

SPINAL CORD INJURY CLINICAL GUIDELINE Guidelines for Respiratory Management Following Spinal Cord Injury

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I. Definition, Assessment, Diagnosis

A. Definition

1. Respiratory dysfunction and associated diseases are common comorbidities of Spinal cord injury (SCI) especially among cervical and higher thoracic injuries. Mechanisms for development of disease can vary depending on both the level of injury and the chronicity of the injury.

a. In general, the higher the SCI, the greater the impairment to the respiratory musculature.

b. SCI that involve the innervation to the phrenic nerve and in turn the diaphragm, C2/3, C4, and C5/6, result in impaired inspiration and expiration. Injuries at these levels often require mechanical ventilation for at least some period and may require phrenic nerve pacing in the future to restore diaphragm function.

1) In patients with cervical or high thoracic SCI, a paradoxical and inefficient mechanism of breathing develops in which the upper rib cage moves inward during inspiration due to decreased activity of the external intercostals creating decreased chest-wall compliance. Conversely, the abdominal compliance in an SCI patient is increased.

2) In patients with complete SCI, this will result in a decrease in vital capacity to 20-50% of predicted value and a weakened cough.

c. Chronicity matters as respiratory function may improve in the short term. It has been shown that both FEV1 and FVC improved in 12 patients with complete SCI over the first year following injury.¹ In another study, vital capacity improved by 13% over a 10-month period following injury, with the most improvement in the first 3 months^{2 11}. However, in the long term there is a decrease in FEV1 that is related to increasing years after injury.

2. Studies have shown that risk factors that predispose a patient to respiratory dysfunction following SCI, measured as decreased FEV1, are: cigarette smoking, history of chest injury or surgery, and asthma.³

B. Assessment

1. The common respiratory dysfunctions in an acute SCI that can lead to respiratory failure are:⁴
 - a. Impaired inspiratory capacity
 - 1) Decreased respiratory muscle strength and fatigue
 - 2) Paradoxical chest wall movement causing an increase in effort of breathing
 - 3) Decreased inspiratory capacity
 - 4) Atelectasis
 - 5) Chest wall rigidity
 - b. Retained secretions and development of mucus plugs
 - 1) Increased secretion production
 - 2) Decreased cough effectiveness
 - c. Autonomic nervous system dysfunction
 - 1) Increased secretions
 - 2) Bronchospasm
 - 3) Pulmonary edema
2. The initial laboratory assessment should include:
 - a. Arterial blood gases
 - b. Routine laboratory studies (complete blood count, chemistry panel, coagulation profile, cardiac enzyme profile, urinalysis, toxicology screen)
 - c. Chest x-ray
 - d. EKG
3. Conduct periodic assessments of respiratory function to include:
 - a. Respiratory complaints
 - b. Physical examination of the respiratory system
 - c. Chest imaging as indicated
 - d. Continuous pulse oximetry
 - e. Performance of the respiratory muscles: vital capacity (VC) is the quickest and simplest way to follow function, serially

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- g. Maximal negative inspiratory pressure
 - h. Forced expiratory volume in 1 second (FEV1) or peak cough flow
 - i. Neurological level and extent of impairment
4. Monitor oxygen saturation and end tidal CO₂ to measure the quality of gas exchange during the first several days after injury in correlation with patient expression of respiratory distress.
5. Monitor for indicators for development of atelectasis or infection, including:
 - a. Rising temperature.
 - b. Change in respiratory rate.
 - c. Shortness of breath.
 - d. Increasing pulse rate.
 - e. Increasing anxiety.
 - f. Increased volume of secretions, frequency of suctioning, and tenacity of secretions.
 - g. Declining vital capacity.
 - h. Declining peak expiratory flow rate, especially during cough.
6. If atelectasis or pneumonia is present on the chest X-ray, institute additional treatment and follow serial chest radiographs. If temperature, respiratory rate, vital capacity, or peak expiratory flow rate is trending in an adverse direction, obtain a chest radiograph.
7. The most common location for atelectasis is the left lower lobe. The physician should attempt to roll the patient to the side or sit up to fully elevate the left lower lobe. This finding is often missed with auscultation of the anterior chest wall, and assessment with a chest x-ray, periodically, is recommended⁵. Proning is a new method to improve air way management in acute respiratory distress with Covid-19 patients and may need to be considered in SCI air way management.
8. Other methods of evaluating the patient should be used, including the serial determination of the vital capacity, the peak expiratory flow rate, the negative inspiratory force (NIF), and oximetry. These should be followed on an individual flow sheet designed for this purpose or on a graph. If any of these measures are deteriorating, a follow up chest radiograph should be performed. A chest radiograph should also be performed if the vital signs are deteriorating, if subjective dyspnea increases, or if the quantity of sputum changes.

