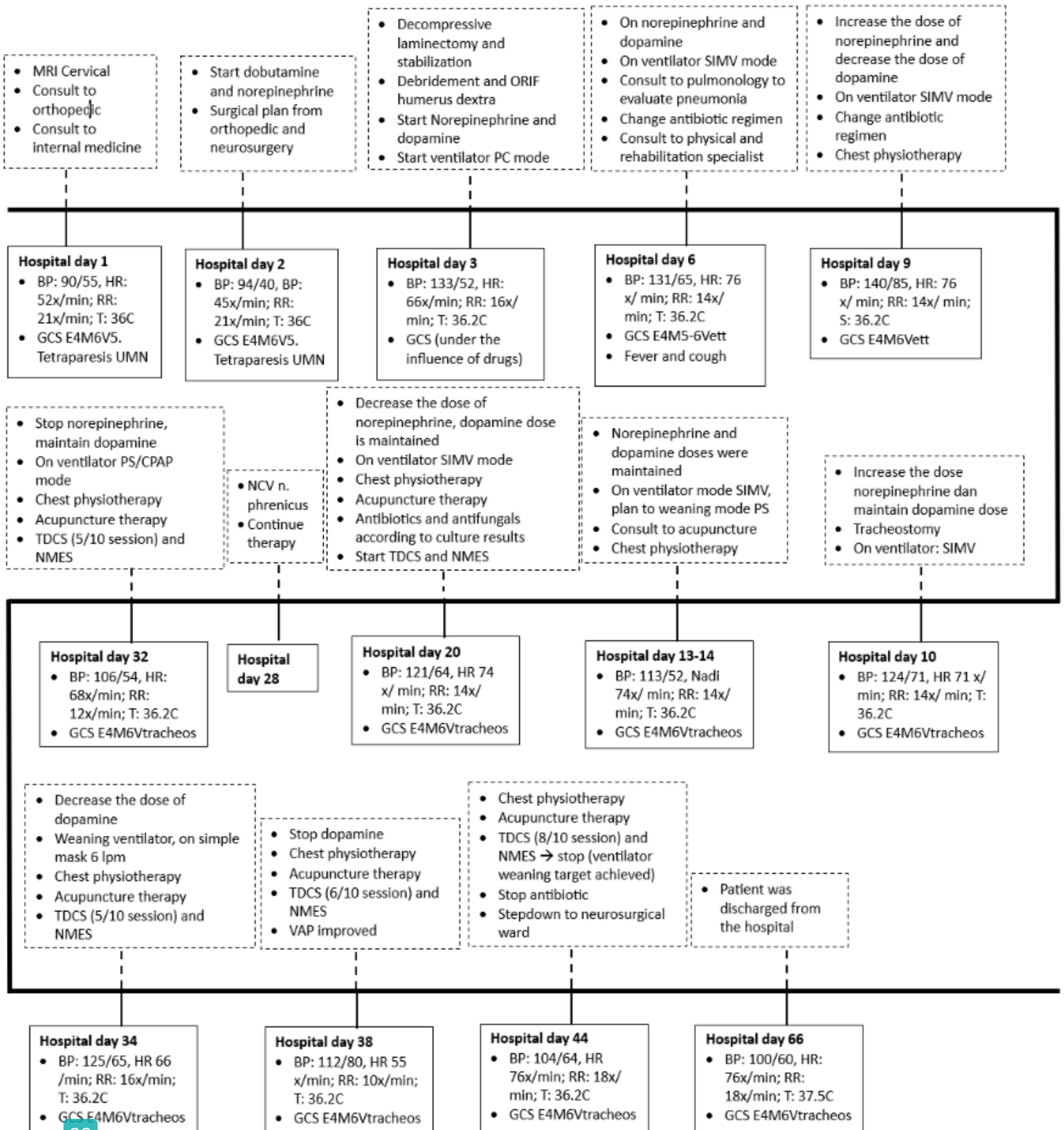

**BP = blood pressure; HR = heart rate; RR = respiratory rate, T = temperature; GCS = Glasgow coma scale; TDCS = Transcranial Direct Current Stimulation; NMES = Neuromuscular Electrical Stimulation; SIMV = Synchronized Intermitten Mandatory Ventilation, PC = Pressure Control; PS = Pressure Support, CPAP = Continuous Positive Airway Pressure, NCV = Nerve Conduction Velocity*

Figure 2. Patient's Progress in Care.

