

# SCORE

SPINAL CORD INJURY REHABILITATION EVIDENCE

## Acute Respiratory Management Following Spinal Cord Injury



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## Key Points

Intubation can reduce arterial oxygen partial pressure ratios in acute SCI individuals.

Tracheostomies can reduce the number of pulmonary complications in acute SCI individuals compared to those not receiving this procedure, and they may result in reduced forced vital capacity and lower gas exchange compared to extubation.

Tracheostomies are associated with an increase in the number of days acute SCI individuals spend on ventilators.

Diaphragm pacing in combination with mechanical ventilation can increase survival rates post SCI.

Endotracheal invasive ventilation can lower partial pressure of carbon dioxide in acute SCI individuals.

Percutaneous tracheostomies may reduce rates of pneumonia when compared to surgical tracheostomies in acute SCI individuals.

Early tracheostomies may result in fewer ICU days and ventilation days, however they may not impact in-hospital mortality, compared to late tracheostomies.

The evidence is inconsistent regarding whether or not early tracheostomies reduce medical complications associated with tracheostomies compared to late tracheostomies.

Weaning from mechanical ventilation is more successful in patients who have not had a tracheostomy, and rates of decannulation and extubation are higher in patients with lower level injuries during the acute phase post SCI.

For mechanical ventilation weaning, progressive ventilator-free breathing may be more successful than intermittent mandatory ventilation, and using higher ventilator tidal volumes may speed up the weaning process compared to lower ventilator tidal volumes during the acute phase post SCI.

Mechanical insufflation/exsufflation coupled with manual respiratory kinesitherapy may be effective for bronchial clearance during the acute phase post SCI.

Inspiratory and expiratory muscle training may improve respiratory muscle function during the acute phase post SCI. Length of stay in intensive care may be reduced by extubation in combination with intensive physiotherapy.

overall may lead to reduced procedures, ventilator days, and hospital length of stay, and improved respiratory and patient discharge status, in the acute phase post SCI.

Diaphragm pacing may not reduce the number of days spent on a ventilator, however it also does not appear to increase the risk of ventilator associated pneumonia in acute SCI patients.

Intermittent positive pressure breathing can increase lung volume as well as vital lung capacity in acute SCI individuals.

Bronchodilator therapy with salbutamol may be an effective treatment for improving pulmonary function during the acute phase post SCI.

Ambroxol may be an effective treatment to reduce pulmonary complications and improve oxygenation status following surgery in acute cervical SCI patients.

Respiratory management hospital programs

## Table of Contents

<b>1.0 Executive Summary</b> .....	1
<b>2.0 Methods</b> .....	2
<b>3.0 Introduction</b> .....	2
<b>3.1 Neuronal Control of Breathing</b> .....	3
<b>3.2 Measurements for Lung Volume and Lung Capacity</b> .....	4
<b>3.3 Pulmonary Complications during Acute SCI</b> .....	4
<b>4.0 Mechanical Ventilation</b> .....	5
<b>4.1 Intubation</b> .....	6
<b>4.2 Tracheostomy</b> .....	7
<b>4.3 Comparative or Combination Interventions</b> .....	13
<b>4.4 Timing of Mechanical Ventilation</b> .....	15
<b>4.5 Ventilation Weaning, Extubation, and Decannulation</b> .....	19
<b>4.6 Secretion Removal Techniques</b> .....	24
<b>5.0 Non-Pharmacological Interventions for Pulmonary Function Improvement during Acute SCI</b> .....	26
<b>5.1 Respiratory Muscle Training</b> .....	26
<b>5.2 Diaphragm Pacing</b> .....	30
<b>5.3 Intermittent Positive Pressure Breathing for Acute SCI patients</b> .....	31
<b>6.0 Pharmacological Interventions for Pulmonary Function Improvement during Acute SCI</b> .....	32
<b>7.0 Hospital Programs for Respiratory Management</b> .....	34
<b>8.0 Summary</b> .....	37
<b>9.0 References</b> .....	41
<b>Abbreviations</b> .....	47

# Respiratory Management during the Acute Phase of Spinal Cord Injury

## 1.0 Executive Summary

The majority of research in the area of early respiratory management is primarily centered on ventilation (including related topics: tracheostomy, intubation, and extubation) and the prevention and treatment of pulmonary complications. The emphasis in acute care is to maintain an open airway and diaphragm functioning while preventing respiratory failure, atelectasis, and pneumonia. This is a delicate balance for medical personnel as the presence of ventilation itself—despite assisting breathing—can directly lead to these pulmonary complications. This review has shown that less than ten percent of studies to date are in the form of randomized controlled trials (RCTs); the majority are retrospective studies examining which factors on admission to acute care are associated with certain interventions and outcomes. This suggests a lack of interventional research in the area of acute respiratory care during acute SCI. Effective RCTs may be difficult to undertake in this research area as there are often standard protocols in place for airway management; further, it may be unethical to create a control group that receives less than the highest quality of pulmonary resuscitation (Casha & Christie, 2011). Lastly, a common theme emerging throughout this chapter is that individuals with complete, high level injuries tend to require more mechanical ventilation, intubation, and tracheostomies than individuals with incomplete or lower level injuries. These patients also experience more pulmonary complications and have more difficulty weaning from ventilation. This patient demographic would benefit most from prospective RCTs in respiratory management; this would allow for improved acute care and rehabilitation outcomes. With significant advances in technology, new interventions may be studied. Neuroplasticity is continuously playing a larger role in neurorehabilitation in all stages and spinal cord injury is no exception. As respiratory function is controlled nervously, it is a prime area for the exploration of neuroplasticity and it can be anticipated that it will start to emerge in the literature more frequently in the near future (Fuller & Mitchell, 2017; Fields & Mitchell, 2015).

## Gaps in the Evidence

Although this is an important area of clinical care, high quality research is lacking, and consists largely of cohort and case-controlled studies. This creates problems in that more severe strokes are more likely to be associated with poorer outcomes and are more likely to have more aggressive treatments, such as a tracheostomy. RCTs are uncommon and of those many are of poor quality with low PEDro scores and/or very small sample sizes. The current literature does point to where high quality RCTs are necessary, preferably multi-sited studies with high PEDro scores. These are designed to answer the following questions which include:

1. What is the efficacy of intermittent positive pressure in acute SCI on pulmonary indices and pulmonary complications?
2. What is the impact of earlier tracheostomies on pulmonary complications and ventilation times?
3. What is the impact of percutaneous tracheostomies on pulmonary complications and ventilation/hospital times when compared to more traditional surgical tracheostomies?

4. Is diaphragmatic pacing better than mechanical ventilation for those SCI patients who need breathing assistance in reducing the incidence of pneumonia and number of ventilator days?
5. In acute SCI patients, does higher tidal volume ventilation speed up the mechanical ventilation weaning process when compared to lower tidal volume ventilation?
6. Does mechanical insufflation/exsufflation techniques clear secretions better than manual assisted coughing techniques?
7. Do combined inspiratory and expiratory muscle training improve pulmonary indices better than inspiratory or expiratory muscle training alone.
8. Do bronchodilators such as Salbutamol improve pulmonary indices when compared to placebo?

## **2.0 Methods**

A literature search was performed using the following databases: Cochrane Library, PubMed/MEDLINE, EMBASE, CINAHL, and Scopus. The following search terms were entered: (spinal cord injury OR paraplegia OR quadriplegia OR tetraplegia) AND respiratory, respiration, pulmonary, inspiratory muscle training, respiratory muscle strength, bronchodilators, bronchial hyperresponsiveness, ipratropium, metaproterenol, salbutamol, salmeterol, anabolic steroid, ambroxol, ventilation, ventilator, phrenic nerve stimulation, diaphragmatic stimulation, tracheostomy, atelectasis, intermittent positive pressure breathing, abdominal binder, vibration, secretion, pneumonia, lung abscess, abdominal neuromuscular electrical, or stimulation. Each search term after the brackets was added separately.

The following limits to the search were applied: the article must have been published between January 1, 1990 and January 1, 2015 (version 1); January 1, 2015 and July 31<sup>st</sup>, 2018 (version 2), in English, and included humans over the age of 18 years. The search was restricted to journal articles, reviews, and systematic reviews; grey literature, conference abstracts, case reports, study protocols, and qualitative studies were excluded. The studies had to include a minimum of three patients, of which  $\geq 50\%$  had spinal cord injuries, unless the results stratified injury etiology. During this process, additional studies were added as a result of cross-referencing between studies. Articles were considered to be 'acute' and therefore suitable for inclusion in this chapter if the participants in each study were enrolled within approximately 1 month of their injury, or if the article did not report the time frame but made it clear that the study was conducted soon after the initial admission to hospital. For studies examining ventilator weaning and physiotherapy, the criteria was more relaxed and included studies where patients began enrollment within 1 month following injury and were included up to 4 months post injury.

## **3.0 Introduction**

The muscle groups required for respiration include the diaphragm, intercostals, abdominal muscles, and accessory muscles. A spinal cord injury (SCI) that occurs in the cervical or thoracic region can affect the nerves that innervate these muscles and, as a result, impair respiration. With an injury above C3, paralysis of these muscles requires lifetime ventilation for survival. Individuals with incomplete or lower level injuries are not as compromised but can still experience weakness or spasticity in these muscles that reduce respiratory flow rates and lung volumes (Galeiras Vázquez et al. 2013). Developing rigorous management and prophylactic protocols for respiration complications are key to improving patient outcomes and preventing morbidity and mortality (Berney et al. 2011). This chapter discusses the interventions available to assist with respiratory management during the acute phase post SCI. Broadly, the

interventions are categorized into mechanical ventilation, non-pharmacological interventions, and pharmacological interventions.

### 3.1 Neuronal Control of Breathing

Breathing is controlled by nerves that originate from the cervical and thoracic levels of the spinal cord. Due to the numerous muscles and nerves involved, the respiratory function that is affected depends on the level and severity of the injury. Table 1 outlines the associated muscles involved in inspiration and expiration that are affected by injuries at various levels; subsequent patient outcomes for these injuries are also detailed. Information for this table was adapted from Warren et al. (2014) and Mansel and Norman (1990).

**Table 1. Effect of Level of Injury on Respiratory Function**

Level	Associated Muscles for Inspiration and Pulmonary Function	Associated Muscles for Expiration	Patient Outcomes
C1	Sternocleidomastoid and accessory muscles (C1-C4)		Complete injury above C3 usually results in paralysis and denervation of all muscles required for inspiration and expiration. Life-long ventilation usually required.
C2			
C3	Diaphragm (C3-C5)		An injury from C3-C5 results in variable inability to inspire and expire. Often ventilated. May be able to wean from ventilation in time, depending on other factors.
C4			
C5	Tidal volume is reduced from injury at or above this level		
C6	Scalenes accessory (C4-C8)	Pectoralis major muscle (C5-T1)	Patients experience more difficulty with expiration than inspiration. May not experience respiratory failure, but often experiences muscle fatigue. Often ventilated initially but can usually achieve independent breathing.
C7			
C8			
T1	External intercostals (T1-T11)  These muscles are responsible for producing vital capacity. Vital capacity reduced by up to 53%, peak expiratory flow rate reduced by up to 42%, and forced expiratory volume is reduced up to 49% of what is seen in healthy individuals.	Internal intercostal muscles (T1-T11)	Patients experience more difficulty with expiration than inspiration. Patients experience a reduced ability to cough in an injury at or above this level.
T2			
T3			
T4			
T5			
T6		Abdominal muscles and internal intercostals (T6-T12)	
T7			
T8			
T9			
T10			
T11			
T12			

### **3.2 Measurements for Lung Volume and Lung Capacity**

Following SCI, lung function tests are performed to evaluate total lung capacity, forced vital capacity, tidal volume, residual volume, expiratory reserve volume, inspiratory reserve volume, forced expiratory flow, and forced expiratory volume. These tests help determine the degree to which respiration is impaired, the degree of ventilation the patient will require, and overall patient outcomes. A detailed explanation of these tests and their parameters is outlined in the Respiratory Management Chapter in SCIRE version 6.0.

### **3.3 Pulmonary Complications during Acute SCI**

Respiratory complications occur in 36-83% of patients with acute SCI, the exact nature of which is dependent on the level of injury as this determines which respiratory muscles are affected due to loss of innervation (Warren et al. 2014). Impaired respiratory muscle function leads to complications such as improper bronchial secretion clearance, pneumonia, atelectasis, septicemia, pulmonary embolism, and reduced vital and inspiratory capacity (Warren et al. 2014). It has been suggested that the key to their prevention is intense secretion management (Claxton et al. 1998). Hygienic behaviours, such as changing the patient's body position to promote postural draining, performing manual assisted coughing or chest percussion, and clearing bronchial secretions, are effective in reducing death from pulmonary complications (Mansel & Norman, 1990). Large volumes of mucus, or mucus harbouring inside the lung for extensive periods of time, encourage the growth of bacteria and subsequent development of pneumonia. With respect to pneumonia, Raab et al. (2016) found that maximal inspiratory pressure was significantly associated with pneumonia risk. Those with maximal inspiratory pressure at 115% above their lesion-specific reference values had significantly fewer instances of pneumonia (Raab et al., 2016). In addition to pneumonia, atelectasis and respiratory failure are the most common pulmonary complications following acute SCI (Berlly & Shem, 2007) which often require mechanical ventilation to manage (Galeiras Vázquez et al. 2013). To confound this problem, mechanical ventilation puts patients at an increased risk for ventilator-assisted pneumonia, demonstrating how these complications can be difficult to control. Individuals with ventilator-assisted pneumonia have a death rate of 20-30% and an extended hospital stay (Call et al. 2011; Cook, 2000). Other conditions such as aspiration, acute lung injury, acute respiratory distress syndrome, and complications related to tracheostomy and intubation, such as tracheal stenosis or stomal cellulitis, also have negative respiratory implications but are less well studied.

The main conclusion drawn from these studies is that respiratory complications are prevalent among patients with acute SCI, and the likelihood of their development depends on a number of factors related to the initial injury on admission. Overall, pneumonia is the most studied associated complication with a greater incidence in patients with a higher level of injury (Cotton et al. 2005; Fishburn et al. 1990), a more severe injury (Hassid et al. 2008; Huang & Ou, 2014), larger lesions (Aarabi et al. 2012), additional fractures (Chen et al. 2013; Harrop et al. 2001), no return of deep tendon reflexes after one day (Lemons & Wagner, 1994), and who received surgical instead of percutaneous tracheostomy (Romero-Ganuza et al. 2011). With regard to tracheostomies, there is conflicting evidence regarding their contribution to respiratory complications. Some studies have found that patients who had tracheostomies experienced reduced respiratory complications compared to patients who did not have a tracheostomy (Leelapattana et al. 2012), whereas other studies reported the opposite (Harrop et al. 2004; Kornblith et al. 2014).