9. The higher the level of spinal cord injury, the greater the risk of pulmonary complications. A reduction in peak expiratory flow rate in tetraplegic patients has been documented⁶. Because peak expiratory flow rate is important in cough, it would be expected that the higher the level of SCI, the greater the likelihood of retention of secretions and atelectasis.

C. Diagnosis

1. The diagnosis of a SCI and extent of respiratory dysfunction is based on Mechanism of injury, CT and MRI findings and the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) exam.

a. The mechanism of injury helps to define the nature of the injury and addresses the potential for recovery and treatment options

b. The CT and MRI defines the pathology and the need for medical or surgical intervention.

c. The ISNCSCI (ASIA) exam assesses the motor and sensory function and defines the level of the SCI and whether it is complete or incomplete which also directs treatment strategy and prognosis as an incomplete SCI has a much better prognosis than a complete SCI.

2. Muscles of inspiration: Diaphragm, external intercostals and the accessory muscles.

a. Diaphragm – C3-5 and providing 65% of tidal volume.

b. Intercostals – T1-T11 elevate the ribs, expanding chest.

c. Scalene – C2-7

d. Trapezius and SCM – C1-4 and CN XI

3. Muscles of expiration (mainly passive)

a. Abdominal muscles (recti, obliques and transversus) – innervated segmentally from T6 to L1. Increase intra-abdominal pressure moves the diaphragm superiorly. Abdominal binder increases the tidal volume by 16%¹⁹

b. Clavicular portion of the Pectoralis has been shown to benefit expiration if strengthened.

4. Normal respiratory function requires the coordinated action of multiple inspiratory and expiratory muscle groups. Central neuronal control occurs via descending efferent signals from ventilator centers in the brainstem to spinal motor neuron pools in the

cervical, thoracic and lumbar spinal cord, therefore injury at nearly any level of the spinal cord can result in some type of respiratory impairment. Expected respiratory dysfunction:

- a. L1 or lower level of injury – minimal dysfunction with weakened cough.
- b. T5-T12 SCI – Intercostal and abdominal muscles are weakened and a weak cough results.
- c. T1-T5 SCI – intercostals are progressively weakened resulting in weak cough and quiet respiration is reduced due to decreased abdominal tone and loss of optimal diaphragm positioning.
- d. C4-8 – expiration is by passive recoil of the rib cage and the diaphragm may have some weakness.
- e. C3 – Diaphragm cannot typically sustain respiration and the accessory muscles can provide 100 to 300 cc.
- f. C2 – apneic if complete SCI

5. Expected respiratory outcomes.^{7 8 9}

- a. C2 Complete – No function of the diaphragm and need ventilatory assistance.
- b. C3 or C4 – some diaphragm function and potential to wean from the vent.
- c. C5 and below - are usually able to breathe without respiratory assistance, however, acutely most will initially require ventilatory support. Vigorous preventive measures to avoid progressive respiratory insufficiency.
- d. FVC Loss: C5- ½ FVC; C6-C8 1/3 FVC; T1-7 slight loss of FVC; Low Paraplegia very slight loss.
- e. The average improvement in Vital capacity in C3-C5 patients over the first two months after injury is around 1000 cc.¹⁰

II. Management and Treatment Recommendations

A. Management/Treatment

1. Atelectasis and Pneumonia Treatment and methods to re-expand affected lung tissue

a. Deep breathing and voluntary coughing exercises are recommended.

b. Assisted coughing, often used with IPPB or insufflator treatments, can be helpful with postural drainage or simply to clear secretions from the throat. Manually assisted coughing has been shown to result in a statistically significant increase in expiratory peak airflow^{11 12}.

c. Insufflation-exsufflation treatment with a “coughalator” or an “in-exsufflator” machine delivers a deep breath and assists with exhalation by “sucking” the air out. It is often accompanied by “assisted coughing.” The object is to improve the rate of airflow on exhalation, thereby improving the clearance of mucus. Normally, pressures are set at a low level, perhaps 10cm of H₂O to start, and then increased to as high as 40cm of H₂O as the individual becomes used to the sensation of the deep breath and suction on exhalation^{13 14 15}.