The final diagnosis of the patient at the end of treatment is as follows:

Clinical Diagnosis	-	Upper motor neuron tetraparesis, hipesthesia below T3, anesthesia below T6, urinary and fecal retention (ASIA Score A)
	-	History of decreased consciousness, secondary headache

Topical Diagnosis	- Spinal cord injury at the level of C5-C6 - Bilateral parieto-occipital region
Etiological Diagnosis	- Compression of the spinal cord - Head impact due to fall injury
Pathological Diagnosis	- Axonal damage - Brain parenchymal bleeding
Other Diagnoses	- Sacral region skin and soft tissue infection (SSTI) with Grade 2 pressure ulcer - Ventilator-associated pneumonia (VAP) with Acinetobacter infection and suspected fungal infection with mucous plug, on tracheostomy, history of prolonged ventilator use with tracheostomy completed - History of neurogenic shock suspected sepsis - Open fracture of the right intercondylar humerus, Jupiter classification high T, Gustillo Anderson 2, post-primary - suture post-debridement, and open reduction internal fixation (ORIF) - Adjustment disorder with depressive reaction - Hypoalbuminemia - Increased transaminase enzymes improvement suggestive of drug-induced liver injury (DILI) with micafungin - Hyponatremia - Hypercoagulable state

DISCUSSION

Clinical manifestations of traumatic spinal cord injury

A 28-year-old male patient presented with complaints of weakness in all four extremities after falling from a height of 3 meters seven days ago. The patient's back and head hit the ground during the fall. The patient experienced a brief loss of consciousness, lasting less than 30 minutes, followed by complaints of neck and back pain, as well as weakness in all four extremities, but still able to perform activities. One day later, weakness in all four extremities worsened. During the 7-day treatment at an external hospital, limb weakness was accompanied by numbness and difficulty in bowel movements.

Upon initial physical examination, bradycardia, tetraparesis, hipesthesia below C6, proprioceptive impairment, fecal retention were observed. Rectal examination revealed lax sphincter tone, collapsed ampulla, and negative bulbocavernosus reflex. Based on the medical history and physical examination, the patient was suspected to have a spinal cord injury due to trauma.

Acute spinal cord injury involves primary injury caused by the initial traumatic force to the spinal cord. This can result from the compression of bones, discs, or ligaments penetrating the spinal canal, the formation of extradural hematoma due to vascular tear, petechial bleeding, diffuse axonal injury, or dynamic instability of the spinal column [1,3].

The primary injury is followed by a long and progressive cascade of secondary injuries occurring from seconds to weeks after the primary injury, potentially worsening damage to the spinal cord. Neuroinflammation, free radical formation, and lipid peroxidation lead to the gradual expansion of the initial lesion rostrocaudally from the injury epicenter. This process is exacerbated by post-traumatic ischemia, changes in sodium and calcium levels, glutamate-mediated excitotoxicity, resulting in the loss of gray matter and sustained degeneration of white matter for several weeks, leading to a progressive decline in neurological function [1,3].

In secondary injury, spinal cord edema and other secondary changes occur within hours after the injury, peaking on the third and sixth days after the injury, gradually decreasing by the ninth day. Blood flow to the spinal cord is reduced immediately after the injury and continues to decline in the following 24 hours, associated with systemic and local factors. Local effects include direct vascular disruption, bleeding, microcirculation disturbances (possibly due to vasospasm), and autoregulation failure. Reduced blood flow can worsen the injury and is exacerbated by systemic hypoxia and hypotension from traumatic injuries to other organ systems or neurogenic shock [1, 3].