The development of respiratory complications is also dependent on several other factors including the completeness of the injury (Lemons & Wagner, 1994), the timing of the tracheostomy (Romero-Ganuza et al. 2011; Romero et al. 2009) and the cause of injury (Aarabi et al. 2012). Age may play a role in the development of complications (Aarabi et al. 2012), although this finding is not always supported (Lemons & Wagner, 1994). Likewise, some studies reported that receiving an early tracheostomy lowered the risk of problems (Kornblith et al. 2014; Romero-Ganuza et al. 2011; Romero et al. 2009), but other studies found it did not matter (Choi et al. 2013). Additional data on the timing of tracheostomies can be found in Section 4.4. Pulmonary complications cause a significant burden to the individual and health care system, as it increases time on ventilation, hospital stay, and costs (Aarabi et al. 2012; Chen et al. 2013; Kornblith et al. 2014; Winslow et al. 2002). Furthermore, if complications cannot be managed initially, they may accumulate and put a patient at risk for more respiratory problems. For example, Huang and Ou (2014) found that the presence of respiratory failure led to a higher likelihood of developing pneumonia. It is therefore important that prophylactic measures be taken to prevent pulmonary complications, and that they are managed intensely should they arise.

Other factors that have been less studied but still shown to be associated with higher rates of respiratory complications include a history of smoking, electrolyte imbalances, and hypoalbuminemia (Chen et al., 2013). The etiology of the SCI is also a factor, specifically sports-related SCIs (Aarabi et al., 2012). There are a variety of factors, both pre-existing and related to the injury, which determine the risk of having a respiratory complication in the acute phase. Overall, the current literature indicates that all individuals with SCI should be screened and monitored for respiratory complications in the acute phase of SCI given their frequency as well as multifaceted origins.

## **4.0 Mechanical Ventilation**

One of the most important avenues of respiratory management is mechanical ventilation. Over the past 40 years, there has been an increase in the incidence of cervical cord injuries and, as a result, an increase in the use of mechanical ventilation (Devivo, 2012; Jackson et al. 2004). Patients can be ventilated with non-invasive mask ventilation or more invasive endotracheal or transtracheal (with a tracheostomy) ventilation. Often these more invasive procedures are needed to allow for the ability to suction excess secretions to prevent the development of complications such as atelectasis or pneumonia (Gregoretti et al. 2005). Patients may experience more than one type of ventilation during their hospital stay as their needs adjust (i.e., they may initially be intubated with endotracheal ventilation and later proceed to transtracheal intubation to assist in ventilator weaning).

In addition to the delivery of ventilation, there are several modes of ventilation used for patients that vary in the amount of volume or pressure controlled based on pre-set variables to maximize lung function. For example, intermittent positive pressure breathing is one of the oldest ventilation strategies in which all inspirations are provided through the application of positive pressure to the airway. Its use is common in acute SCI patients, yet its general efficacy is still largely unknown (Dyah henehy & Berney, 2001) and is understudied in the SCI population. Intubation for mechanical ventilation often occurs at the time of injury to manage respiratory failure or to protect the airway in cases of complete SCI between C1 and C5 (Berney et al. 2011). In contrast, incomplete injuries lower than C5, where the airway is not immediately compromised or at risk, ventilation is often still initiated approximately four days after injury

when levels of carbon dioxide rise in the blood due to difficulty expiring (Galeiras Vázquez et al. 2013). Although ventilatory needs are unique for each patient, it is useful to determine which factors predict the need for mechanical ventilation in an effort to develop practice guidelines and reduce overall hospital stay (Casha & Christie, 2011).

Certain risk factors of mechanical ventilation have also been identified (Montoto-Marques et al., 2018). One observational study found, not unexpectedly, that patients with ASIA grades A and B were more likely to require mechanical ventilation, as well as those with higher injury severity scores (Montoto-Marques et al., 2018). The last factor discussed by this study was the role that gender played. Males were reported to require higher levels of mechanical ventilation than females (Montoto-Marques et al., 2018); however, this could be due to the overwhelming number of men in this study compared to women. Other factors include complete injuries, high Injury Severity Score (ISS), and compounding injuries (Velmahos et al., 2003; Como et al., 2005; Seidl et al., 2010).

#### 4.1 Intubation

Patients with acute SCI requiring ventilation are usually intubated, either in the field or upon admission to the hospital. Intubation can either be orotracheal or nasotracheal; both options are normally used for short periods of ventilation of less than 10 days (Shirawi & Arabi, 2006). Prolonged intubation is not recommended as it can lead to the development of pneumonia, subglottic or tracheal stenosis, and increased airway resistance. In addition, it limits patients' mobility, prolongs ventilator weaning, and makes pulmonary and oral hygiene difficult (Shirawi & Arabi, 2006). In cases where ventilation is required for longer than 10 days, a tracheostomy is usually performed. Intubation is safest when it is performed electively under anesthesia to reduce neurological damage experienced from neck manipulation (Durbin et al. 2014), so it often occurs before a patient is experiencing severe breathing difficulty. The risk of damage is elevated when intubation is performed urgently in the case of sudden respiratory distress.

**Table 2. Evaluation of the Use of Intubation for Respiratory Function during Acute SCI**

Author Year Country Research Design Sample Size	Methods	Outcomes
Iwashita et al. (2006) Japan Cohort N=49	<p><b>Population:</b> Mean age: 51 yr; Gender: male=40, female=8; Level of injury: C2-C7; Severity of injury: complete=28, incomplete=21.</p> <p><b>Intervention:</b> Patients were either intubated or not intubated.</p> <p><b>Outcome Measures:</b> The following retrospectively: ratio of arterial oxygen partial pressure to fractional inspired oxygen (PaO<sub>2</sub>/FiO<sub>2</sub>), partial pressure of carbon dioxide in arterial blood (PaCO<sub>2</sub>), arterial pH, injury severity, level of injury.</p> <p><b>Chronicity:</b> Time since injury not specified.</p>	<ol style="list-style-type: none"> <li>1. Patients who were intubated experienced a significantly lower PaO<sub>2</sub>/FiO<sub>2</sub> (p=0.0014), a lower arterial pH (p=0.0001), and a higher PaCO<sub>2</sub> (p&lt;0.0001), than patients who were not intubated.</li> <li>2. Patients with complete injuries were intubated significantly more than patients with incomplete injuries (p=0.011).</li> <li>3. Patients with a higher level of cervical SCI were intubated significantly more than patients with a lower level of cervical SCI (p=0.002).</li> </ol>

#### Discussion

A cohort study found that intubation significantly reduced the ratio of arterial oxygen partial pressure to fractional inspired oxygen (Iwashita et al., 2006), as well the need for intubation was higher in patients with complete injuries. This is significant as acute lung injury is present when the ratio of arterial oxygen partial pressure to fractional inspired oxygen is <300, and acute respiratory distress syndrome is present when it is <200. Several observational studies have found similar results in terms of individuals with complete injuries requiring higher rates of intubation (Como et al., 2005; Velmahos et al., 2003; Seidl et al., 2010).

## Conclusion

***There is level 2 evidence (from one cohort study; Iwashita et al., 2006) that acute SCI patients who are intubated may have reduced ratios of arterial oxygen partial pressure to fractional inspired oxygen compared to no intubation.***

Intubation can reduce arterial oxygen partial pressure ratios in acute SCI individuals.
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## 4.2 Tracheostomy

Between 21% and 77% of patients with cervical SCI require a tracheostomy, with the variability of these numbers being due to the influence of at least 16 other factors (e.g., severity of the injury, presence of other injuries, admission Glasgow Coma Scale score, age, etc.) (Branco et al. 2011; Como et al., 2005). The interactions of these other parameters make it difficult to establish clear criteria for who should receive a tracheostomy. Identifying when a tracheostomy should be performed is also important to determine, as timing may impact a patient's recovery with regards to developing complications and weaning from ventilation. In a systematic review of non-SCI patients who required tracheostomies, Griffiths et al. (2005) concluded that individuals who received an early tracheostomy did not experience fewer complications but did experience a shorter duration of mechanical ventilation. The timing of tracheostomy following spinal fixation should also be considered. Currently, the typical time is 1-2 weeks post-surgery, but this timing lacks conclusive evidence (Galeiras Vázquez et al. 2013). In addition to who should receive a tracheostomy and when it should be performed, there is also controversy surrounding whether tracheostomies are always beneficial, effective in ventilator weaning, and result in a reduced number of pulmonary complications. In fact, complications resulting from tracheostomies, such as tracheal stenosis, occur in up to 6% of patients (Lissauer, 2013), so the risks and benefits must be evaluated. Other complications have been reported to include tightness at the scar location, difficulty swallowing, and cosmetic inconveniences (Biering-Sorensen & Biering-Sorensen, 1992). Several studies have retrospectively examined the predictors for needing a tracheostomy and complications associated with the procedure; these are presented in Table 3.

There are two techniques for tracheostomy: surgical (open) and percutaneous. Surgical tracheostomy is the traditional technique that requires opening up the entire trachea to insert the tube. Percutaneous tracheostomy is an alternative procedure that was first developed in the late 1950s and can be performed at the patient's bedside with fewer materials (Gysin et al. 1999). Percutaneous tracheostomy is less invasive and involves inserting a tracheostomy tube through the skin without directly visualizing the trachea. Due to its less invasive nature, this procedure was thought to be associated with fewer complications and infections, although this relationship is unclear (Gysin et al. 1999). Lastly, patients who required a tracheostomy had longer length of stay in hospitals as well as higher hospital costs (Winslow et al., 2002).

Several studies have investigated factors associated with needing a tracheostomy in acute SCI patients, such as higher injury severity and complete lesions (Leelapattana et al. 2012; McCully et al. 2014; Menaker et al. 2013; O'Keeffe et al. 2004; Yugue et al. 2012), as well as a cervical level of injury (Biering-Sorensen & Biering-Sorensen, 1992; McCully et al. 2014; Romero-Ganuzo et al. 2011a; Seidl et al. 2010; Yugue et al. 2012). Other reported factors include older age (Harrop et al. 2004; Yugue et al. 2012) and a lower ASIA motor grade upon hospital admission (Menaker et al. 2013).

**Table 3. Evaluation of the Use of Tracheostomy during Acute**

<b>Author Year Country Research Design Sample Size</b>	<b>Methods</b>	<b>Outcomes</b>
Sustic et al. (2002) Croatia RCT PEDro=3 N=16	<p><b>Population:</b> Age range: 19-59 yr; Gender: male=13, female=3; Level of injury: C3-C6; Severity of injury: not specified.</p> <p><b>Intervention:</b> Patients were randomized to receive either a surgical tracheostomy (ST) or an ultrasound-guided percutaneous dilational tracheostomy (PDT).</p> <p><b>Outcome Measures:</b> The following post procedure: incidence of complications, duration of procedure.</p> <p><b>Chronicity:</b> Time since injury not specified. Average intensive care unit length of stay=22 days (ST) and 20 days (PDT).</p>	<ol style="list-style-type: none"> <li>1. No patients experienced any major complications due to either tracheostomy procedure.</li> <li>2. The duration of the PDT procedure was significantly shorter than the duration of the ST procedure (<math>p&lt;0.05</math>).</li> </ol>
Leelapattana et al. (2012) Canada Cohort N=66	<p><b>Population:</b> Mean age: 38 yr; Gender: male=50, female=16; Level of injury: C4-C7; Severity of injury: complete=12, incomplete=45.</p> <p><b>Intervention:</b> Patients either received a tracheostomy or did not.</p> <p><b>Outcome Measures:</b> The following at discharge: duration of mechanical ventilation, injury severity score (ISS). The following after three days of ventilation: ratio of arterial oxygen partial pressure to fractional inspired oxygen.</p> <p><b>Chronicity:</b> Patients included in the study were within 24 hr of sustaining injury upon hospital admission.</p>	<ol style="list-style-type: none"> <li>1. Patients who had a tracheostomy had a significantly lower motor score at discharge (<math>p=0.04</math>), a longer hospital stay (<math>p&lt;0.001</math>), a longer ICU stay (<math>p=0.002</math>), and required mechanical ventilation for longer (<math>p=0.001</math>) compared to patients who did not have a tracheostomy.</li> <li>2. Patients who had a tracheostomy had fewer pulmonary complications (<math>p=0.001</math>) and fewer cases of death (<math>p=0.025</math>) than patients who did not have a tracheostomy.</li> <li>3. Early tracheostomy correlated to fewer days on ventilation (<math>p=0.038</math>) and fewer days spent in the hospital (<math>p=0.004</math>) compared to late tracheostomy.</li> <li>4. The number of days spent in hospital increased by 2.3 days for every additional day from injury to tracheostomy (<math>p&lt;0.001</math>).</li> <li>5. An ISS score <math>&gt;32</math>, complete SCI, and a PF ratio <math>&lt;300</math> on day 3 of ventilation were predictors for requiring mechanical ventilation for greater than 7 days.</li> </ol>

<p>Romero-Ganuza et al. (2011a) Spain Cohort N=28</p>	<p><b>Population:</b> Mean age: 40 yr; Gender: male=23, female=5; Level of injury: cervical; Severity of injury: complete=21, incomplete=7; AIS A-C. <b>Intervention:</b> All patients received a percutaneous tracheostomy following anterior cervical spine fixation. <b>Outcome Measures:</b> Timing of tracheostomy, neurological deterioration, incidence of complications. <b>Chronicity:</b> The mean time from injury to fixation surgery was 2.25 days. The mean time from surgery to tracheostomy was 8.25 days.</p>	<ol style="list-style-type: none"> <li>1. Patients received a tracheostomy an average of 8.25 days after they received spinal fixation surgery. Tracheostomy was performed within 6 days or less in 42.9% (12/28) of cases.</li> <li>2. No patients experienced neurological deterioration as a result of spinal surgery or tracheostomy procedure.</li> <li>3. No patient experienced an infection at the cervical fixation wound, however, 10.7% (3/28) of patients experienced minor complications at the tracheostomy site.</li> <li>4. The authors note that tracheostomy quickly performed after fixation surgery does not increase the rate of surgical wound infection.</li> </ol>
<p>McCully et al. (2014) USA Case Control N=256</p>	<p><b>Population:</b> Mean age: 46 yr; Gender: male=192, female=64; Level of injury: C1-T3; Severity of injury: complete=77, incomplete=179. <b>Intervention:</b> Patients either received a tracheostomy or did not. <b>Outcome Measures:</b> The following retrospectively: number of days on ventilator, severity of injury. <b>Chronicity:</b> Time since injury not specified. Median hospital length of stay was 7 days (no tracheostomy) and 33 days (tracheostomy).</p>	<ol style="list-style-type: none"> <li>1. Patients who received a tracheostomy had more days on a ventilator than patients who did not receive a tracheostomy (<math>p&lt;0.05</math>).</li> <li>2. The occurrence of complete injury and intubation was higher in patients who received a tracheostomy (<math>p&lt;0.05</math>) than patients who did not.</li> </ol>
<p>Berney et al. (2011) Australia Case Control N=114</p>	<p><b>Population:</b> Mean age: 32 yr; Gender: male=86, female=28; Level of injury: C0-C8; Severity of injury: complete=72, incomplete=42; AIS A-D. <b>Methods:</b> Patients who were extubated were compared to patients who received a tracheostomy. <b>Outcome Measures:</b> The following during hospital stay: pulmonary secretion production, number of associated injuries, mental state, ASIA score, ratio of arterial oxygen partial pressure to fractional inspired oxygen, forced vital capacity (FVC). <b>Chronicity:</b> Time since injury not specified.</p>	<ol style="list-style-type: none"> <li>1. Patients with a tracheostomy produced significantly more pulmonary secretions (<math>p=0.003</math>), had significantly more associated injuries (<math>p=0.02</math>), had a more alert mental state (<math>p=0.005</math>), and had more complete injuries (<math>p=0.026</math>) compared to patients who were extubated.</li> <li>2. Patients with a tracheostomy had significantly lower gas exchange (<math>p=0.02</math>) and FVC (<math>p&lt;0.001</math>) than patients who were extubated.</li> </ol>