d. IPPB “stretch” is similar to the in-exsufflation treatment described above. IPPB is administered, usually with a bronchodilator, starting at a level of pressure of 10-15cm of H₂O and increasing the pressure as the treatment progresses to as high as the machine will go, but not exceeding 40cm of H₂O pressure (See Appendix A in reference 1).

e. Glossopharyngeal breathing can be used to help the patient obtain a deeper breath. Glossopharyngeal breathing is accomplished by “gulping” a rapid series of mouthfuls of air and forcing the air into the lungs, and then exhaling the accumulated air. It can be used to help with coughing, often along with assisted coughing. Montero et al. (1967) showed improvement from 35% predicted to 65% of predicted vital capacity after training in glossopharyngeal breathing and also improvements in maximum expiratory flow rate, maximum breathing capacity, and breath-holding time. Loudness of the voice also improved¹⁶.

f. Incentive spirometry is widely used with other patients as well, such as the able-bodied patient who is post-op. It is something that the tetraplegic patient’s family members can help with, thereby involving them in the daily care of their loved one. (See Appendix A in reference 1).

g. Chest physiotherapy, along with positioning of the patient, is a logical form of therapy to prevent and treat respiratory complications.

h. Intrapulmonary percussive ventilation (IPV) can be done with the ventilator, and a similar concept can be used in the form of a “flutter valve” during nebulizer treatments. Patients report that secretions are loosened with these techniques; however, there are no reports that objectively document the efficacy of these procedures.

i. Bronchoscopy with bronchial lavage can be useful in clearing the lungs of mucus that the patient cannot raise, even with the help of the above listed modalities. The bronchoscopy can be performed whether the patient is on or off the ventilator. It should be kept in mind that the bronchoscopy is used to clear the airway of secretions, not to inflate the lung (unless it is done with a method for inflating the lung through the bronchoscopy). Just clearing the lungs of the mucus will not be adequate treatment by itself.

j. Positioning the patient in the supine or Trendelenburg position improves ventilation. In a study of 20 patients with a C4-8 tetraplegia it was found that the mean value of the forced vital capacity was 300 ml higher in the supine or Trendelenburg positions than in the sitting position¹⁷. In another study of the vital capacities of patients when supine and when sitting. It was found that most tetraplegic patients had increases in vital capacity and FEV1 when supine, compared to the erect position¹⁸.

k. Abdominal binders offer no pulmonary advantage for the typical patient with cervical spinal cord injury when positioned supine in bed. However, the observed 16-28% increment of vital capacity of tetraplegic patients when supine, compared to sitting, can be eliminated by wearing an abdominal binder^{19 20}. An abdominal binder acts to keep the abdominal contents from exerting a traction effect on the diaphragm. Therefore, especially in the early phases of injury, it is helpful for the patient to wear a binder when sitting up in a chair.

l. Recommended procedures for suctioning.²¹

- 1) Aseptic technique using sterile gloves
- 2) Maximum of 2 passes at each procedure
- 3) Suctioning pressure to be 100–200 mmHg in adults
- 4) Application of suction to occur as catheter is drawn out to avoid damage to tracheal mucosa

- 5) Multi-eyed catheters to be used as they produce less tracheal mucosa damage
- 6) Catheter insertion should be limited to one third of its length or ~15 cm into an adult tracheostomy tube
- 7) Suction catheter should be one half the diameter of the endotracheal/tracheostomy tube
- 8) Hyperoxygenate for 1 minute with 100% oxygen before and after suctioning
- 9) Closed suctioning system should be used to reduce infection

m. Respiratory muscle training is recommended after a SCI. A significant benefit of this training has been shown in five pulmonary outcomes: vital capacity, maximal inspiratory pressure, maximal expiratory pressure, maximum voluntary ventilation and inspiratory capacity. No effect was found for total lung capacity, peak expiratory flow rate, functional residual capacity, residual volume, expiratory reserve volume or forced expiratory volume in 1 second.²²

2. Medications

a. Bronchodilators. Long-acting and short-acting Beta agonists should be used concomitantly to reduce respiratory complications in tetraplegics and those with lower level lesions that are prone to respiratory complications. In addition to the direct benefits of bronchodilation, these agents promote the production of surfactant and help diminish atelectasis. Studies have not assessed the long-term benefits of bronchodilator therapy in this population but do suggest that use may mimic the reduction in respiratory symptoms seen with airway hyperactivity in able-bodied patients.