The interaction process between reactive astrocytes, infiltrating microglia, and macrophages increases the synthesis of glial fibrillary acidic protein, leading to local inflammation and astrogliosis that can hinder neural regeneration and repair. The injured spinal cord will be replaced by necrotic tissue [1, 3].

After experiencing a fall-related trauma, the patient developed neck pain accompanied by worsening tetraparesis, sensory impairment, and autonomic dysfunction. It is considered that the patient is undergoing primary injury due to the trauma mechanism followed by secondary injury that exacerbates the clinical manifestations. On the cervical MRI conducted 9 days after the trauma, a fracture was found in the C5 vertebra accompanied by spinal cord edema at the C3-C7 levels.

This is consistent with the patient's worsening symptoms, reflecting the progression of the spinal cord injury process, where both primary and secondary injuries occur in the patient [1].

The severity of the condition also needs to be assessed to evaluate the neurological dysfunction involved. The assessment is performed using the American Spinal Injury Association (ASIA) score. The patient exhibits motor, sensory, and autonomic symptoms. To assess the sacral segments S4-S5, a rectal examination is performed, revealing weak sphincter ani tone in this patient. Based on the physical examination results, the patient in this case is experiencing spinal cord injury with an ASIA score of grade A.

Respiratory disturbance in spinal cord injury

The patient underwent a laminektomi decompression and vertebral stabilization procedure, followed by debridement and open reduction internal fixation (ORIF) surgery on the humerus. The patient was intubated for the lengthy surgical procedure and started on mechanical ventilation. The placement of the mechanical ventilator in the patient lasted for an extended period, approximately 32 days. During the ventilator placement, the patient developed pneumonia on the third day.

The prolonged use of a ventilator in the patient can be considered due to cervical spinal cord injury and the necessity for airway patency during the patient's surgery. This consideration arises because the nervous system in the spinal cord also plays a role in respiratory function. In the nervous system, there are organs that function as chemoreceptors both peripherally and centrally, sending signals to the central nervous system to induce breathing and signaling to the periphery to initiate the activity of respiratory muscles [4].

Respiratory regulation is governed by a negative feedback system that controls the levels of PO2, PCO2, and pH to achieve homeostasis. Afferent input is obtained from peripheral chemoreceptors (carotid bodies, carotid artery bifurcation, and aortic arch) and central chemoreceptors that are interconnected [4]. The input from chemoreceptors is sent to the respiratory rhythm pattern generators found in the medulla oblongata and other locations in the brainstem. The triggers for this respiratory rhythm pattern are divided as follows [4]:

- Dorsal respiratory group (DRG) activated before inspiration
- Ventral respiratory group (VRG) modulates expiration to regulate the rhythm of [redacted]and contains chemosensitive neurons.
- Pontine respiratory group (PRG) plays a role in transitioning from inspiration to [redacted]and modulating airway patency during breathing (Kölliker-Fuse and parabrachial nucleus).

Signals from respiratory rhythm pattern generators are transmitted through several pathways, including towards the cortex through the corticospinal tract (voluntary breathing) and bulbospinal tract, from the brainstem to spinal respiratory neurons. In addition to these pathways, respiratory patterns can also be regulated by the frontal region. Efferent pathways will activate respiratory muscles to control the expansion and contraction of the thoracic cavity. These muscles are innervated by the nervous system according to the spinal cord level, consisting of the following [1,5]:

- Inspiratory muscles consisting of main inspiratory muscles, including diaphragm [redacted]nerve (C3-C5), scalene muscles, external intercostal muscles and accessory inspiratory muscles, including sternocleidomastoid muscle (XI nerve), trapezius muscle (XI nerve), scalene muscle (C2-C7), pectoralis major muscle (C5-C7) and minor, serratus anterior muscle, latissimus dorsi muscle (C6-C8), serratus posterior superior muscle.
- Expiratory muscles, including internal intercostal muscles, rectus abdominis [redacted](T5-L1), internal and external oblique muscles (intercostal nerve VI, subcostal nerve).
- Upper airway muscles, including muscles in the soft palate, pharynx, larynx, trachea, [redacted]and mouth, innervated by cranial nerves V, VIII, IX, X, and XII. These muscles play a role in maintaining the airway open during inspiration, regulating airflow resistance, and partitioning airflow through the nasal and oral routes.