<p>Berney et al. (2008) Australia Case Control N=71</p>	<p><b>Population:</b> Mean age: 40 yr; Gender: male=46, female=25; Level of injury: C1-C8; Severity of injury: complete=45, incomplete=26; AIS A-D. <b>Intervention:</b> Patients either received tracheostomy following anterior cervical spine fixation or posterior spine fixation (control group). <b>Outcome Measures:</b> The following retrospectively: timing of the tracheostomy since surgery, prevalence of infection. <b>Chronicity:</b> The median time from injury to stabilization surgery was 3 days. The mean time from surgery to tracheostomy was 3.8 days (anterior fixation) and 3.1 days (posterior fixation).</p>	<ol style="list-style-type: none"> <li>1. There were no significant differences between the timing of tracheostomy in patients who received it after anterior cervical spine fixation compared to patients who received it after posterior fixation (<math>p=0.09</math>).</li> <li>2. 24% (17/71) of patients developed an infection at the tracheostomy site or cervical site. Patients who received a tracheostomy after posterior fixation developed significantly more incision site infections than patients who received a tracheostomy after anterior fixation (<math>p&lt;0.05</math>).</li> </ol>
<p>Berney et al. (2002) Australia Case Control N=14</p>	<p><b>Population:</b> Mean age 28 yr; Gender: male=11, female=3; Level of injury: cervical; Severity of injury: complete. <b>Intervention:</b> Patients who received a tracheostomy were compared to patients who were extubated and received physiotherapy. <b>Outcome Measures:</b> The following at the time of extubation/the day of tracheostomy: forced vital capacity (FVC), ratio of arterial oxygen partial pressure to fractional inspired oxygen (<math>PaO_2/FiO_2</math>), total number of physiotherapy treatments, number of physiotherapy treatments in intensive care unit (ICU), length of stay in ICU, days requiring mechanical ventilation, length of stay in acute ward after discharge from ICU, days from injury to fixation. <b>Chronicity:</b> The mean time from injury to fixation was 1.9 days.</p>	<ol style="list-style-type: none"> <li>1. There was no significant difference in FVC between tracheostomized patients and physiotherapy patients (<math>p&gt;0.05</math>).</li> <li>2. There was no significant difference in <math>PaO_2/FiO_2</math> ratios between tracheostomized patients and physiotherapy patients (<math>p&gt;0.05</math>).</li> <li>3. There was no significant difference in total number of physiotherapy treatments between tracheostomized patients and extubated patients. Patients who were extubated and received physiotherapy required significantly fewer treatments compared to tracheostomized patients in ICU (<math>p=0.047</math>).</li> <li>4. Tracheostomized patients spent significantly more days in ICU than physiotherapy patients (<math>p=0.006</math>) and required mechanical ventilation for significantly longer than the physiotherapy group (<math>p=0.018</math>).</li> <li>5. There was no significant difference in the length of stay in the acute ward between groups (<math>p&gt;0.05</math>).</li> <li>6. There was no significant difference in the time from injury to fixation between groups (<math>p&gt;0.05</math>).</li> </ol>

<p>Kornblith et al. (2014) USA Case Series N=344</p>	<p><b>Population:</b> Mean age: 43 yr; Gender: male=275, female=69; Level of injury: cervical to lumbar; Severity of injury: complete=69, incomplete=275. <b>Intervention:</b> Patients either had a tracheostomy or did not. In addition, patients were either mechanically ventilated at discharge or were not. <b>Outcome Measures:</b> The following retrospectively: instances of prolonged mechanical ventilation, ventilator-associated pneumonia (VAP), acute lung injury (ALI), duration in intensive care unit (ICU), duration in hospital, number of ventilator-free days, extubation attempts, injury severity score (ISS). <b>Chronicity:</b> Time since injury not specified. Average number of hospital days=20.</p>	<ol style="list-style-type: none"> <li>1. Patients who received a tracheostomy were associated with a 14.1-fold higher odds of requiring prolonged mechanical ventilation (<math>p&lt;0.05</math>) compared to patients who did not receive a tracheostomy.</li> <li>2. Patients who received a tracheostomy had fewer ventilator-free days (<math>p&lt;0.05</math>) compared to patients who did not receive a tracheostomy.</li> <li>3. Patients who had a tracheostomy required mechanical ventilation at discharge more often than patients who did not have a tracheostomy (<math>p&lt;0.05</math>).</li> <li>4. Patients who required mechanical ventilation at discharge had a higher ISS (<math>p&lt;0.05</math>), significantly higher rates of VAP (<math>p&lt;0.05</math>) and ALI (<math>p&lt;0.05</math>), and longer ICU (<math>p&lt;0.05</math>) and hospital stays (<math>p&lt;0.05</math>) compared to patients who did not require mechanical ventilation at discharge.</li> </ol>
<p>O'Keeffe et al. (2004) USA Case Series N=17</p>	<p><b>Population:</b> Mean age 43 yr; Gender: male=12, female=5; Level of injury: cervical; Severity of injury: not specified. <b>Intervention:</b> All patients received a tracheostomy following anterior cervical spine fixation. <b>Outcome Measures:</b> The following after tracheostomy: neurologic deterioration, incidence of complications, mortalities, injury severity. <b>Chronicity:</b> Time since injury not specified.</p>	<p>Overall Analyses:</p> <ol style="list-style-type: none"> <li>1. No patients experienced neurologic deterioration after tracheostomy following spine fixation.</li> <li>2. No patients developed infections at the anterior cervical fusion site following tracheostomy. 82% (14/17) patients developed pneumonia. There were no deaths related to airway difficulties.</li> </ol> <p>Analyses of entire population of patients with cervical SCI, including patients that did not receive an anterior cervical spine fixation (N=60):</p> <ol style="list-style-type: none"> <li>3. The need for a tracheostomy correlated with injury severity (<math>p&lt;0.001</math>) with ASIA level A and B patients requiring the most tracheostomies.</li> </ol>

## Discussion

Tracheostomy is believed to facilitate weaning because it reduces the effort required to breathe (Peterson et al. 1994). Several studies examined the effect of tracheostomy on duration of mechanical ventilation. Among studies that did not stratify for time, tracheostomy was consistently reported to prolong mechanical ventilation (Berney et al. 2002; Leelapattana et al. 2012; McCully et al. 2014).

The influence of tracheostomy procedures on the development of respiratory complications has also been examined by a number of studies. Patients who have had a tracheostomy have been reported to have fewer pulmonary complications when compared to patients who have not had a tracheostomy (Leelapattana et al. 2012). Regarding type of tracheostomy, Sustic et al. (2002) compared percutaneous dilational tracheostomy with surgical tracheostomy, investigating the



development of perioperative and postoperative complications associated with each procedure. The authors found that no patients, regardless of intervention received, developed any major complication in relation to tracheostomy, however the percutaneous dilational tracheostomy was a significantly shorter procedure. Kornblith et al. (2014) found that patients who received a tracheostomy were associated with a 14.1-fold higher odds of requiring prolonged mechanical ventilation ( $p < 0.05$ ) compared to patients who did not receive a tracheostomy.

## Conclusion

***There is level 2 evidence (from one RCT; Sustic et al., 2002) that percutaneous dilational tracheostomies are a significantly shorter procedure and have fewer pulmonary complications compared to surgical tracheostomies for individuals with acute SCI.***

***There is level 2 evidence (from one cohort study; Leelapattana et al., 2012) that tracheostomies can reduce the number of pulmonary complications in individuals with acute SCI compared to late or no tracheostomy.***

***There is level 2 evidence (from one cohort study; Romero-Ganuza et al., 2011a) that tracheostomies performed directly after spinal fixation surgery do not increase the rate of surgical wound infection compared to non-immediate tracheostomies in acute SCI individuals.***

***There is level 3 evidence (from one case control study; McCully et al., 2014, and one case series; Kornblith et al., 2014) that acute SCI individuals who receive a tracheostomy may spend more days on a ventilator than those who do not.***

***There is level 3 evidence (from one case control study; Berney et al., 2011) that acute SCI individuals who receive a tracheostomy, compared to those who are extubated, may have more pulmonary secretions, lower gas exchange, and lower forced vital capacity.***

***There is level 4 evidence (from one case series; O’Keeffe et al., 2004) that tracheostomies in acute SCI individuals may not increase the risk of neurologic deterioration or surgical site infection.***

Tracheostomies can reduce the number of pulmonary complications in acute SCI individuals compared to those not receiving this procedure, and they may result in reduced forced vital capacity and lower gas exchange compared to extubation.

Tracheostomies are associated with an increase in the number of days acute SCI individuals spend on ventilators.

## 4.3 Comparative or Combination Interventions

There are limited studies examining combinations of interventions for the improvement of respiratory function post SCI. However, of those that meet the SCIRE inclusion criteria, the primary focus is on the type of ventilation received by patients: multiple, singular, or none.

**Table 4. Comparative or Combination Interventional Studies for Respiratory Function during Acute SCI.**

Author Year Country Research Design Sample Size	Methods	Outcomes
Gregoretti et al. (2005) Italy Prospective Controlled Trial N=10	<p><b>Population:</b> Mean age: 34 yr; Gender: male=10, female=0; Level of injury: C4-C6; Severity of injury: not specified.</p> <p><b>Intervention:</b> Patients first received endotracheal invasive ventilation (EIV) for 1-15 days and then later received transtracheal open ventilation (TOV) for 1 day.</p> <p><b>Outcome Measures:</b> The following during EIV treatment, at 1-hr post TOV treatment, and 24 hrs post TOV treatment: ratio of arterial oxygen partial pressure to fractional inspired oxygen (PaO<sub>2</sub>/FiO<sub>2</sub>), arterial blood gas analysis in the form of partial pressure of inspired oxygen in arterial blood (PaO<sub>2</sub>), partial pressure of carbon dioxide in arterial blood (PaCO<sub>2</sub>), Respiratory rate, pressure within the distal trachea, pressure-time product of esophageal pressure.</p> <p><b>Chronicity:</b> Time since injury not specified.</p>	<ol style="list-style-type: none"> <li>1. There were no significant differences between the EIV treatment and the TOV treatment with regards to PaO<sub>2</sub>/FiO<sub>2</sub>, PaO<sub>2</sub>, respiratory rate, and pressure within the distal trachea (p&gt;0.05).</li> <li>2. Patients had a significantly lower PaCO<sub>2</sub> while receiving EIV compared to 1 hr post TOV and 24 hr post TOV (p&lt;0.0001).</li> <li>3. Patients had a significantly lower pressure-time product of esophageal pressure after 24 hr of receiving TOV compared to 1 hr post TOV and during EIV (p&lt;0.05).</li> </ol>
Watt et al. (2011) United Kingdom Case Control N=189	<p><b>Population:</b> Mean age: 32 yr; Gender: male=163, female=26; Level of injury: C1-S5; Severity of injury: complete=136, incomplete=53; AIS A-D.</p> <p><b>Intervention:</b> Patients were either weaned from ventilation at discharge or remained on ventilation at discharge. Among those who required mechanical ventilation, some patients also used diaphragm pacing. Patients were further stratified by age 0-30 yr, 31-45 yr, and 46+ yr.</p> <p><b>Outcome Measures:</b> Mean survival time.</p> <p><b>Chronicity:</b> Time since injury not specified. The date of ventilation was within a few days of injury.</p>	<ol style="list-style-type: none"> <li>1. Patients aged 31-35 who were weaned from the ventilator at discharge had a significantly higher mean survival time than patients who still required ventilation at discharge (p=0.047). There were no significant differences in survival times in the other age groups.</li> <li>2. Among those who required mechanical ventilation at discharge, patients who used diaphragm pacing had a significantly better survival than the group who only used mechanical ventilation (p&lt;0.05).</li> </ol>
Romero-Ganuzas et al. (2011b) Spain Case Control N=323	<p><b>Population:</b> Mean age: 42 yr; Gender: male=255, female=68; Level of injury: cervical to thoracic; Severity of injury: complete=229, incomplete=94.</p> <p><b>Intervention:</b> Patients either received a tracheostomy or did not. Of those who did, they either received a surgical tracheostomy or a percutaneous tracheostomy. They also either received an early tracheostomy (≤7 days post intubation) or a late tracheostomy (&gt;7 days post intubation).</p> <p><b>Outcome Measures:</b> The following during hospital stay: incidence of tracheostomy, incidence of complications.</p> <p><b>Chronicity:</b> Mean interval from injury to admission=11.4 days.</p>	<ol style="list-style-type: none"> <li>1. There were 69 cases of perioperative complications following tracheostomy. Patients who received an early tracheostomy had significantly fewer cases of tracheal stenosis than patients who received a late tracheostomy (p=0.003). There were no significant differences in pneumonia (p=0.81), stomal cellulitis (p=0.45), bleeding (p=0.96), or mortality rate (p=0.22) between the two groups.</li> <li>2. Patients who received a percutaneous tracheostomy experienced fewer cases of pneumonia (p=0.011) compared to patients who received a surgical tracheostomy.</li> </ol>

## Discussion

A case control study by Watt et al. (2011) determined that patients who used diaphragm pacing with mechanical ventilation compared to those who only had mechanical ventilation had significantly higher survival rates. Of those patients between the ages of 31-35 years, those who were weaned from a ventilator before discharge experienced higher rates of survival compared to those that were not weaned from a ventilator before discharge (Watt et al., 2011). With respect to other respiratory parameters, when comparing endotracheal invasive ventilation with transtracheal open ventilation, there were no significant differences in partial pressure of oxygen between the two treatment types, although patients did have significantly lower partial pressure of carbon dioxide with endotracheal invasive ventilation (Gregoretti et al., 2005). The last study by Romero-Ganuza et al. (2011b) examined timing, type, and presence of tracheostomies in acute SCI patients. Of those who received an early tracheostomy there were fewer cases of tracheal stenosis compared to late tracheostomy. The type of tracheostomy that patients received also resulted in significant differences, where patients who had a percutaneous tracheostomy experienced fewer cases of pneumonia compared to surgical tracheostomy.