b. It has been demonstrated that greater than 40% of nonacute dyspneic tetraplegics administered metoprolenol or ipratropium responded with an improvement in FEV1 of at least 12%²³. There is also evidence in the literature that atropine blocks the release of surfactant from the type II alveolar cells. Because ipratropium is an atropine analogue, some experts believe that ipratropium should not be used in spinal cord injured patients, since the production of surfactant is essential for prevention and treatment of atelectasis²⁴.

c. Cromolyn sodium. Cromolyn sodium is an inhaled anti-inflammatory agent that is used in asthma. Theoretically, since tetraplegic patients have bronchospasm and inflammation, it would be helpful in tetraplegia; however, there are no studies of cromolyn sodium in tetraplegia.

d. Antibiotics. Although pneumonia commonly occurs in the post-injury period and has a high mortality rate among pulmonary complications in SCI patients²⁵²⁶, in the absence of signs and symptoms of infection, the use of antibiotics for treatment of bacterial colonization will only foster the development of resistant organisms and is not recommended. When treatment is warranted and culture results are not yet available for optimal antibiotic selection, empiric therapy should be directed to cover nosocomial bacteria²⁷.

e. Methylxanthines. Methylxanthines may be of benefit in improving diaphragmatic contractility and respiratory function in this population. Studies of methylxanthines in the SCI population are lacking, and studies in other populations have produced mixed results. In a small study the efficacy of aminophylline was demonstrated via improved contractility in eight able-bodied subjects after diaphragmatic fatigue was induced via resistive breathing²⁸. A theophylline study in chronic obstructive pulmonary disease (COPD) patients produced similar results²⁹. However, another study in COPD patients by found no improvement in diaphragmatic contractility or respiratory response to theophylline³⁰.

f. Anabolic steroids. Correction of malnutrition is recommended for optimal effect on strength and endurance of the diaphragm and accessory muscles, which may assist with ventilator weaning. Short-term treatment with anabolic steroids has demonstrated promising results in this area. The use of oxandrolone for strengthening of the respiratory musculature in a small uncontrolled case series looked at ten complete tetraplegics who were titrated to a dose of 20mg/day and treated for 30 days. Spirometry was measured at baseline and at the end of the trial. Forced Vital Capacity (FVC) increased from 2.8L to 3.0L by the end of the trial and maximal inspiratory and expiratory pressures improved by approximately 10%. Subjective symptoms of resting dyspnea also improved³¹.

g. Mucolytics. The solubilizing effect of this therapy may make tenacious secretions easier to eliminate and may be of benefit when secretion management via other modalities has not provided adequate results. Nebulized sodium bicarbonate is frequently used for this purpose. Nebulized acetylcysteine is also effective for loosening secretions, although it may be irritating and trigger reflex bronchospasm.

h. Hydrating agents. Isotonic sterile saline given by inhalation is useful in mobilizing secretions thickened due to dehydration.

3. Indications for Mechanical Ventilation

a. Respiratory failure— $pO_2 < 50$, or $pCO_2 > 50$, by arterial blood gas testing, while the patient is on room air.

b. If mechanical ventilation is necessary, use a protocol that includes increasing ventilator tidal volumes to resolve or prevent atelectasis. In a study of patients treated during a 10-year time period, who were either ventilated with low tidal volume or ventilated by protocol that gradually increased tidal volume over 2 weeks. All were ventilator-dependent on arrival at a tertiary care facility. Protocol-ventilated patients saw decrease incidence of atelectasis from 84% on admission to 16% in 2 weeks; small tidal volume patients saw increase in incidence in atelectasis from 39% to 52% after 2 weeks. In addition, protocol patients were totally weaned from ventilator in an average of 37.6 days, whereas those ventilated with lower tidal volumes were weaned in an average of 58.7 days.³²

c. Ordinarily, smaller tidal volumes used to control pCO_2 . However, this will cause atelectasis, or a sensation of stress in the tetraplegic patient. Adding dead space, however, counteracts the hyperventilation effect of larger tidal volumes. Larger tidal volumes stimulate the release of surfactant³³ and the compliance of the lungs is thereby improved. With improved compliance, effort necessary to ventilate lungs spontaneously is reduced.

d. Set the ventilator so that the patient does not override the ventilator settings.