Respiratory disturbances in spinal cord trauma can result from damage to the spinal cord and causes related to thoracic trauma (pneumothorax, hemothorax, lung contusion, rib fractures, flail chest). Respiratory dysfunction due to spinal cord injury corresponds to the level of the lesion because it is associated with the innervation of respiratory muscles. In cervical injuries, disruptions to the phrenic nerve (C3-C5) can lead to paralysis of the main respiratory muscles and efferent tract disturbances, while spinal cord injuries at lower levels are associated with additional respiratory muscle dysfunction[1, 7]. The respiratory function impairments in spinal cord injury can be explained as follows:

- Injury at C1–C3 level: possibility of ventilator dependency due to diaphragm paralysis. Ventilator weaning might be possible to do in a short period if adequate frog/GPB ventilation is provided. Potential candidates for diaphragm pacing.
- Injury at C3–C4 level: Diaphragm function can be disrupted, reducing tidal volume and lung vital capacity. Ventilator-free periods can occur and be assisted with nocturnal ventilation
- Injury at C5 level: Spontaneous breathing can occur despite ventilator assistance. Diaphragm function is intact, but intercostal and abdominal muscles may be paralyzed, resulting in reduced lung volume and cough effectiveness

- Injury at C6–C8 level: Spontaneous breathing. Patients with lesions below C7 can perform inspiration and cough with accessory muscles, especially the pectoralis minor and major muscles
- Injury at T1–T4 level: Inspiratory capacity and forced expiratory capacity are assisted by intercostal activity, but cough efficacy decreases due to abdominal weakness
- Injury at T5–T12 level: Muscle strength can improve at levels below the lesion, and minimal autonomic dysfunction has little impact on the cardiovascular system below T6
- Injury at T12 level: Minimal decline in respiratory function

Respiratory dysfunction can have a subacute or chronic onset, possibly due to spinal manipulation during fracture stabilization. In chronic injuries, spastic respiratory muscles may interfere with vital lung capacity and inspiratory pressure [1, 8].

In this case, the patient experienced a spinal cord injury at the level of C5-C6, with the result of the examination of the phrenic nerve conduction velocity within normal limits. The spinal cord lesion in the patient can lead to disturbances in accessory inspiratory muscles (pectoralis, scalenus), diaphragm muscles (considering partial impairment), and expiratory muscles, which can reduce cough reflex function, forced expiratory lung capacity, and maximum inspiratory capacity. This can result in decreased lung capacity, atelectasis, and sputum retention, increasing the risk of respiratory failure.

The patient was initiated on mechanical ventilation during the surgical procedure and faced challenges in weaning from the ventilator. Ventilator initiation occurred on the tenth day post-trauma. Difficulty weaning the patient from the ventilator may still be considered a consequence of respiratory muscle dysfunction due to the spinal cord injury and respiratory infection. Approximately 42% of spinal cord injury cases that initially show no signs of respiratory impairment upon arrival at healthcare facilities may develop severe respiratory dysfunction within a few days after hospitalization (estimated around 3 days) [8]

Airway Management

Airway management in spinal cord injuries is a crucial aspect of overall trauma management. Acute spinal cord injury management begins with the primary survey, including airway, breathing, and circulation, along with cervical immobilization until the absence of injury is confirmed through anamnesis, physical examination, and relevant radiological examinations in the cervical region. Upon arrival at RSCM, the patient referred from RSUD Cibitung had undergone stabilization of airway, breathing, and circulation, and cervical immobilization had been performed. Radiological examination revealed cervical injuries, leading to the retention of cervical immobilization for airway stabilization and prevention of more severe mechanical injuries [1, 8].

Use of respiratory assistance devices and ventilator weaning management

In the illustrated case, a patient with cervical spinal cord injury with ASIA score A began mechanical ventilator placement around the tenth day post-trauma, with a ventilator usage duration of approximately 32 days.