## Conclusion

***There is level 2 evidence (from one prospective controlled trial; Gregoretti et al., 2005) that endotracheal invasive ventilation may lower partial pressure of carbon dioxide compared to transtracheal open ventilation in acute SCI individuals.***

***There is level 3 evidence (from one case control study; Watt et al., 2011) that diaphragm pacing in combination with mechanical ventilation may result in higher survival than mechanical ventilation alone in acute SCI populations.***

***There is level 3 evidence (from one case control study; Romero-Ganuza et al., 2011b) that percutaneous tracheostomies may result in fewer cases of pneumonia compared to surgical tracheostomies in acute SCI individuals.***

Diaphragm pacing in combination with mechanical ventilation can increase survival rates post SCI.

Endotracheal invasive ventilation can lower partial pressure of carbon dioxide in acute SCI individuals.

Percutaneous tracheostomies may reduce rates of pneumonia when compared to surgical tracheostomies in acute SCI individuals.

## 4.4 Timing of Mechanical Ventilation

Many recent studies have focused on patient outcomes based on when individuals received mechanical ventilation (Beom & Seo, 2018; Flanagan et al., 2018; Choi et al., 2013). There has been debate as to whether early tracheostomies result in better outcomes, fewer ventilator days, decreased rates of pneumonia, and even cognitive decline.

**Table 5. Evaluation of the Use of Early versus Late Tracheostomy during Acute SCI**

Author Year Country Research Design Sample Size	Methods	Outcomes
Beom and Seo (2018) Korea Case Control N=48	<p><b>Population:</b> Mean age: 53.6 yr; Gender: male=43, female=5; Level of injury: N/R; Severity of injury: Mean ASIA impairment scale score (tracheostomy)=14.1 points, mean ASIA impairment scale score (non-tracheostomy)=23.4 points.</p> <p><b>Intervention:</b> Patients either received an early tracheostomy (within 7 days of initial SCI surgery) or a late tracheostomy (after 7 days of initial SCI surgery) or no tracheostomy.</p> <p><b>Outcome Measures:</b> Length of ventilation, ICU duration.</p> <p><b>Chronicity:</b> Time since injury not specified, patients were treated on average 29 days after initial SCI surgical intervention.</p>	<ol style="list-style-type: none"> <li>1. There were no significant differences in the duration of post-operative ventilation between early vs late tracheostomy patients.</li> <li>2. The early tracheostomy group had a significantly shorter length of stay in the ICU than the late tracheostomy group (p=0.03).</li> </ol>
Flanagan et al. (2018) United States Case Control N=70	<p><b>Population:</b> Mean age: 50.5 yr; Gender: male=53, female=17; Level of injury: C2=10, C3=12, C4=19, C5=9, C6=6, C7=2; Severity of injury: Mean ISS=19.6;</p> <p><b>Intervention:</b> Patients either received an early tracheostomy (&lt;7 days) or late (&gt;7 days) from their initial intubation.</p> <p><b>Outcome Measures:</b> Ventilator days, tracheostomy days, ICU length of stay, early pneumonia and surgical site infections, in-hospital mortality, 90-day mortality, 90-day readmission.</p> <p><b>Chronicity:</b> Patients are defined as being in the acute stage.</p>	<ol style="list-style-type: none"> <li>1. Early tracheostomy patients had fewer ventilator days compared to late tracheostomy patients (p=0.028).</li> <li>2. There was no significant difference in the number of days from tracheostomy to decannulation between early and late tracheostomy patients.</li> <li>3. Patients with early tracheostomy had significantly fewer ICU stays (p=0.021).</li> <li>4. There was no significant difference in the rates of early pneumonia and surgical site infections between the two groups, although both groups had high incidences.</li> <li>5. There were no significant differences between groups in terms of in-hospital mortality, 90-day mortality, and 90-day readmission.</li> </ol>
Kornblith et al. (2014) USA Case Control N=344	<p><b>Population:</b> Mean age: 43 yr; Gender: male=275, female=69; Level of injury: cervical to lumbar; Severity of injury: complete=69, incomplete=275.</p> <p><b>Intervention:</b> Patients either had a tracheostomy or did not. Of those requiring a tracheostomy, patients either experienced an early tracheostomy or a late tracheostomy. In addition, patients were either mechanically ventilated at discharge or were not.</p> <p><b>Outcome Measures:</b> The following retrospectively: instances of prolonged mechanical ventilation, ventilator-associated pneumonia (VAP), acute lung injury (ALI), acute respiratory distress syndrome (ARDS), duration in intensive care unit (ICU), duration in hospital, number of ventilator-free days, extubation attempts, injury severity score (ISS).</p>	<ol style="list-style-type: none"> <li>1. Patients who received a tracheostomy had higher rates of VAP (p&lt;0.05), higher rates of ALI (p&lt;0.01), spent significantly more days in ICU (p&lt;0.05) and hospital (p&lt;0.05), and had fewer ventilator-free days (p&lt;0.05) compared to patients who did not receive a tracheostomy.</li> <li>2. There were no significant differences with regards to death (p&gt;0.05) between patients who received a tracheostomy and patients who did not.</li> <li>3. Patients who had a late tracheostomy had higher rates of VAP (p&lt;0.05), ALI (p&lt;0.05), and ARDS (p&lt;0.05) compared to patients who had an early tracheostomy.</li> <li>4. Patients who required mechanical ventilation at discharge had a higher ISS (p&lt;0.05), significantly higher rates of VAP (p&lt;0.05) and ALI (p&lt;0.05), and</li> </ol>

	<p><b>Chronicity:</b> Time since injury not specified. Average number of hospital days=20.</p>	<p>longer ICU (<math>p&lt;0.05</math>) and hospital stays (<math>p&lt;0.05</math>) compared to patients who did not require mechanical ventilation at discharge.</p>
<p>Choi et al. (2013) Korea Case Control N=21</p>	<p><b>Population:</b> Mean age: 50 yr; Gender: male=19, female=2; Level of injury: C1-C7; Severity of injury: complete=8, incomplete=13; AIS A-D. <b>Intervention:</b> Patients either received an early tracheostomy (<math>\leq 10</math> days after injury) or a late tracheostomy (<math>&gt;10</math> days after injury). <b>Outcome Measures:</b> The following retrospectively: duration of mechanical ventilation. <b>Chronicity:</b> Time since injury not specified. Average number of hospital days=78.</p>	<ol style="list-style-type: none"> <li>1. Patients who received an earlier tracheostomy had a significantly shorter total ICU stay than patients who received a late tracheostomy (<math>p=0.01</math>).</li> <li>2. Patients who received an earlier tracheostomy experienced a significantly shorter duration of mechanical ventilation (<math>p=0.009</math>).</li> <li>3. There were no significant differences with regards to pneumonia (<math>p=0.283</math>) or tracheal stenosis (<math>p=0.999</math>) between the two groups.</li> </ol>
<p>Babu et al. (2013) USA Case Control N=20</p>	<p><b>Population:</b> Mean age: 47 yr; Gender: male=18, female=2; Level of injury: cervical; Severity of injury: complete=11, incomplete=9; AIS A-E. <b>Intervention:</b> Patients either received an early tracheostomy (<math>\leq 6</math> days after anterior cervical spine fixation) or a late tracheostomy (<math>&gt;6</math> days after anterior cervical spine fixation). <b>Outcome Measures:</b> The following retrospectively: length of hospital stay, incidence of complications, incidence and risk of complications. <b>Chronicity:</b> Time since injury not specified. The mean time from hospital presentation to anterior cervical spine fixation was 2.8 days. The mean length of hospital stay was 39 days.</p>	<ol style="list-style-type: none"> <li>1. Patients who underwent an early tracheostomy had a shorter hospitalization stay compared to those who received a late tracheostomy, but this difference was not significant (<math>p=0.11</math>).</li> <li>2. One patient developed pneumonia after tracheostomy. Patients who received a late tracheostomy were at a significantly increased risk for developing pulmonary complications (<math>p=0.033</math>).</li> </ol>
<p>Romero-Ganuzo et al. (2011b) Spain Case Control N=323</p>	<p><b>Population:</b> Mean age: 42 yr; Gender: male=255, female=68; Level of injury: cervical to thoracic; Severity of injury: complete=229, incomplete=94. <b>Intervention:</b> Patients either received a tracheostomy or did not. Of those who did, they either received a surgical tracheostomy or a percutaneous tracheostomy. They also either received an early tracheostomy (<math>\leq 7</math> days post intubation) or a late tracheostomy (<math>&gt;7</math> days post intubation). <b>Outcome Measures:</b> The following during hospital stay: incidence of mechanical ventilation and tracheostomy, injury level, injury severity, acute physiology and chronic health evaluation II (APACHE II) scores, incidence of complications, duration of mechanical ventilation, duration of intensive care unit (ICU) stay. <b>Chronicity:</b> Mean interval from injury to admission=11.4 days.</p>	<ol style="list-style-type: none"> <li>1. 92% (297/323) of patients required mechanical ventilation and 67% (215/323) required a tracheostomy.</li> <li>2. Patients who received a tracheostomy had significantly higher injury levels (<math>p&lt;0.001</math>) more severe injuries (<math>p&lt;0.001</math>), more associated injuries (<math>p=0.003</math>), and higher APACHE II scores (<math>p=0.03</math>) than patients who did not require a tracheostomy.</li> <li>3. There were 69 cases of perioperative complications following tracheostomy. Patients who received an early tracheostomy had significantly fewer cases of tracheal stenosis than patients who received a late tracheostomy (<math>p=0.003</math>). There were no significant differences in pneumonia (<math>p=0.81</math>), sternal cellulitis (<math>p=0.45</math>), bleeding (<math>p=0.96</math>), or mortality rate (<math>p=0.22</math>) between the two groups.</li> <li>4. Patients who received an early tracheostomy spent significantly fewer days on mechanical ventilation (<math>p&lt;0.001</math>) and significantly fewer days</li> </ol>

		<p>in ICU (<math>p &lt; 0.001</math>) compared to patients who received a late tracheostomy.</p> <p>5. Patients who received a percutaneous tracheostomy spent significantly fewer days in ICU (<math>p = 0.004</math>) and experienced fewer cases of pneumonia (<math>p = 0.011</math>) compared to patients who received a surgical tracheostomy.</p>
<p>Romero et al. (2009) Spain Case Control N=152</p>	<p><b>Population:</b> Mean age: 41 yr; Gender: male=122, female=30; Level of injury: cervical to thoracic; Severity of injury: complete=119, incomplete=33; AIS A-D.</p> <p><b>Intervention:</b> Patients either received a tracheostomy early (<math>\leq 7</math> days of admission) or late (<math>&gt; 7</math> days of admission).</p> <p><b>Outcome Measures:</b> The following retrospectively: total time of mechanical ventilation, time of mechanical ventilation post tracheostomy.</p> <p><b>Chronicity:</b> Mean time interval between injury and admission=27 days.</p>	<p>1. Patients who received an early tracheostomy had significantly fewer episodes of pneumonia during intubation than patients who received a late tracheostomy (<math>p &lt; 0.001</math>). There were no significant differences in incidences of pneumonia post tracheostomy (<math>p = 0.80</math>) and total incidences of pneumonia (<math>p = 0.27</math>) between the two groups.</p> <p>2. There were no differences in mortality between early vs late tracheostomy (<math>p = 0.12</math>).</p> <p>3. Patients who received an early tracheostomy had significantly shorter post tracheostomy duration on mechanical ventilation (<math>p &lt; 0.005</math>) and total duration on mechanical ventilation (<math>p &lt; 0.001</math>) compared to patients who received a late tracheostomy.</p> <p>4. Patients who received an early tracheostomy spent significantly fewer post tracheostomy days in ICU (<math>p &lt; 0.05</math>) and total days in ICU (<math>p &lt; 0.0010</math>) than patients who received a late tracheostomy.</p> <p>5. Patients who received an early tracheostomy had significantly fewer total complications than patients who received a late tracheostomy (<math>p &lt; 0.05</math>).</p>

## Discussion

Seven case control studies have examined the use of early versus late tracheostomy during acute SCI. Beom and Seo (2018) reported no difference in the number of ventilator days between early versus late patients, while other studies found that early patients had significantly fewer ventilator days compared to late (Flanagan et al. 2018; Choi et al. 2013; Romero-Ganuzza et al. 2011b; Romero et al. 2009). Multiple studies found that early tracheostomy patients had significantly fewer ICU days than the late group (Beom & Seo, 2018; Flanagan et al., 2018; Choi et al., 2013; Romero et al., 2009; Romero-Ganuzza et al. 2011b), with the exception of one study (Babu et al. 2013). In addition, Flanagan et al. (2018) also found that there were no differences in the number of days to decannulation, rates of pneumonia, or in-hospital mortality between early versus late tracheostomy patients. However, multiple studies have also found conflicting results as to whether an early tracheostomy results in higher rates of medical complications in SCI patients. Choi et al. (2013) found no significant differences between groups in terms of rates of pneumonia, or tracheal stenosis, while other case control studies (Babu et al., 2013; Kornblith et al., 2014) have found an increased risk of pneumonia for late tracheostomy patients. A large case control by Romero-Ganuzza et al. (2011b) (N=323) found that patients who received an early tracheostomy had a significantly increased risk of

tracheal stenosis, but no significant differences in rates of pneumonia. Lastly, early tracheostomies, compared to late, did not seem to affect rates of in-hospital mortality (Romero-Ganuza et al. 2011b; Romero et al., 2009; Flanagan et al., 2018).

## Conclusion

***There is level 3 evidence (from five case control studies; Beom and Seo, 2018; Flanagan et al., 2018; Choi et al. 2013; Romero-Ganuza et al. 2011b; Romero et al. 2009) that early tracheostomies may result in fewer ICU days than late tracheostomies in acute SCI patients.***

***There is level 3 evidence (from four case control studies; Flanagan et al., 2018; Choi et al. 2013; Romero-Ganuza et al. 2011b; Romero et al. 2009) that early tracheostomies may result in fewer ventilation days compared to late tracheostomies in acute SCI patients.***

***There is conflicting level 3 evidence (from six case control studies; Flanagan et al., 2018; Choi et al., 2013; Babu et al., 2013, Romero-Ganuza et al., 2011b; Romero et al., 2009; Kornblith et al. 2014) as to whether or not early tracheostomies decrease the risk of medical complications compared to late tracheostomies in acute SCI patients.***

***There is level 3 evidence (from 3 case control studies; Flanagan et al., 2018; Romero-Ganuza et al., 2011b; Romero et al., 2009) that the timing of tracheostomy may not influence in-hospital mortality rates in acute SCI individuals.***

Early tracheostomies may result in fewer ICU days and ventilation days, however they may not impact in-hospital mortality, compared to late tracheostomies.

The evidence is inconsistent regarding whether or not early tracheostomies reduce medical complications associated with tracheostomies compared to late tracheostomies.