4. Ventilator Management to prevent atelectasis

a. Increase the tidal volumes by 100 mL and the ventilator flow rate increased by 10 L/min at periodic intervals³⁴. Typically, the increases are done on a daily basis unless peak pressures exceed 40 cmH₂O. By gradually increasing tidal volumes, the risk of barotrauma remains low because peak pressures only increase slightly.

b. Add dead space by adding ventilator tubing as indicated to prevent high volume and low respiratory rates from decreasing PCO_2 to less than 28.

c. Positive-end expiratory pressure (PEEP) is not recommended because of the lack of studies showing the effectiveness of PEEP in treating atelectasis in acute SCI.

d. It is recommended both tidal volumes and flow rates be increased until chest radiographs indicate that atelectasis has cleared or peak pressures have reach 40 cmH₂O.

e. Targeting a tidal volume of 20 ml/kg of IBW has been shown to be safe using higher tidal volumes over a 14 day weaning protocol in SCI patients.³⁵

f. In a study of 181 patients, 85 (47%) developed Ventilator associated pneumonia (VAP). High tidal volumes was used in 22 (12%) patients. VAP developed in 68% of patients receiving high tidal volumes and in 44% receiving standard tidal volumes ($P = 0.06$). After adjustment, High tidal volumes was associated with a 1.96 relative risk of VAP development (95% credible interval 1.55–2.17) on Bayesian analysis. High tidal volume was also associated with increased rates of ventilator dependence. The study was limited by sample size and selection bias, but showed an association between high tidal volume ventilation and increased VAP. This gives us pause about the use of higher tidal volumes with SCI ventilation, and further investigation into optimal early ventilation settings is needed for SCI patients, who are at a high risk of VAP.³⁶

g. Early intubation/tracheostomy of patients with complete cervical spinal cord injury above C5 is recommended and will hopefully improve the care of these patients with serious SCI.³⁷

5. Criteria for Weaning off the Ventilator

- a. Afebrile, vital signs stable
- b. Vital Capacity of least 15 mL/kg of ideal body weight
- c. Inspiratory force greater than negative 24 cmH₂O
- d. Respiratory stable for at least 24 hours
- e. PaO₂ greater than 75
- f. PCO₂ equal to 35–45
- g. pH equal to 7.35–7.45
- h. No PEEP required
- i. FIO₂ no more than 25%
- j. Manageable secretions
- k. Medically stable for at least 24 hours
- l. Chest x-ray clear
- m. Psychologically willing and ready to participate

6. A multifaceted, multidisciplinary respiratory management program can change the process of care used for difficult-to-wean patients with SCI.³⁸

B. Restrictions

1. No study shows that assisted coughing by itself results in a lower incidence of atelectasis or pneumonia.
2. Glossopharyngeal breathing can be used to help the patient obtain a deeper breath, but can be hard to learn and the patient must have good bulbar function. It is estimated that about 2/3rd's of SCI patients on vent support can learn this method. The technique involves the use of the glottis to add to an inspiratory effort by pistoning (gulping) boluses of air into the lungs. The glottis closes with each 'gulp'. One breath usually consists of six to nine gulps of 40–200 ml each. During the training period, the efficiency of GPB can be monitored by spirometrically measuring the milliliters of air per gulp, gulps per breath, and breaths per minute.³⁹
3. Incentive spirometry can be used at bedside by the patient and family, but there are no documented studies indicating efficacy in tetraplegic patients. Without periodic stretching of the ribcage in breathing, the joints of the ribcage can become calcified and rigid and result in reduced ventilation and expedited diaphragmatic fatigue.
4. Chest Physiotherapy can be helpful in managing respiratory secretions and in delivering treatments, but some patients may not be able to assume the head down position to facilitate drainage of the lower lobes. Because as gravity pulls the abdominal contents against their diaphragm it severely limits their ability to take a deep breath. Also, positioning of the patient with the head down may increase gastroesophageal reflux or emesis. Positioning the patient is also difficult for patients with halo-vest immobilization. There are no studies indicating the efficacy of chest physiotherapy and positioning in tetraplegic patients.
5. Bronchoscopy can be very helpful in the acute management of respiratory compromise and mucus plugging in SCI but other treatments must be instituted to inflate the lungs and prevent reaccumulation of secretions.
6. Abdominal binders can be very helpful in acute management of SCI with respiratory compromise as they restore more normal diaphragmatic position when sitting up. Some patients will regain some muscle tone in the abdomen and/or adapt to the problem in time after the injury; these patients can then stop using the abdominal binder.
7. Although the use of ipratropium is recommended initially, it should be discontinued after stabilization since the anticholinergic effects may thicken secretions and also diminish optimal respiratory capacity.
8. Steroids. Other than in the setting of acute spinal cord injury and those with an asthmatic component of reactive airway disease, these agents should be reserved for short-term use in acute respiratory distress. Aged patients administered intravenous high-dose methylprednisolone in the acute setting post injury were noted to be more prone to develop atelectasis and pneumonia⁴⁰