In cases of cervical spinal cord injury, mechanical ventilation is anticipated to be mostly necessary [8]. The indications for mechanical ventilation use in patients with spinal cord injuries are; signs of respiratory failure (tachypnea, difficulty speaking), increased respiratory effort, decreased level of consciousness, hypercapnia ($PaCO_2$ >60 mmHg, >8kPa), hypoxemia (PO_2 <60 mmHg, <8kPa), vital capacity <10 ml/kgBW or tidal volume <5 ml/kgBW, airway obstruction in drug overdose patients, chest trauma, cardiac arrest, and prolonged surgery[9].

The indication for ventilator use in patients is to maintain airway patency, especially in cases of prolonged surgeries. Post-surgery, patients may face challenges in weaning from the ventilator, with a usage duration of approximately 32 days during treatment (categorized as prolonged ventilator use).

Several factors affect ventilator weaning in patients with spinal cord injuries. Severity can be one factor influencing ventilator duration, where complete spinal cord injuries with tetraparesis may be associated with a prolonged weaning process (more than 7 days). Around 30% of spinal cord injury patients with ventilators become ventilator-dependent [10].

Apart from severity, other factors impact ventilator duration. Motor scores upon admission are considered predictive factors for the likelihood of mechanical ventilator use [11]. In a study by Füssenich W et al, the level of injury also influenced the weaning process. The average weaning duration in the study was approximately 37 days, with average durations for C0-C4 injuries at 46.3 (32.2) days, C5-C8 at 35.8 (28.8) days, and T1 or below at 48.9 (51.4) days. Risk factors such as age (above 56 years), injury level (C4 and above), vital capacity (<1500 ml), obesity, and chronic obstructive pulmonary disease can reduce the chances of weaning. Spinal cord injury level, age, and decreased vital capacity can increase weaning duration [10].

In several studies, injury level, injury severity, pre-existing comorbidities, time of transfer to trauma management centers, initial vital conditions, and early respiratory function can impact the duration of mechanical ventilator use in spinal cord injury patients. In the case of a patient with a spinal cord injury at the C5 level with edema from C3-C7, categorized as lower cervical spinal cord injury, the patient has ASIA score A and pneumonia, which can be factors affecting the patient's ventilator duration (Table 1).

The patient in this case has a history of prolonged mechanical ventilator use and a history of pneumonia during ventilator use. Pneumonia can be a risk factor that may extend the duration of ventilator use and the efforts for weaning trials [12]. The patient has already received pneumonia management with antibiotics and rehabilitation.

Respiratory management for ventilator weaning can be approached through various methods. In this case, the patient underwent rehabilitation therapy, acupuncture, neurorestorative procedures (neuromuscular electrical stimulation), pharmacological therapy, and surgery to aid the ventilator weaning process.

Physiotherapy is one of the rehabilitation therapies employed for patients with spinal cord injuries and respiratory impairments. The respiratory rehabilitation protocol aims to strengthen and prevent atrophy in respiratory muscles, assist in airway secretion clearance to reduce airway resistance, optimize lung compliance, and reduce respiratory effort [13].

The techniques used can be manual or involve mechanical aids [13]. The respiratory rehabilitation therapy consists of position adjustment, airway clearance with the assistance of the cough reflex and secretion removal aid, and respiratory muscle exercises. Studies on the effectiveness of rehabilitation therapy in ventilator weaning, as well as the interventions performed, are discussed in (Table 1).

The patient in this case received rehabilitation on the 6th day of treatment (13 days after onset). This is due to hemodynamic disturbances in the patient (hypotension and bradycardia) at the start of treatment so that stabilization is necessary. Initiation of rehabilitation begins after the condition is stable.