## 4.5 Ventilation Weaning, Extubation, and Decannulation

Independence from ventilation is a primary goal for patients with SCI, but the ability to wean from the ventilator is primarily determined by the level of injury. A C1 or C2 level injury results in lifetime ventilator dependency because there is loss of function of the diaphragm, abdomen, and accessory muscles that control breathing. A C3-C4 injury is more variable in whether independent breathing will be achieved, with approximately 40% of these patients managing successful weaning (Berney et al. 2011). Patients with an injury at C5 or lower often need ventilation only in the earliest stages of the injury and during spine fixation surgery but are able to wean from the ventilator soon after. Although this review focuses on ventilator weaning, extubation and decannulation during the first weeks and months of SCI, this process can span much longer in some cases (Galeiras Vázquez et al. 2013). For more information on long-term ventilator weaning, refer to the section “Mechanical Ventilation and Weaning Protocols” in the Respiratory Management chapter in SCIRE version 6.0. Before a patient initiates the weaning process, extubation or decannulation, a vital capacity of 1500 mL, clear lung radiographs, stable blood gases, stable heart rate and respiratory rate, and stable excretion levels must be achieved (Chiodo et al. 2008; Peterson et al. 1999).

To begin weaning, a patient is removed from the ventilator for short periods of time that progress to longer and more frequent intervals of independent breathing. There are several protocols for this process; progressive ventilator-free breathing (PVFB), intermittent mandatory ventilation (IMV), and pressure support are the most common protocols (Weinberger & Weiss, 1995). Newer studies are also examining the safety of higher tidal volumes for ventilator weaning (Fenton et al., 2016). PVFB is the process whereby a patient experiences intervals of ventilator-free time that increases in length throughout the day to build muscle tone (Galeiras Vázquez et al. 2013). If PVFB is the chosen method for weaning, a patient can be weaned using either low tidal volume or high tidal volume. Using larger ventilator volumes (greater than 20 mL/kg) is thought to be more effective than low tidal volume and can resolve atelectasis and increase surfactant production; however, this method is also associated with more pulmonary complications in certain patient cohorts (Peterson et al. 1999; Wallbom et al. 2005). IMV is the process whereby the ventilator provides a predetermined number of breaths within a certain time frame and the patient is encouraged to spontaneously breathe in between them when they can. The number of breaths decreases as patients gain pulmonary independence. Lastly, pressure support ventilation is the technique whereby the patient must initiate every breath and the ventilator assists with the rest of the breathing process. Biphase positive airway pressure (BiPAP) and continuous positive airway pressure (CPAP) are two systems designed for non-invasive respiratory pressure support (Tromans et al. 1998). In addition to these ventilation procedures, transition from intubation to a tracheostomy, immediate extubation, and the use of diaphragmatic pacemakers are alternatives to patients requiring full time ventilation.

**Table 6. Examination of Mechanical Ventilator Weaning, Extubation and Decannulation during Acute SCI**

Author Year Country Research Design Sample Size	Methods	Outcomes
Peterson et al. (1999) USA Cohort N=42	<p><b>Population:</b> Age range: 15-60 yr; Gender: male=37, female=5; Level of injury: C3-C4; Severity of injury: complete.</p> <p><b>Intervention:</b> Patients either received high tidal volume (HTV) (20mL/kg) or low tidal volume (LTV) (15.5mL/kg) for progressive ventilator-free breathing.</p> <p><b>Outcome Measures:</b> incidence of atelectasis, lung pressure measured through centimetre of water (cmH<sub>2</sub>O).</p> <p><b>Chronicity:</b> Mean duration of injury at time of hospital admission=56 days (LTV group) and 49 days (HTV group).</p>	<ol style="list-style-type: none"> <li>1. Patients who received LTV had significantly more atelectasis compared to patients who received HTV (p=0.01).</li> <li>2. Patients who received HTV had significantly higher cmH<sub>2</sub>O compared to patients who received LTV (p&lt;0.001).</li> </ol>
Kornblith et al. (2014) USA Case Control N=344	<p><b>Population:</b> Mean age: 43 yr; Gender: male=275, female=69; Level of injury: cervical to lumbar; Severity of injury: complete=69, incomplete=275.</p> <p><b>Intervention:</b> Patients either had a tracheostomy or did not. Of those requiring a tracheostomy, patients either experienced an early tracheostomy or a late tracheostomy. In addition, patients were either</p>	<ol style="list-style-type: none"> <li>1. Patients who received a tracheostomy had higher rates of VAP (p&lt;0.05), higher rates of ALI (p&lt;0.01), spent significantly more days in ICU (p&lt;0.05) and hospital (p&lt;0.05), and had fewer ventilator-free days (p&lt;0.05) compared to patients who did not receive a tracheostomy.</li> <li>2. There were no significant differences with regards to death (p&gt;0.05) between patients who received a tracheostomy and patients who did not.</li> </ol>



Author Year Country Research Design Sample Size	Methods	Outcomes
	<p>mechanically ventilated at discharge or were not.</p> <p><b>Outcome Measures:</b> The following retrospectively: instances of prolonged mechanical ventilation, ventilator-associated pneumonia (VAP), acute lung injury (ALI), acute respiratory distress syndrome (ARDS), duration in intensive care unit (ICU), duration in hospital, number of ventilator-free days, extubation attempts, injury severity score (ISS).</p> <p><b>Chronicity:</b> Time since injury not specified. Average number of hospital days=20.</p>	<ol style="list-style-type: none"> <li>3. Patients who had a late tracheostomy had higher rates of VAP (<math>p&lt;0.05</math>), ALI (<math>p&lt;0.05</math>), and ARDS (<math>p&lt;0.05</math>) compared to patients who had an early tracheostomy.</li> <li>4. Patients who required mechanical ventilation at discharge had a higher ISS (<math>p&lt;0.05</math>), significantly higher rates of VAP (<math>p&lt;0.05</math>) and ALI (<math>p&lt;0.05</math>), and longer ICU (<math>p&lt;0.05</math>) and hospital stays (<math>p&lt;0.05</math>) compared to patients who did not require mechanical ventilation at discharge.</li> </ol>
<p>Nakashima et al. (2013) Japan Case Control N=164</p>	<p><b>Population:</b> Mean age: 45 yr; Gender: male=143, female=21; Level of injury: cervical; Severity of injury: complete=58, incomplete=106; AIS A-E.</p> <p><b>Intervention:</b> Patients either received a tracheostomy or did not. Of those who did, they were either successfully decannulated or not.</p> <p><b>Outcome Measures:</b> Proportion of patients who received a tracheostomy, proportion of patients who were successfully decannulated, level of injury, ASIA score.</p> <p><b>Chronicity:</b> Mean time interval from injury to tracheostomy=5 days; Mean time interval from tracheostomy to decannulation=46 days. Time since injury not specified for patients who did not receive tracheostomy.</p>	<ol style="list-style-type: none"> <li>1. 15.2% (25/164) received a tracheostomy, 84% (21/25) of these were successfully decannulated.</li> <li>2. Patients who received a tracheostomy had a history of smoking significantly more than patients who did not receive a tracheostomy (<math>p=0.02</math>).</li> <li>3. Patients with a complete injury from C1–C4 (<math>p=0.01</math>) or C5–C7 (<math>p&lt;0.001</math>) received a tracheostomy significantly more than patients with an incomplete injury at any level.</li> <li>4. All patients with C5–7 ASIA A were successfully decannulated. Patients with C1–4 ASIA A were significantly more common in the non-decannulation group compared to patients with other injury severities and injury levels (<math>p&lt;0.05</math>).</li> </ol>
<p>Call et al. (2011) USA Case Control N=87</p>	<p><b>Population:</b> Mean age: 39 yr; Gender: male=70, female=17; Level of injury: cervical to lumbar; Severity of injury: not specified.</p> <p><b>Intervention:</b> Patients were either discharged on ventilator support, tracheostomy collar, or natural airway. Of patients who were extubated, they were either successful on their first try, experienced 1 failure, or experienced multiple failures.</p> <p><b>Outcome Measures:</b> The following during hospital stay: attempt at extubation, number of ventilator-free days, incidence of mechanical ventilation at discharge. The following at discharge: length of intensive care unit (ICU) stay, incidence of ventilator-associated pneumonia (VAP).</p>	<p><b>Outcome of patients by degree of injury severity:</b></p> <ol style="list-style-type: none"> <li>1. Patients with cervical injuries and complete motor loss had a higher rate of no attempt at extubation (<math>p=0.041</math>), significantly fewer ventilator-free days (<math>p=0.003</math>), and higher incidence of mechanical ventilation at discharge (<math>p=0.014</math>) compared to patients without complete motor loss.</li> </ol> <p><b>Outcomes of patients at hospital discharge:</b></p> <ol style="list-style-type: none"> <li>2. Patients who were discharged on positive pressure ventilation had longer ICU stays compared to extubated patients (<math>p&lt;0.001</math>). Patients discharged on a tracheostomy collar had longer ICU stays than those who were extubated or decannulated (<math>p&lt;0.001</math>).</li> <li>3. The incidence of VAP was significantly higher in patients requiring mechanical ventilation (<math>p&lt;0.001</math>) and those discharged on tracheostomy collar (<math>p=0.001</math>) compared to patients who were discharged with a natural airway.</li> </ol>

Author Year Country Research Design Sample Size	Methods	Outcomes
	<p>The following after extubation: length of ICU stay, number of ventilator-free days, length of hospital stay, incidence of VAP.</p> <p><b>Chronicity:</b> Time since injury not specified. The mean time to tracheostomy=12 days. The mean length of hospital stay=33 days.</p>	<p><b>Outcome of patients who underwent extubation:</b></p> <ol style="list-style-type: none"> <li>4. Of patients in whom extubation was attempted, those who extubated successfully on the first attempt had significant shorter ICU stays (<math>p&lt;0.001</math>), more ventilator-free days (<math>p&lt;0.001</math>), and shorter hospital stays (<math>p=0.009</math>) compared with patients who failed one or more weaning or extubation attempts.</li> <li>5. Patients failing one or more attempts had a significantly higher incidence of VAP (<math>p&lt;0.001</math>) compared to patients who were successful on their first attempt.</li> </ol>
<p>Peterson et al. (1994) USA Case Control N=52</p>	<p><b>Population:</b> Mean age: 39 yr; Gender: male=80%, female=20%; Level of injury: cervical to lumbar; Severity of injury: not specified.</p> <p><b>Intervention:</b> Patients were either discharged on ventilator support, tracheostomy collar, or natural airway. Of patients who were extubated, they were either successful on their first try, experienced 1 failure, or experienced multiple failures.</p> <p><b>Outcome Measures:</b> The following during hospital stay: attempt at extubation, number of ventilator-free days, incidence of mechanical ventilation at discharge. The following at discharge: length of intensive care unit (ICU) stay, incidence of ventilator-associated pneumonia (VAP). The following after extubation: length of ICU stay, number of ventilator-free days, length of hospital stay, incidence of VAP.</p> <p><b>Chronicity:</b> Time since injury not specified. The mean time to tracheostomy=12 days. The mean length of hospital stay=33 days.</p>	<ol style="list-style-type: none"> <li>1. At one month post injury, significantly more patients who received PVFB had weaned compared to patients who received IMV (<math>p=0.01</math>).</li> <li>2. The overall ventilator weaning success rate for PVFB was significantly higher than the success rate of IMV (<math>p=0.02</math>).</li> </ol> <p><b>Outcome of patients by degree of injury severity:</b></p> <ol style="list-style-type: none"> <li>3. Patients with cervical injuries and complete motor loss had a higher rate of no attempt at extubation (<math>p=0.041</math>), significantly fewer ventilator-free days (<math>p=0.003</math>), and higher incidence of mechanical ventilation at discharge (<math>p=0.014</math>) compared to patients without complete motor loss.</li> </ol> <p><b>Outcomes of patients at hospital discharge:</b></p> <ol style="list-style-type: none"> <li>4. Patients who were discharged on positive pressure ventilation had longer ICU stays compared to extubated patients (<math>p&lt;0.001</math>). Patients discharged on a tracheostomy collar had longer ICU stays than those who were extubated or decannulated (<math>p&lt;0.001</math>).</li> <li>5. The incidence of VAP was significantly higher in patients requiring mechanical ventilation (<math>p&lt;0.001</math>) and those discharged on tracheostomy collar (<math>p=0.001</math>) compared to patients who were discharged with a natural airway.</li> </ol> <p><b>Outcome of patients who underwent extubation:</b></p> <ol style="list-style-type: none"> <li>6. Of patients in whom extubation was attempted, those who extubated successfully on the first attempt had significant shorter ICU stays (<math>p&lt;0.001</math>), more ventilator-free days (<math>p&lt;0.001</math>), and shorter hospital stays (<math>p=0.009</math>) compared with patients who failed one or more weaning or extubation attempts.</li> <li>7. Patients failing one or more attempts had a significantly higher incidence of VAP</li> </ol>

Author Year Country Research Design Sample Size	Methods	Outcomes
		(p<0.001) compared to patients who were successful on their first attempt.

## Discussion

In comparing methods of ventilator weaning, one case control showed that PVFB allowed patients to wean faster than IMV (Peterson et al. 1994). This finding is recommended by the Paralyzed Veterans of America Consortium for Spinal Cord Medicine (2005) and is consistent with other studies that examined non-SCI patients (Brochard et al. 1994; Esteban et al. 1995). The only study to investigate the efficacy of high versus low tidal volume on ventilator weaning found that high tidal volume resulted in faster weaning and more instances of resolved atelectasis than low tidal volume (Peterson et al. 1999). The weaning period for patients on high tidal volume ventilation was an average of three weeks sooner than those who received low tidal volume ventilation.

Successful decannulation and extubation has been found to be affected by the level and severity of injury whereby a higher rate of extubation is more likely to be achieved in patients with lower spinal cord injuries (Call et al. 2011). Decannulation is performed with a higher rate of success among patients with lower level cervical injuries compared to those with higher cervical cord injuries (Nakashima et al. 2013). The presence of a tracheostomy was found by Kornblith et al. (2014) to reduce attempts at extubation, but in cases where extubation was successful on the first attempt, patients had shorter intensive care unit and hospital stays compared to those who have failed one or more times (Call et al. 2011). Kornblith et al. (2014) also noted that among the patients included in their study, the majority of individuals did not require mechanical ventilation at the time of discharge indicating that the many SCI patients can be successfully weaned from ventilators; however, this was significantly more common in patients who did not have a tracheostomy compared to those who did require this procedure (p<0.05).

## Conclusion

***There is level 3 evidence (from one case control study; Kornblith et al. 2014) that acute SCI patients who do not require tracheostomies have a higher success rate of mechanical ventilation weaning compared to those who do require this procedure.***

***There is level 3 evidence (from two case control studies; Nakashima et al. 2013; Call et al. 2011) that higher level SCI correlates with lower rates of decannulation and extubation in acute SCI patients.***

***There is level 2 evidence (from one cohort study; Peterson et al. 1999) that higher ventilator tidal volumes may speed up the mechanical ventilation weaning process compared to lower ventilator tidal volumes in acute SCI patients.***

***There is level 3 evidence (from one case control; Peterson et al. 1994) that progressive ventilator-free breathing is a more successful method of weaning acute cervical SCI patients from mechanical ventilation than intermittent mandatory ventilation.***

Weaning from mechanical ventilation is more successful in patients who have not had a tracheostomy, and rates of decannulation and extubation are higher in patients with lower level injuries during the acute phase post SCI.