9. Anticoagulation to prevent pulmonary embolism is important, acutely. Current guidelines established by the Consortium for Spinal Cord Medicine call for prophylaxis with low molecular weight heparin as soon as possible after a SCI. Treatment should continue for 8 weeks in patients at high risk of a deep vein thrombosis or until discharge from rehabilitation. These recommendations also apply to patients with inferior vena cava filters (see the Consortium for Spinal Cord Medicine Clinical Practice Guideline: Prevention of Thromboembolism in Spinal Cord Injury, 3rd ed. (2016)).

III. Prevention and Education

A. Respiratory management of SCI in the first five days⁴¹

1. Respiratory complications after acute SCI are highly prevalent and are predictable based on neurologic impairment, associated injuries, and preinjury medical conditions.
2. Patients may rapidly deteriorate over the first 5 days, with the need for intubation occurring most commonly 3 to 4 days after injury.
3. Care within specialized SCI centers has been shown to significantly decrease the number and severity of complications and shorten intensive care unit (ICU) length of stay, especially if the patient is transferred within the first week after injury.
4. Aggressive respiratory care needs to begin immediately after injury. Clearing of secretions through IPV, bronchodilators, postural drainage, and cough assist machines can virtually eliminate the need for bronchoscopies.
5. Deteriorating vital capacities and blood gases should be followed vigilantly to prevent the need for emergent intubation.
6. Once intubated, the use of high tidal volumes is supported by spinal cord literature. However, additional research is needed to support this recommendation.

B. Chronic Respiratory management⁴²

1. Respiratory impairment results from one of two disease processes and it is very important that physicians distinguish between the two paradigms so that they can be managed, effectively.
 - a. Lung/airways diseases, in which case pulmonary function testing (PFT) can be diagnostic and supplemental oxygen beneficial, and is characterized by hypoxia in the presence of eucapnia or hypocapnia until an exacerbation results in acute respiratory failure (ARF).
 - b. Ventilatory impairment, most often from respiratory muscle dysfunction, which is characterized by hypoventilation-induced hypercapnia and hypoxia with intercurrent episodes of ARF due to an ineffective cough.

2. Noninvasive Ventilation

- a. There are no effective noninvasive measures to counter bulbar dysfunction aspiration. Thus, the only indication for tracheotomy in an alert, but ‘unweanable’ patient with spinal cord injury (SCI) is when saliva aspiration occurs to the degree that the oxyhemoglobin saturation (SpO₂) decreases and remains below 95% irrespective of optimal use of noninvasive intermittent positive pressure ventilation (NIV) and mechanically assisted coughing (MAC).
- b. Continuous positive airway pressure (CPAP) and bi-level positive airway pressure (BiPAP) can be used to rest the non-intubated patient and also to give the patient a deep breath to help with managing secretions. A facemask or a mouthpiece can be used. CPAP and BiPAP may be useful in the short term to get the patient over the acute phase after injury and may keep some patients from needing intubation or a tracheostomy.
- c. Long term use of Full, continuous ventilatory support using noninvasive intermittent positive pressure ventilation is an alternative to tracheotomy and electrophrenic/diaphragm pacing. It can be delivered via lip seals, nasal, and oral–nasal interfaces for nocturnal ventilatory support.

3. Mechanically Assist Cough (MAC) is the combination of the use of mechanical insufflation–exsufflation (CoughAssist™ Philips-Respironics International Inc., Murrayville, PA, USA) with an exsufflation-timed abdominal thrust. Insufflations at pressures of 40–60 cmH₂O followed immediately by exsufflations to – 40 to – 60 cmH₂O are most effective and preferred⁴³.