Another management option considered to assist weaning is acupuncture. Acupuncture involves the insertion of needles at acupuncture points following standard procedures. The effects of acupuncture on ventilator weaning are described in (Table 1). In previous studies, acupuncture was found to improve respiratory function by reducing dyspnea, enhancing respiratory muscle strength, and increasing chest wall movement. The exact mechanism of acupuncture is not fully understood, but it is reported to increase inspiratory muscle strength. Additionally, acupuncture is believed to play a role in inducing relaxation of accessory respiratory muscles, as evidenced by increased chest cavity movement and forced vital capacity after acupuncture therapy. The increase in B-endorphin is associated with reduced dyspnea and improved respiratory function. Acupressure has also been reported to increase tidal volume in ICU patients [14]. Acupuncture is thought to enhance the regulation of the immune system, such as the cholinergic anti-inflammatory pathway, and aid in stimulating nervous system regeneration [15]. Further studies are needed to assess the role of acupuncture in respiratory function in patients with spinal cord injuries.

The patient also underwent neuromuscular electrical stimulation (NMES) to assist in ventilator weaning. NMES uses electrical stimulation on muscles to induce muscle contractions through electrodes attached to the skin [16]. This method is a consideration for improving muscle strength in immobilized ICU patients. NMES can be applied to both respiratory muscles and limb muscles. In this case, NMES was performed on the respiratory muscles in the pectoralis and bilateral flank muscles. NMES in spinal cord injury patients can help improve muscle strength, thereby enhancing cough reflex and respiratory function [17]. The role of NMES in respiratory function and the use of mechanical ventilation is discussed in (Table 1).

Other modalities employed in the respiratory management of spinal cord injury patients include pharmacological therapy. Options for pharmacological agents include bronchodilators, mucolytics, xanthine derivatives, and antibiotics. In this case, antibiotics were administered for the management of Ventilator-Associated Pneumonia (VAP). Bronchodilators and mucolytics were also given to the patient. Bronchodilators have the effect of dilating the airways to reduce the risk of atelectasis and stimulate surfactant production. Mucolytic agents like acetylcysteine can be used to aid in the clearance of secretions or sputum.

Another modality that can be considered is tracheostomy. Tracheostomy can reduce airway resistance, decrease complications associated with intubation (subglottic edema, laryngeal and tracheal stenosis, ulcers), and facilitate suction access. The optimal timing for tracheostomy has not been conclusively determined. In the study by Foran et al., both early tracheostomy (within 7 days of intubation) and late tracheostomy (after 7 days) had effects in reducing the duration of ventilator use and length of treatment [18]. The description of the study is provided in (Table 1).

The respiratory management of the patient in this case involves rehabilitation therapy, pharmacological intervention, neurorestorative procedures (NMES), acupuncture, and tracheostomy. Rehabilitation and pharmacological therapies are standard regimens in respiratory management for ventilator weaning in patients. This management approach is multidisciplinary and can contribute to improving the patient's respiratory function. Factors such as the level of injury, degree of spinal cord injury, intubation-related complications, and tetraplegia in patients (decubitus, VAP) are considered to potentially influence the duration of ventilator use. The multidisciplinary management applied to the patient can aid in addressing these factors and contribute to overall patient management.

Table 1. Studies on Mechanical Ventilation Weaning – Overview of several studies regarding mechanical ventilation weaning.

Article	Domain	Outcome	Design	Level of Evidence (LoE)	Number of subjects	Intervention	Conclusion
Study Characteristic on Factors Influencing Mechanical Ventilation Weaning on Patients with Spine Injury (Observational Study)							
Korupolu, et al.[19] (2022)	Spine injury patients on mechanical ventilation	Factors predicting ventilation weaning	Retrospective cohort	III	137	Physical therapy, ocupational therapy, speaking therapy done 4-5 times per week and daily respiration therapy. Patients were given pharmacological therapy such as nebulization (β2-agonists with and/or without anticholinergic agent), lung expansion therapy, fluid management with insufflation–mechanic exsufflation, and repeated suction.	Higher lung capacity during admission (≥ 5.8 mL/kg PBW), lower level of spine injury (under C3). Ventilator weaning duration has a median of 12 (7-18) days.
Study Characteristic on Factors Influencing Mechanical Ventilation Weaning on Patients with Spine Injury (Systematic Review)							
Schreiber AF, et al.[2](2021)	Spine injury patients on mechanical ventilation	Duration and probability of ventilation weaning Factors influencing mechanical ventilation	Systematic review and meta analysis	IIA	39 study (14.637 patients)	-	Medical rehabilitation (varied according to study) of cervical spine injury patients treated in ICU has mechanical ventilation duration of 27 days (20-34 days), with the probability of successful weaning approximately 63% (45-78%) and mortality rate of 8%, while in rehabilitation center, patients are found to have higher cervical level lesion, have mean ventilation duration of 97 days (65-128), where 82% patients experience successful weaning Spine level injury, degree of injury, (complete or incomplete lesion), trauma elsewhere, transfer time from spine trauma center, condition upon entering ICU (high pulse rate, low tidal wave, high PEEP), and comorbid condition; all of them increase and decrease the chance of successful ventilator weaning.