For mechanical ventilation weaning, progressive ventilator-free breathing may be more successful than intermittent mandatory ventilation, and using higher ventilator tidal volumes may speed up the weaning process compared to lower ventilator tidal volumes during the acute phase post SCI.

#### **4.6 Secretion Removal Techniques**

A major cause for pulmonary complications in acute SCI patients is the inability to clear bronchial secretions. In cervical spinal cord injuries, nerves that innervate the diaphragm and associated muscles may be damaged, leading to impaired coughing ability. The failure to perform deep coughing can cause pulmonary problems in two ways. First, patients can be in immediate pulmonary distress from choking or aspiration. Second, the retention of mucus can lead to respiratory infections such as bronchitis or pneumonia. In 1 in 5 cases of acute tetraplegia, patients produce an excess of 1 L of mucous each day (Ramakrishnan Bhaskar et al. 1991), further demanding the need for effective coughing techniques. The peak cough expiratory flow necessary to clear bronchial secretions is 3.1 L/s (Bach et al. 1993), and SCI patients often test well below this number. Several mechanisms exist to improve coughing ability in patients with SCI. Manual assisted coughing is an effective option whereby a caregiver applies firm and rapid pressure to the abdomen to force air out of the lungs. Mechanical assisted coughing, most commonly by mechanical insufflation-exsufflation, stimulates coughing by having a machine fill the lungs with air and then quickly reverse the flow to create negative pressure and push out secretions (Volsko, 2013). Additionally, positive expiratory pressure therapy systems are handheld devices used to create pressure in the lungs and facilitate clearance of secretions (Volsko, 2013). If needed, more invasive procedures to remove secretions can be used, such as directly suctioning the trachea with a catheter. The comparison between these methods is a poorly researched area, with only one RCT comparing manual assisted coughing techniques to mechanical insufflation/exsufflation.

**Table 7. Mechanical Insufflation/Exsufflation as an Adjunctive Therapy for Bronchial Clearance during Acute SCI**

<b>Author Year Country Research Design PEDro Sample Size</b>	<b>Methods</b>	<b>Outcomes</b>
Pillastrini et al. (2006) Italy RCT PEDro=3 N=N/S	<p><b>Population:</b> <i>Control Group:</i> Mean Age: 52.2 yr; Gender: male=75%, female=25%; <i>Treatment Group:</i> Mean Age: 31.5 yr; Gender: male=80%, female=20%; Level of injury: cervical; Severity of injury: complete =100%; AIS A.</p> <p><b>Intervention:</b> The patients were randomized to receive either mechanical insufflation/exsufflation in addition to manual kinesitherapy, or kinesitherapy only.</p> <p><b>Outcome Measures:</b> Forced vital capacity (FVC), forced expiratory volume in one second (FEV<sub>1</sub>), peak expiratory flow (PEF), (FEV<sub>1</sub>/FVC), arterious pressure of O<sub>2</sub> (Pa O<sub>2</sub>), arterious pressure of CO<sub>2</sub> (Pa CO<sub>2</sub>), (pH), saturation of oxygen (SaO<sub>2</sub>).</p> <p><b>Chronicity:</b> Time since injury not specified.</p>	<ol style="list-style-type: none"> <li>1. Among patients who received mechanical insufflation/exsufflation, FVC and FEV<sub>1</sub> was significantly higher at the end of treatment compared to the beginning (p=0.0001).</li> <li>2. Among patients who received mechanical insufflation/exsufflation, PEF was significantly higher at the end of treatment compared to the beginning (p=0.0093).</li> <li>3. Among patients in the control group, there was no significant improvement in FVC, FEV<sub>1</sub>, or PEF (p&gt;0.05) between the end of treatment and the beginning.</li> <li>4. There were no significant differences in FEV<sub>1</sub>/FVC, Pa O<sub>2</sub>, Pa CO<sub>2</sub>, pH, and SaO<sub>2</sub> in either of the groups (p&gt;0.05 in all cases).</li> </ol>

## Discussion

A single RCT found that mechanical insufflation/exsufflation is more effective at restoring cough than manual techniques alone (Pillastrini et al. 2006). This study did not test the efficacy of removing secretions directly, but instead tested them indirectly by measuring coughing ability through measurements such as forced vital capacity, forced expiratory volume, and peak cough expiratory flow. These measures were significantly improved with the addition of mechanical insufflation/exsufflation, demonstrating that these devices can enhance cough in acute SCI patients.

## Conclusion

***There is level 2 evidence (from one RCT; Pillastrini et al. 2006) in support of mechanical insufflation/exsufflation as an effective adjunctive therapy to the use of respiratory kinesitherapy for bronchial clearance in acute SCI patients.***

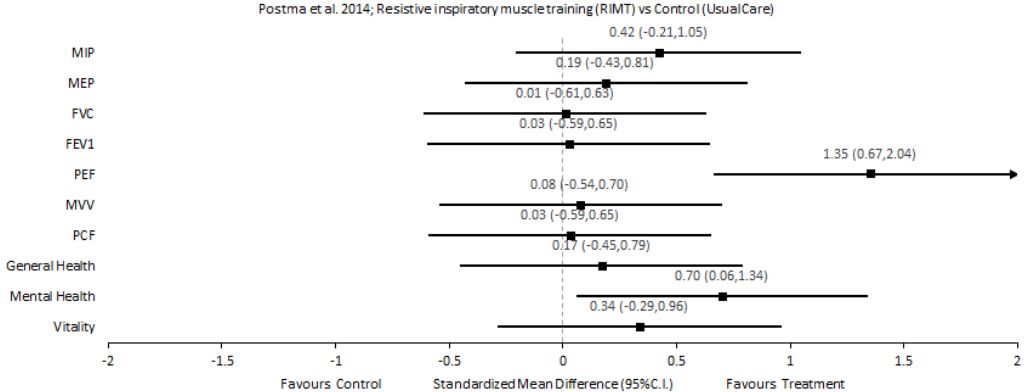
Mechanical insufflation/exsufflation coupled with manual respiratory kinesitherapy may be effective for bronchial clearance during the acute phase post SCI.

## **5.0 Non-Pharmacological Interventions for Pulmonary Function Improvement during Acute SCI**

### **5.1 Respiratory Muscle Training**

After patients have been intubated for a sufficient time during the earliest phase of SCI treatment, a decision must be made as to whether patients will 1) remain on long-term mechanical ventilation through the endotracheal tube, 2) receive a tracheostomy for long-term ventilation or to assist in weaning, or 3) will be extubated and breathing independently. Traditionally, immediate extubation has been viewed as risky and often leads to pulmonary infections or the need for urgent reintubation. Alternatively, long-term ventilation through an endotracheal tube prolongs the weaning process and the duration of hospital stay. The routine practice has been to receive a tracheostomy to initiate weaning and accelerate discharge from the hospital and not be as abrupt as extubation (Berly & Shem, 2007). However, in patients who tolerate independent breathing and are weaned successfully off the ventilator, respiratory muscle training or acute physiotherapy can be initiated. Acute physiotherapy is an emerging non-invasive option to help patients resume normal pulmonary functioning and timely discharge. Early prophylactic treatment in the form of physiotherapy has been shown to improve diaphragm function and reduce secretions in patients with acute SCI (McMichan et al. 1980). Assisted coughing, intermittent positive pressure breathing, and regular changes in body positioning are some of the techniques used to help keep patients' airways clear and breathing independently (Berney et al. 2002). In addition, breathing exercises and diaphragm strengthening can also improve lung functioning and assist in weaning from mechanical ventilation. Resistive inspiratory muscle training (RIMT) and abdominal weights training (Gross et al. 1980; Lin et al. 1999) as well as cough training combined with functional electrical stimulation (McBain et al. 2013) are techniques that have been implemented for physiotherapy in chronic SCI patients. RIMT (Derrickson et al. 1992; Postma et al. 2014), expiratory resistive muscle training (Roth et al. 2010) and abdominal weights training (Derrickson et al. 1992) have been studied in the acute SCI population and are reviewed below.

**Table 8. Effect of Respiratory Muscle Training on Pulmonary Function during Acute SCI**

Author Year Country Research Design PEDro Sample Size	Methods	Outcomes																																	
<p>Postma et al. (2014) The Netherlands RCT PEDro=7 N=40</p>	<p><b>Population:</b> <i>Resistive inspiratory muscle training group (RIMT):</i> Mean age: 47.1 yr; Gender: male=20, female=1; <i>Control Group:</i> Mean age: 46.6 yr; Gender: male=15, female=4; Level of injury: T12 and above; Severity of injury: complete=24, incomplete=16. <b>Intervention:</b> Patients were randomly assigned to receive usual rehabilitation care plus RIMT with a threshold trainer (RIMT group), or usual rehabilitation care only (control group). <b>Outcome Measures:</b> The following at baseline, after 8 weeks of intervention, 8 weeks after intervention, 1 yr after discharge from inpatient rehabilitation: maximum inspiratory pressure (MIP), maximum expiratory pressure (MEP), forced vital capacity (FVC), forced expiratory volume in one second (FEV<sub>1</sub>), peak expiratory flow rate, maximum ventilation volume, health-related quality of life (HRQoL), and 36-item short-form health survey (SF-36). <b>Chronicity:</b> Median number of days since injury was 74 (RIMT group) and 88 (control group).</p> <p><b>Effect Sizes:</b> Forest plot of standardized mean differences (SMD ± 95% C.I.) as calculated from pre- and post-intervention data.</p>  <table border="1"> <caption>Forest Plot Data</caption> <thead> <tr> <th>Outcome</th> <th>SMD</th> <th>95% C.I.</th> </tr> </thead> <tbody> <tr> <td>MIP</td> <td>0.19</td> <td>(-0.43, 0.81)</td> </tr> <tr> <td>MEP</td> <td>0.01</td> <td>(-0.61, 0.63)</td> </tr> <tr> <td>FVC</td> <td>0.03</td> <td>(-0.59, 0.65)</td> </tr> <tr> <td>FEV1</td> <td>0.03</td> <td>(-0.54, 0.70)</td> </tr> <tr> <td>PEF</td> <td>0.08</td> <td>(-0.59, 0.65)</td> </tr> <tr> <td>MVV</td> <td>0.03</td> <td>(-0.45, 0.79)</td> </tr> <tr> <td>PCF</td> <td>0.17</td> <td>(-0.45, 0.79)</td> </tr> <tr> <td>General Health</td> <td>0.17</td> <td>(-0.45, 0.79)</td> </tr> <tr> <td>Mental Health</td> <td>0.70</td> <td>(0.06, 1.34)</td> </tr> <tr> <td>Vitality</td> <td>0.34</td> <td>(-0.29, 0.96)</td> </tr> </tbody> </table>	Outcome	SMD	95% C.I.	MIP	0.19	(-0.43, 0.81)	MEP	0.01	(-0.61, 0.63)	FVC	0.03	(-0.59, 0.65)	FEV1	0.03	(-0.54, 0.70)	PEF	0.08	(-0.59, 0.65)	MVV	0.03	(-0.45, 0.79)	PCF	0.17	(-0.45, 0.79)	General Health	0.17	(-0.45, 0.79)	Mental Health	0.70	(0.06, 1.34)	Vitality	0.34	(-0.29, 0.96)	<ol style="list-style-type: none"> <li>MIP improved more in the RIMT group compared with the control group 1 week after the intervention period (mean difference=11.67 cm H<sub>2</sub>O, p=0.002); this difference was no longer significant 8 weeks after the intervention period (p=0.065) or at 1 yr after discharge from inpatient rehabilitation (p=0.271).</li> <li>No other between-group differences were found in any of the other measures of respiratory function.</li> <li>The RIMT group improved more in mental health compared with the control group 1 week after the intervention period (p=0.006).</li> </ol>
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<p>Roth et al. (2010) USA RCT PEDro=4 N=29</p>	<p><b>Population:</b> <i>Resistance Training Group:</i> Mean age: 31.1 yr; Gender: male=81%, female=19%; <i>Sham Training Group:</i> Mean age: 28.9 yr; Gender: male=69%, female=31%; Level of injury: C4-C7, T1; Severity of injury: complete. <b>Intervention:</b> Patients were randomly assigned to either expiratory muscle resistance training or sham training for a total of 6 weeks. <b>Outcome Measures:</b> The following before and after the training program: forced vital capacity (FVC), forced expiratory volume in one second (FEV<sub>1</sub>), maximum expiratory pressure (MEP), maximum inspiratory pressure (MIP), inspiratory capacity, expiratory reserve volume (ERV), total lung capacity (TLC), functional residual capacity (FRC), and residual volume (RV).</p>	<ol style="list-style-type: none"> <li>Multivariate analysis did not reveal any significant differences between the resistance training and sham training groups for any of the pulmonary function tests (p=0.22).</li> <li>Univariate analysis revealed significant improvements in FVC (p=0.02), FEV<sub>1</sub> (p=0.02), ERV (p=0.04), MIP (p=0.002), and MEP (p&lt;0.001) in the resistance training group.</li> <li>Univariate analysis revealed significant improvements in FVC (p=0.04), FEV<sub>1</sub> (p=0.01) and ERV (p&lt;0.01) in the sham training group.</li> </ol>																																	