- a. One treatment consists of about five cycles of MAC followed by a short period of normal breathing or ventilator use to avoid hyperventilation. Exsufflation-timed abdominal thrusts are always used unless specifically contraindicated. Treatment continues until no further secretions are expelled and secretion-related oxyhemoglobin desaturations are reversed.
- b. MAC treatment can be given as frequently as every 30 minutes almost around the clock during chest infections and for 1–2 days following extubation or decannulation.
- c. MAC is effective for patients with completely intact bulbar function, such as for many patients with high level SCI, can usually air stack to volumes of 3 liter or more, and, unless very old, scoliotic, or obese, a properly delivered abdominal thrust can result in assisted Cough Peak Flow (CPF) of 6 to 9 l/s. These flow rates should be more than adequate to clear the airways and prevent pneumonia and ARF without MAC. Thus, the patients who benefit most from MAC tend to be older and with assisted CPF <300 l/m.

C. Neuroplasticity⁴⁴

1. Respiratory complications continue to be the leading cause of morbidity and mortality after SCI^{45 46}. Our current clinical treatment paradigm involves managing respiratory dysfunction primarily with positive pressure assisted ventilation, yet ventilator dependence remains a strong predictor of negative outcome⁴⁷.
2. There continues to be important advances in the management of respiratory dysfunction with a particular focus towards achieving ventilator independence. Phrenic nerve (PNP) and diaphragm (DP) pacing are two strategies designed to promote ventilator independence by delivering electrical stimulation to drive diaphragmatic contraction. For some individuals, PNP and DP generate sufficient negative intra-thoracic pressure for independent ventilation, however, in only about 50% of cases^{48 49 50}.
3. Activity-dependent respiratory training has demonstrated success in improving rates of independent ventilation, even in those with complicated underlying pulmonary and neuromuscular conditions who have failed prior attempts at extubation^{51 52 53}. While these therapeutic approaches undoubtedly provide clinical benefit for those who are successfully treated, there still remains the large percentage of those who continue with respiratory dysfunction, along with the other significant neurologic impairments that result from SCI.
4. Therefore, in developing the next generation of SCI therapies, the challenge remains identifying processes that may optimize repair and recovery of the underlying neural substrate with the hope of restoring long-term multi-system function. Several promising areas of study are:
 - a. Acute intermittent hypoxia - Exposure to repeated episodes of hypoxia (i.e. low oxygen levels) interspersed with a return to normal oxygen levels has been shown to elicit a long-lasting increase in respiratory motor output or drive, a phenomenon known as long term facilitation (LTF)⁵⁴. Acute intermittent hypoxia applied 4 to 8 weeks after C2 hemisection of the spinal cord resulted in a serotonin-dependent plasticity⁵⁵. There is also some evidence that intermittent hypoxia may improve non-respiratory motor function after spinal cord injury^{56 57}.
 - b. Improving cough - new techniques such as functional electrical stimulation, surface stimulation, or magnetic stimulation may be able to isolate expiratory muscles to preserve cough⁵⁸. Animal studies have produced positive airway pressure in both the dog and cat model by stimulating spinal cord levels between T9 through T10 to generate a cough^{59 60}. Such promising studies support the importance of a holistic approach to restoration of muscle function in spinal cord injury.
 - c. The intercostal muscles are essential for deep inhalation to relieve atelectasis in an able-bodied individual; normal respiration would need restoration of the periodic sigh provided by external intercostal contraction. This may only be

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possible with neuroplasticity and further recovery or with the use of external stimulation.

D. Vaccinations are recommended for all individuals with SCI. Although studies indicating a decreased incidence of influenza or pneumococcal pneumonia after vaccination are lacking in this population.

1. There are no studies evaluating the efficacy of influenza vaccines, but one study found no differences in the immune responses to five pneumococcal polysaccharides in 40 SCI and 40 able-bodied subjects after receiving the pneumococcal vaccine. Adverse reactions occurred in approximately one-third of each group⁶¹.
2. Another study evaluated the immune response in 87 SCI patients and found that at 2 months post injection 95% of patients that received the vaccine and 35% of the placebo group developed an immune response to at least one of the five serotypes tested.
3. Approximately 93% of vaccinated patients maintained a two-fold increase in antibody concentration to at least one serotype at 12 months post injection. This study indicated adequate pneumococcal vaccine response in SCI patients irrespective of the time of administration⁶².

This guideline was developed to improve health care access in Arkansas and to aid health care providers in making decisions about appropriate patient care. The needs of the individual patient, resources available, and limitations unique to the institution or type of practice may warrant variations.

Guideline Developers

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