Study Characteristic on Factors Influencing Ventilation Weaning

Article	Domain	Outcome	Design	Level of Evidence (LoE)	Number of Subjects	Intervention	Conclusion
Richard Dennis A, et al.[12] (2018)	Complete tetraplegic patients	Duration of mechanical ventilation and predicting factors	Retrospective cohort	IIB	81	High frequency percussive ventilation, mechanical and/or manual assisted cough, and non-invasive respiratory assistance	Duration of mechanical ventilation use on delayed post operation transfer group compared to pre operation 68.0 ± 64.2 days vs. 21.8 ± 29.7 days, p = 0.006, Time of transfer from spine trauma center influences the duration of mechanical ventilation use
Füssenich W, et al.[10] (2018)	Spine injury patients on mechanical ventilation	Risk factors, duration, number of trial of mechanical ventilation	Cohort	IIB	165	- not explained	Average duration of weaning process was 37 days. Mechanical ventilation risk factors include age (>56 years) injury level (C4 level or above), lung vital capacity(<1500 ml), obesity, and COPD
Liebscher T, et al.[20] (2015)	Spine injury patients level C4-C8 ASIA score A or B	Mechanical ventilation duration, number of weaning trials, factors influencing ventilation weaning	Retrospective cohort	IIB	37	Mobilization, physiotherapy (respiration therapy according to physiotherapy)	Mechanical ventilation duration was75 days (95% CI 59.2; 90.8). Comorbid conditions (hypertension, smoking, cardiovascular disease, alcohol consumption, diabetes mellitus) and tetraplegic associated complications (urine incontinence et alvi, urinary tract infection, orthostatic dysregulation, dysphagia, decubitus, sepsis, thrombosis) affect ventilation duration.
Yu WK et al.[21] (2015)	Cervical spine injury patients on mechanical ventilation >48 hours.	Duration and risk factors of ventilation weaning	Retrospective cohort	IIB	523	- unexplained	Average ventilation weaning duration was 38.3 days (SD ± 30.5). Ventilation weaning failure group was affected with older age, spine level injury C1-C3, low pulse, worse Glasgow Comma Scale upon admission, higher level of blood ureanitrogen, and acute kidney failure.

Characteristic Study on The Role of Rehabilitation Towards Breathing Function and Mechanical Ventilation Weaning