Author Year Country Research Design PEDro Sample Size	Methods	Outcomes
	<p><b>Chronicity:</b> Patients were invited to participate in the study if the SCI was recent and had occurred within 6 months' time. No further information regarding time since injury was provided.</p>	
<p>Derrickson et al. (1992) USA RCT PEDro=3 N=11</p>	<p><b>Population:</b> Age range: 16-41 yr; Gender: male=6, female=5; Level of injury: C4-5 to C7; Severity of injury: complete. <b>Intervention:</b> Patients were randomly assigned to receive resistive inspiratory muscle training (RIMT) or abdominal weights (AbWts) training for 7 weeks. Training sessions consisted of two 15-minute treatments each day, 5 days a week. <b>Outcome Measures:</b> The following after one week and seven weeks: forced vital capacity (FVC), inspiratory capacity (IC), maximal voluntary ventilation (MVV), peak expiratory flow (PEF) rate, and increased inspiratory mouth pressure (PImax). <b>Chronicity:</b> Time since injury was an average of 12 days (RIMT group) and 25 days (AbWts group).</p>	<p><b>Between group comparison:</b></p> <ol style="list-style-type: none"> <li>1. There were no significant differences in FVC, MVV, PEF, PImax, and IC between patients who received RIMT training and those who received AbWts training (<math>p&gt;0.05</math> in all cases).</li> </ol> <p><b>Within group comparison:</b></p> <ol style="list-style-type: none"> <li>2. After 7 weeks, patients who received RIMT training experienced a significantly larger FVC (<math>p&lt;0.001</math>), a larger MVV (<math>p&lt;0.05</math>), a higher PEF (<math>p&lt;0.01</math>), a lower PImax (<math>p&lt;0.001</math>), and a higher IC (<math>p&lt;0.05</math>) compared to these measures after 1 week.</li> <li>3. After 7 weeks, patients who received AbWts training experienced a significantly larger FVC (<math>p&lt;0.001</math>), a larger MVV (<math>p&lt;0.001</math>), a higher PEF (<math>p&lt;0.001</math>), and a lower PImax (<math>p&lt;0.001</math>) compared to these measures after 1 week.</li> </ol>
<p>Raab et al. (2018) Switzerland Case Control N=79</p>	<p><b>Population:</b> <i>Inspiratory Muscle Training Group – AIS A/B:</i> Mean age: 48 yr; Gender: male=10, female=5; Level of injury: N/R; Injury severity: tetraplegia=7, paraplegia=8. <i>Inspiratory Muscle Training Group – AIS C/D:</i> Mean age: 63 yr; Gender: male=22, female=5; Level of injury: N/R; Injury severity: tetraplegia=22, paraplegia=5. <i>Combined In- and Expiratory Muscle Training Group – AIS A/B:</i> Mean age: 44.5 yr; Gender: male=14, female=2; Level of injury: N/R; Injury severity: tetraplegia=7, paraplegia=9. <i>Combined In- and Expiratory Muscle Training Group – AIS C/D:</i> Mean age: 60 yr; Gender: male=18, female=3; Level of injury: N/R; Injury severity: tetraplegia=18, paraplegia=3. <b>Intervention:</b> Individuals had up to 5 training sessions per week of either inspiratory muscle training or combined in- and expiratory muscle training. <b>Outcome Measures:</b> Maximal inspiratory pressure (PImax), expiratory pressure (PEmax), forced vital capacity, forced expiratory volume, sniff nasal inspiratory pressure, and peak expiratory flow. Results were stratified by AIS groups A/B and C/D. <b>Chronicity:</b> On average patients were 2.4 mo post injury.</p>	<ol style="list-style-type: none"> <li>1. PI max was seen to significantly increase for those treated with combined muscle training, regardless of AIS score (<math>p&lt;0.001</math>) and for those treated with inspiratory muscle training only (<math>p=0.008</math>).</li> <li>2. PEmax was seen to significantly increase for those treated with combined muscle training, regardless of AIS score (<math>p&lt;0.001</math>) and for those with AIS scores of C or D treated with inspiratory only muscle training (<math>p&lt;0.001</math>).</li> <li>3. Forced vital capacity was seen to significantly increase in those who were treated with combined muscle training, regardless of AIS score (<math>p&lt;0.001</math>). The same trends were observed for those in the inspiratory only muscle training groups (<math>p&lt;0.05</math>).</li> <li>4. Forced expiratory volume was found to significantly increase in individuals treated with combined muscle training, regardless of AIS score (<math>p&lt;0.05</math>), while the same trend was observed for those treated with inspiratory only muscle training (<math>p&lt;0.05</math>).</li> <li>5. Sniff nasal inspiratory pressure was found to significantly increase in those treated with combined muscle training (<math>p&lt;0.001</math>), regardless of AIS score. No significant</li> </ol>



Author Year Country Research Design PEDro Sample Size	Methods	Outcomes
		<p>improvements were observed in the inspiratory only muscle training group.</p> <p>6. Peak expiratory flow was only seen to improve significantly in the AIS C and D groups regardless of type of intervention (<math>p &lt; 0.05</math>), but not the AIS A/B groups.</p>
<p>Berney et al. (2002) Australia Case Control N=14</p>	<p><b>Population:</b> Mean age: 28 yr; Gender: male=11, female=3; Level of injury: C5-C7; Severity of injury: complete.</p> <p><b>Intervention:</b> Patients who received a tracheostomy were compared to patients who were extubated and received physiotherapy.</p> <p><b>Outcome Measures:</b> The following at the time of extubation/the day of tracheostomy: forced vital capacity (FVC), ratio of arterial oxygen partial pressure to fractional inspired oxygen (<math>PaO_2/FiO_2</math>), total number of physiotherapy treatments, number of physiotherapy treatments in intensive care unit (ICU), length of stay in ICU, days requiring mechanical ventilation, length of stay in acute ward after discharge from ICU, days from injury to fixation.</p> <p><b>Chronicity:</b> Patients were studied beginning within 24 hr of injury.</p>	<ol style="list-style-type: none"> <li>1. There was no significant difference in FVC between tracheostomized patients and physiotherapy patients (<math>p &gt; 0.05</math>).</li> <li>2. There was no significant difference in <math>PaO_2/FiO_2</math> ratios between tracheostomized patients and physiotherapy patients (<math>p &gt; 0.05</math>).</li> <li>3. There was no significant difference in total number of physiotherapy treatments between tracheostomized patients and extubated patients. Patients who were extubated and received physiotherapy required significantly fewer treatments compared to tracheostomized patients in ICU (<math>p = 0.047</math>).</li> <li>4. Tracheostomized patients spent significantly more days in ICU than physiotherapy patients (<math>p = 0.006</math>) and required mechanical ventilation significantly longer than the physiotherapy group (<math>p = 0.018</math>).</li> <li>5. There was no significant difference in the length of stay in the acute ward between groups (<math>p &gt; 0.05</math>).</li> <li>6. There was no significant difference in the time from injury to fixation between groups (<math>p &gt; 0.05</math>).</li> </ol>

## Discussion

Three RCTs have examined the effectiveness of physiotherapy techniques on the pulmonary function of patients with SCI. Postma et al. (2014) investigated the effect of RIMT in individuals with SCI during inpatient rehabilitation. This technique was found to have a positive short-term effect on inspiratory muscle function 1 week following the intervention period; however, this effect was no longer significant 8 weeks post muscle training. Two types of breathing exercise programs have been shown by one small RCT (Derrickson et al. 1992) to be effective at improving pulmonary function in patients with acute tetraplegia. Abdominal weights training and RIMT both appeared to be similar in efficacy and resulted in within-group improvements for all five (RIMT group) and four of five (abdominal weights training group) pulmonary function measures used in the study. Finally, Roth et al. (2010) assessed the effectiveness of expiratory muscle training compared to sham training in patients with SCI at an acute inpatient rehabilitation hospital. Multivariate analysis did not reveal any significant between-group differences for any pulmonary function tests conducted after the 6-week training period. A moderate sized case control study also found positive results with both inspiratory and combination in- and expiratory muscle training regardless of AIS score (Raab et al., 2018). It

was found that measures of inspiratory and expiratory pressure significantly increased, as well as forced vital capacity regardless of muscle training group (Raab et al., 2018). Muscle training appears to be effective for improving respiratory parameters in acute SCI patients.

A case control study (Berney et al. 2002) has shown that extubation along with initiation of intensive physiotherapy can improve lung function, reduce the rate of pulmonary complications and decrease the length of stay in intensive care for patients with acute tetraplegia. It should be noted that both patients who have been extubated or who have had a tracheostomy are able to receive physiotherapy, as long as treatment occurs once the patient is in stable condition.

Physiotherapy treatments during acute SCI would be useful for stable patients and in hospitals that have the resources for on-call physiotherapists. Prospective large-scale RCTs should be conducted to confirm these preliminary findings that physiotherapy is an effective adjuvant to improve acute pulmonary functioning.

## Conclusion

***There is level 1b evidence (from two RCTs; Postma et al., 2014; Derrickson et al., 1992, and one case control study; Raab et al., 2018)) in support of inspiratory muscle training as an effective means to improve respiratory muscle function compared to usual care in acute SCI patients regardless of AIS status.***

***There is level 3 evidence (from one case control; Berney et al. 2002) that extubation and intensive physiotherapy reduces length of stay in intensive care in acute SCI patients.***

Inspiratory and expiratory muscle training may improve respiratory muscle function during the acute phase post SCI. Length of stay in intensive care may be reduced by extubation in combination with intensive physiotherapy.

## 5.2 Diaphragm Pacing

The diaphragm is primarily controlled by the phrenic nerve. Diaphragm pacing involves the stimulation of the phrenic nerve to restore diaphragm function, and ultimately independent respiratory control (Madden, 2016). In 2008 the Food and Drug Administration approved the use of the NeuRx Diaphragm Pacing System (DPS) for humanitarian-use for patients with SCI (Madden, 2016).

**Table 9. Effect of Diaphragm Pacing on Respiration during Acute SCI.**

Author Year Country Research Design PEDro Sample Size	Methods	Outcomes
Kerwin et al. (2018) United States Case Control N=101	<b>Population:</b> DPS Group, n=40: Mean age: 45 yr; Gender: male=29, female=11; Level of injury: C1-C4= 35%, C5-C7= 65%; Severity of injury: complete=88%, incomplete=12%. No DPS Group, n=61: Mean age: 39 yr; Gender: male=54, female=7; Level of injury: C1-C4=33%, C5-	1. There were no significant differences between groups in terms of the number of days spent on ventilators. 2. There were no significant differences between groups in terms of the rates of ventilator associated pneumonia.

<b>Author Year</b> <b>Country</b> <b>Research Design</b> <b>PEDro</b> <b>Sample Size</b>	<b>Methods</b>	<b>Outcomes</b>
	C7=67%; Severity of injury: complete= 82%, incomplete= 15%. <b>Intervention:</b> Patients either underwent diaphragm pacing system implantation or did not. <b>Outcome Measures:</b> Ventilator days, ventilator associated pneumonia. <b>Chronicity:</b> Patient population defined as acute.	

**Discussion**

To date only one case control study has examined diaphragm pacing during the acute SCI phase. Diaphragm pacing is one of the newer approved interventions for respiratory functions post SCI. In the recent study by Kerwin et al. (2018), diaphragm pacing was found to have no significant influence on the rates of ventilator associated pneumonia. However, it's efficacy as an intervention for improving respiratory outcomes needs to be further examined as there were no significant effects of diaphragm pacing on the number of days spent on a ventilator. As only one respiratory outcome and one complication were examined in this sole study, more research needs to be conducted to make conclusions about the value of diaphragm pacing for acute SCI patients.

**Conclusion**

***There is level 3 evidence (from one case control study; Kerwin et al., 2018) that diaphragm pacing may not increase the risk of ventilator associated pneumonia or reduce the number of ventilator days compared to no implantation for acute SCI patients.***

Diaphragm pacing may not reduce the number of days spent on a ventilator, however it also does not appear to increase the risk of ventilator associated pneumonia in acute SCI patients.

**5.3 Intermittent Positive Pressure Breathing for Acute SCI patients**

Intermittent positive pressure breathing (IPPB) is a respiratory therapy that is used to expand the lungs and induce hyperinflation (Laffont et al. 2008). Little is known about the effects of IPPB in SCI patients, and very little literature is published for patients with acute SCI. The limited studies that do exist examining IPPB in patients with quadriplegia, very few complications occur after treatment (Laffont et al. 2008).

**Table 10. Intermittent Positive Pressure Breathing for Acute SCI patients**

Author Year Country Research Design Sample Size	Methods	Outcomes
Stiller et al. (1992) Australia Pre-Post N=5	<p><b>Population:</b> Mean age: 34 yr; Gender: male=3, female=2; Level of injury: C5-C7; Severity of injury: not specified.</p> <p><b>Intervention:</b> All patients received intermittent positive pressure breathing (IPPB).</p> <p><b>Outcome Measures:</b> Lung volume, vital capacity, tidal volume.</p> <p><b>Chronicity:</b> Patients were studied beginning within 24 hr of sustaining injury.</p>	<ol style="list-style-type: none"> <li>1. On admission, patients had significantly reduced resting vital capacity compared to normal values (<math>p &lt; 0.001</math>).</li> <li>2. Lung volume was significantly higher during IPPB compared to resting values (<math>p &lt; 0.001</math>).</li> <li>3. Immediately after receiving IPPB, vital capacity (<math>p &lt; 0.02</math>), but not tidal volume (<math>p &gt; 0.05</math>), was significantly higher compared to resting levels.</li> </ol>

### Discussion

In a pre-post study by Stiller et al. (1992), the effectiveness of intermittent positive pressure breathing on lung capacity was studied. The authors found that this style of mechanical ventilation significantly increased lung volume, as well as vital capacity (Stiller et al., 1992).

### Conclusion

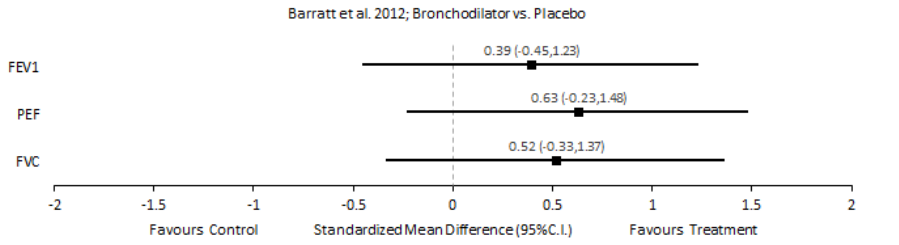
***There is level 4 evidence (from one pre-post study; Stiller et al., 1992) that intermittent positive pressure breathing may increase lung volume as well as vital lung capacity in acute SCI individuals.***

Intermittent positive pressure breathing can increase lung volume as well as vital lung capacity in acute SCI individuals.

## 6.0 Pharmacological Interventions for Pulmonary Function Improvement during Acute SCI

Pharmacological treatments for pulmonary function in SCI patients aims to improve breathing and coughing, thereby gaining more independence from mechanical ventilation, and to decrease the likelihood of infection. This area of research has been explored largely in patients with chronic SCI, where bronchodilators and anabolic steroids have shown varying degrees of success (see the rehabilitation chapter on Respiratory Management in SCIRE version 6.0).