Article	Domain	Outcome	Design	Level of Evidence (LoE)	Number of Subjects	Intervention	Conclusion
Gundogdu I, et al.[13] (2017)	Cervical spine injury patients with ASIA score A-C on mechanic ventilation	Duration and number of patients with successful mechanical ventilation weaning	Experimental study	III	35	a) Clearance of airway secretions consists of: • Abdominal binder • High-frequency chest wall oscillation with a frequency of 20Hz for 20 minutes 1-2 times/day for 3-12 weeks • Physiotherapy (left-right tilting, postural drainage, vibration, percussion, shaking) for 30-60 minutes 1-2 times per Manual assisted cough, cough assist machine, and suction b) Inspiratory muscle training • Done in 10 repetitions, 3 times per day for 5 days in a week. • Oxygen administration and ventilation placement are done as needed during the session.	Average weaning duration was approximately (37.0 ± 11.6 days) and average tracheostomy decanulation was (31.7 ± 16.9 days) measured from the start of protocol. During protocol there were complications such as mucus plug, atelectasis, and pneumonia
Gutierrez CJ, at al.[22] (2003)	Cervical spine injury patients on mechanical ventilation	Inspiration and expiration capacity, lung vital capacity on-vent endurance and off-vent breathing times	Experimental pilot study	III	7	Protocol 1. Pretraining optimization: Tredelenburg position,: suction, aerosol with albuterol and ipratropium bromide hyperinflation by lowering tidal volume 20cc and increasing breathing frequency 2 times 2. Inspiratory/expiratory resistance training : Inspiratory/expiratory trainer, Cuff deflated and red cap on trach tube 3. On-vent endurance training Off-vent endurance training	Duration of 1-15 months or until weaned off of ventilator. Patients with cervical spine injury level C2 had improving breathing capacity, could be off of ventilator for several minutes. Patients with lower cervical spine injury level (below C4) could weaned off ventilator after 1-2 months of practice (4 out of 5 patients)
Characteristic Study on The Role of Acupuncture on Breathing Function and Mechanical Ventilation Weaning							

Article	Domain	Outcome	Design	Level of Evidence (LoE)	Number of Subjects	Intervention	Conclusion
Matsumoto-Miyazaki, et al.[14] (2018)	ICU patients on mechanic ventilator >21 days	Respiration functional status (tidal volume, breathing frequency, oxygen saturation dynamic lung compliance, rapid shallow breathing)	Retrospective cohort	IV	16	• Acupuncture points: LU1, LI4, ST36, CV12, KI3, and CV4 • Manual acupuncture session 4 session per week for 40 days or until weaned off of ventilator	11 patients successfully weaned off of ventilator with improved tidal volume and dynamic compliance
Characteristic Study on The Role of NMES on Breathing Function and Mechanical Ventilation Weaning							
Article	**Domain**	**Outcome**	**Design**	**Level of Evidence (LoE)**	**Number of Subjects**	**Intervention**	**Conclusion**
Liu Y, et al.[16] (2023)	Patients on mechanical ventilation >72 hours	Duration of mechanical ventilation	Randomized controlled study	IIB	80	NMES (Neuromuscular Electrical Stimulation) session for 30 minutes with a frequency of [illegible]Hz, pulse duration of 300 ms, rise time of 1s, stimulus time of 3s, decay time of 1s, and relaxation time of 10s. The negative electrode is placed in the major pectoralis muscle, rectus abdominis muscle, and bilateral quadriceps muscle, while thepositive electrode is placed at a location distant from the stimulated muscle. This is done for 15 days or until the patient can be weaned off the ventilator	The duration of mechanical ventilation on study group was significantly shorter compared to control; 109.5 (88.0, 213.0) hours on study group and 189.5 (131.5, 343.5) hours on control group, p = 0.023
McCaughey EJ, et al.[17] (2015)	Spine injury patients with clinical manifestation of tetraplegy on ventilator	Duration of mechanical ventilation	Retrospective cohort	IIB	10	Electrical stimulation session of 20-40 minutes per day (the duration was increased gradually every week) for 4 weeks.	Intervention group generally has faster weaning duration compared to control group (average of 11 days ± 26 days)

CONCLUSION

The clinical manifestations of spinal cord injury correspond to the level and severity of the injury, which can undergo changes due to the processes of both primary and secondary trauma. The level of spinal cord injury, the severity of spinal cord injury, and the time of transfer to healthcare facilities can increase the risk of respiratory disturbances and the duration of ventilator use, especially at cervical levels. Therefore, respiratory management needs to be considered in patients with spinal cord injury. In addition to the level of injury, respiratory complications such as pneumonia, respiratory muscle spasticity, age, can affect the ventilator weaning process in spinal cord injury patients. Multidisciplinary management, including rehabilitation therapy, acupuncture, neurorestorative procedures, pharmacological therapy, and surgical interventions, is a comprehensive approach that can be considered for the mechanical ventilator weaning process.

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