**Table 11. Pharmacological Interventions for Pulmonary Function during Acute SCI**

<b>Author Year Country Research Design PEDro Sample Size</b>	<b>Methods</b>	<b>Outcomes</b>																
<p>Barratt et al. (2012) Australia RCT PEDro=9 N=12</p>	<p><b>Population:</b> Age range: 25-37 yr; Gender: male=9, female=3; Level of injury: C5-C7; Severity of injury: complete=10, incomplete=2; AIS A-B. <b>Intervention:</b> Patients were randomized to receive either bronchodilator therapy (inhaler, 100 µg salbutamol) or placebo (propellant only). <b>Outcome Measures:</b> The following at 10 minutes and 30 minutes after inhalation: forced vital capacity (FVC), forced expiratory volume in one second (FEV<sub>1</sub>), and peak expiratory flow (PEF) rate. <b>Chronicity:</b> The median time since injury was 24 (18-35) days.</p> <p><b>Effect Sizes:</b> Forest plot of standardized mean differences (SMD ± 95% C.I.) as calculated from pre- (baseline) and post-intervention (after 10 minutes) data.</p>  <table border="1" data-bbox="511 871 1404 1113"> <caption>Forest Plot Data</caption> <thead> <tr> <th>Outcome</th> <th>SMD</th> <th>95% C.I. (Lower)</th> <th>95% C.I. (Upper)</th> </tr> </thead> <tbody> <tr> <td>FEV1</td> <td>0.39</td> <td>-0.45</td> <td>1.23</td> </tr> <tr> <td>PEF</td> <td>0.63</td> <td>-0.23</td> <td>1.48</td> </tr> <tr> <td>FVC</td> <td>0.52</td> <td>-0.33</td> <td>1.37</td> </tr> </tbody> </table>	Outcome	SMD	95% C.I. (Lower)	95% C.I. (Upper)	FEV1	0.39	-0.45	1.23	PEF	0.63	-0.23	1.48	FVC	0.52	-0.33	1.37	<ol style="list-style-type: none"> <li>After 10 minutes, patients who received the bronchodilator therapy experienced a significant improvement in FVC (<math>p &lt; 0.05</math>), FEV<sub>1</sub> (<math>p &lt; 0.05</math>), and PEF (<math>p &lt; 0.05</math>) compared to patients who received the placebo.</li> <li>After 30 minutes, patients who received the bronchodilator therapy experienced a significant improvement in FVC (<math>p &lt; 0.05</math>) and FEV<sub>1</sub> (<math>p &lt; 0.05</math>) compared to patients who received the placebo. There were no significant differences between groups with regard to PEF (<math>p &gt; 0.05</math>).</li> </ol>
Outcome	SMD	95% C.I. (Lower)	95% C.I. (Upper)															
FEV1	0.39	-0.45	1.23															
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<p>Li et al. (2012) China RCT PEDro=6 N=61</p>	<p><b>Population:</b> Age range: 39-67 yr; Gender: male=40, female=21; Level of injury: cervical; Severity of injury: complete=27, incomplete=34 AIS A-B. <b>Intervention:</b> Patients were randomized to receive either high-dose ambroxol (990 mg/day for 5 days) or placebo (5% glucose in 500 mL saline for 5 days) after spinal fixation surgery. <b>Outcome Measures:</b> The following during hospital stay: post-operative pulmonary complications in the form of pulmonary infection, atelectasis, and hypoxemia. The following after 3 and 5 days in the intensive care unit (ICU): arterial blood gas analysis in the form of partial pressure of inspired oxygen in arterial blood (PaO<sub>2</sub>), partial pressure of carbon dioxide in arterial blood (PaCO<sub>2</sub>), and ratio of arterial oxygen partial pressure to fractional inspired oxygen. <b>Chronicity:</b> Time since injury not specified.</p> <p><b>Effect Sizes:</b> Forest plot of standardized mean differences (SMD ± 95% C.I.) as calculated from pre- and post-intervention data.</p>	<ol style="list-style-type: none"> <li>Patients who received high dose ambroxol experienced significantly fewer episodes of pneumonia (<math>p = 0.027</math>) and hypoxemia (<math>p = 0.047</math>) than patients who received placebo. There were no significant differences with regards to atelectasis between groups (<math>p = 0.430</math>).</li> <li>After 3 days in ICU, patients who received high dose ambroxol had a significantly higher oxygenation index than patients who received placebo (<math>p = 0.049</math>). There were no significant differences in PaO<sub>2</sub> (<math>p = 0.683</math>) and PaCO<sub>2</sub> (<math>p = 0.847</math>) between groups.</li> <li>After 5 days in ICU, patients who received high dose ambroxol had a significantly higher oxygenation index than patients who received placebo (<math>p = 0.032</math>). There were no significant differences in PaO<sub>2</sub> (<math>p = 0.193</math>) and PaCO<sub>2</sub> (<math>p = 0.928</math>) between groups.</li> </ol>																

Author Year Country Research Design PEDro Sample Size	Methods	Outcomes												
	Li et al. 2012; High-dose ambroxol (990 mg) vs. placebo (5% glucose)	<p>Standardized Mean Difference (95% C.I.)</p> <table border="1"> <thead> <tr> <th>Outcome</th> <th>Mean Difference</th> <th>95% C.I.</th> </tr> </thead> <tbody> <tr> <td>PaO<sub>2</sub></td> <td>0.01</td> <td>(-0.50, 0.51)</td> </tr> <tr> <td>PaCO<sub>2</sub></td> <td>0.38</td> <td>(-0.13, 0.88)</td> </tr> <tr> <td>PaO<sub>2</sub>/FiO<sub>2</sub></td> <td>0.70</td> <td>(0.18, 1.22)</td> </tr> </tbody> </table>	Outcome	Mean Difference	95% C.I.	PaO <sub>2</sub>	0.01	(-0.50, 0.51)	PaCO <sub>2</sub>	0.38	(-0.13, 0.88)	PaO <sub>2</sub> /FiO <sub>2</sub>	0.70	(0.18, 1.22)
Outcome	Mean Difference	95% C.I.												
PaO <sub>2</sub>	0.01	(-0.50, 0.51)												
PaCO <sub>2</sub>	0.38	(-0.13, 0.88)												
PaO <sub>2</sub> /FiO <sub>2</sub>	0.70	(0.18, 1.22)												

**Discussion**

Although several types of bronchodilators and secretolytic agents exist, only two have been tested within the acute SCI population which also met the SCIRE inclusion criteria. Based on one study alone, bronchodilator therapy with salbutamol provided effective short-term improvements in lung function. Barratt et al. (2012) showed that these drugs increased forced vital capacity and forced expiratory volume; these improvements were maintained for half an hour. Peak cough expiratory flow also improved, but this effect deteriorated after ten minutes. The second RCT by Li et al. (2012) studied ambroxol and demonstrated more long-term improvements in pulmonary functioning. Oxygenation indexes remained elevated after five days, and patients had fewer episodes of pneumonia and hypoxemia overall. These two studies showed that pharmacological interventions may be helpful in improving breathing and reducing infection, but long-term treatments (>1 month) and the efficacy of alternative drugs remain unknown.

**Conclusion**

***There is level 1b evidence (from one RCT; Barratt et al. 2012) that bronchodilator therapy with salbutamol may improve pulmonary function compared to placebo in acute SCI patients.***

***There is level 1b evidence (from one RCT; Li et al. 2012) that high-dose ambroxol may reduce postoperative respiratory complications and increase blood oxygenation following surgery compared to placebo in acute cervical SCI patients.***

Bronchodilator therapy with salbutamol may be an effective treatment for improving pulmonary function during the acute phase post SCI.

Ambroxol may be an effective treatment to reduce pulmonary complications and improve oxygenation status following surgery in acute cervical SCI patients.

**7.0 Hospital Programs for Respiratory Management**

Respiratory management for SCI patients is thought to be most effective when the care extends beyond the individual to incorporate specialized hospital programs (Parker et al. 2010). Studies

have examined the effect of respiratory management programs on enhancing patient recovery and decreasing hospital stay compared to regular hospital treatment that may differ for each individual.

**Table 12. Effect of Hospital Programs for Respiratory Management during Acute SCI**

Author Year Country Research Design Sample Size	Methods	Outcomes
Richard-Denis et al. (2018) Canada Case Control N=81	<p><b>Population:</b> (<i>Group 1</i>): Mean age: 43.6 yr; Gender: male=75.4%, female=24.6%; Injury severity: Mean ISS= 35.3. (<i>Group 2</i>): Mean age; 42.5yr; Gender: male=83.3%, female=16.7%; Injury severity: Mean ISS=42.7%.</p> <p><b>Intervention:</b> Patients in group 1 were transferred early to a level-1 trauma center for surgical management of SCI. Patients in Group 2 were transferred late (post-operatively) to the same SCI trauma center for care.</p> <p><b>Outcome Measures:</b> Tracheostomy requirement, mechanical ventilation requirement, ventilation support duration,</p> <p><b>Chronicity:</b> Patient population was defined as acute SCI.</p>	<ol style="list-style-type: none"> <li>Group 2 had significantly higher rates of required tracheostomies (p=0.004).</li> <li>There were no significant differences between groups in terms of the number of patients who required mechanical ventilation support.</li> <li>There was a significant difference between groups for the number of days spent on ventilation, with Group 2 spending on average 50 more days on ventilation (p=0.006).</li> </ol>
Romero-Ganuzas et al. (2015) Spain Pre-Post Test N=68	<p><b>Population:</b> Mean age: 53.8 yr; Gender: male=49, female=19; Level of SCI: C1-C4=44, C5-C8=11, thoracic=13.</p> <p><b>Intervention:</b> Patients were treated with a specific respiratory care comprehensive rehabilitation program.</p> <p><b>Outcome Measures:</b> Hospital mortality, length of stay, discharged to community, discharged home, discharge to extended care facilities, discharge to acute care hospital, weaned from ventilation, patients with permanent respiratory support.</p> <p><b>Chronicity:</b> Patients were admitted within 3 months of injury.</p>	<ol style="list-style-type: none"> <li>Five patients died in hospital.</li> <li>The average length of stay for survivors was 195.6 days.</li> <li>63/68 of patients were discharged to the community, 47 patients were discharged home, 13 were discharged to extended-care facilities, and 3 were sent to an acute care hospital setting.</li> <li>23 patients were weaned at the hospital.</li> <li>20 patients had permanent respiratory support.</li> </ol>
Wong et al. (2012) USA Post Test N=24	<p><b>Population:</b> Mean age: 33 yr; Gender: male=22, female=2; Level of injury: C1-C4; Severity of injury: complete=79%, incomplete=21%; AIS A-D.</p> <p><b>Intervention:</b> Retrospective analysis of patients who received a hospital program at an SCI specialty unit of high tidal volume ventilation, high frequency percussive ventilation, and mechanical insufflation-exsufflation were compared before and after the program.</p> <p><b>Outcome Measures:</b> Occurrence of high tidal ventilation, high frequency percussive ventilation, mechanical insufflation-exsufflation, initiating a speaking valve, ventilator weaning attempts, time from admission to ventilator wean</p> <p><b>Chronicity:</b> Average time from injury to transfer to the SCI unit was 33.8 days.</p>	<ol style="list-style-type: none"> <li>In 14 patients who were weaned off the ventilator, the average day to be weaned from the time of admission was 27.6 days (<i>SD</i> 12.9 days).</li> <li>Three individuals with C3 AIS A were ventilator weaned in 24 to 62 days (average 43.67 days). Eight individuals with C4 AIS A were ventilator weaned in 14 to 31 days (average 22.13 days). Two individuals with C4 AIS B were weaned from the ventilator in 19 to 22 days (average 20.5 days). One individual with C4 AIS C was weaned in 37 days.</li> <li>Six subjects were decannulated prior to discharge to home, and the average days to be decannulated after admission was 42.0 days (<i>SD</i> 16.6 days).</li> </ol>

Author Year Country Research Design Sample Size	Methods	Outcomes
Cameron et al. (2009) Australia Cohort N=102	<p><b>Population:</b> Age range: 24-52 yr; Gender: male=78, female=24; Level of injury: C4-C8, T1-T5, T6 and below; Severity of injury: complete=44, incomplete=58; AIS A-D.</p> <p><b>Intervention:</b> Patients either received tracheostomy review and management services (post-TRAMS group, 2003-2006) or did not receive tracheostomy review and management services (pre-TRAMS group, 1991-2001).</p> <p><b>Outcome Measures:</b> Hours mechanically ventilated, hours in intensive care unit (ICU), length of hospital stay, duration of cannulation, initiation of communication through a one-way speaking valve, deaths.</p> <p><b>Chronicity:</b> Length of acute hospital stay was a median of 60 days (pre-TRAMS group) and 41.5 days (post-TRAMS group); time since injury was not specified.</p>	<ol style="list-style-type: none"> <li>1. There were no significant differences with regards to hours mechanically ventilated (<math>p=0.71</math>) and hours in ICU (<math>p=0.60</math>) between pre-TRAMS patients and post-TRAMS patients.</li> <li>2. Post-TRAMS patients had a significantly shorter hospital stay compared to pre-TRAMS patients (<math>p=0.03</math>).</li> <li>3. Post-TRAMS patients had a significantly shorter duration of cannulation compared to pre-TRAMS patients (<math>p=0.03</math>).</li> <li>4. Post-TRAMS patients began using one-way speaking valves significantly earlier than pre-TRAMS patients (<math>p&lt;0.01</math>).</li> <li>5. There were no tracheostomy-related deaths in either group.</li> </ol>
Vitaz et al. (2001) USA Cohort N=58	<p><b>Population:</b> Mean age: 33 yr; Gender: not specified; Level of injury: C1-T5; Severity of injury: not specified.</p> <p><b>Intervention:</b> Patients either received treatment according to the clinical care pathway (Group 1) or received regular treatment (Group 2; control).</p> <p><b>Outcome Measures:</b> The following during hospital stay: episodes of pneumonia, length of hospital stay, length of intensive care unit (ICU) stay, days on ventilator.</p> <p><b>Chronicity:</b> Average overall length of hospital stay was 36 days and 24 days for Group 1 and Group 2 patients, respectively; time since injury was not specified.</p>	<ol style="list-style-type: none"> <li>1. Patients in Group 1 experienced significantly fewer episodes of pneumonia compared to patients in the control group (<math>p&lt;0.05</math>).</li> <li>2. Patients in Group 1 experienced a significantly shorter stay in the hospital (<math>p&lt;0.05</math>) and ICU (<math>p&lt;0.05</math>), and required significantly fewer days on the ventilator (<math>p&lt;0.05</math>) compared to patients in the control group.</li> </ol>

## Discussion

Overall, hospital programs for respiratory management have been shown to benefit individuals more so than traditional hospital care. These programs reduce length of hospital stay and ventilator days (Cameron et al., 2009; Vitaz et al., 2001; Richard-Denis et al., 2018), help individuals gain independence by initiating speaking valves sooner (Wong et al. 2012) and reduce the incidence of pulmonary complications (Vitaz et al. 2001). Although Wong et al. (2012) did not perform statistical analyses to compare the efficacy of their program, the patients who received all three respiratory management therapies had less complications than those who did not.

A newer case control study, of moderate size, found that patients admitted early to a specialized level-1 trauma center had over all fewer procedures and complications (Richard-Denis et al., 2018). Early admission to this center significantly decreased the rates of tracheostomies, as well as the total number of days in hospital. Early admitted patients spent on average 50 fewer days on ventilation (Richard-Denis et al., 2018). Another study examining specialized care by Romero-Ganuza et al. (2015) found that a third of patients were able to be weaned at the hospital, and 63/68 individuals were discharged to the community and not long-term care. All of



these patients treated with a specialized respiratory care protocol, however more research is needed to determine how this level of specialized care compares to other standards of care.

## **Conclusion**

***There is level 4 evidence (from one post test; Wong et al., 2012) that the implementation of specialized respiratory management results in stabilization and improvement of respiratory status in acute SCI patients.***

***There is level 2 evidence (from one cohort study; Cameron et al. 2009) that the tracheostomy review and management service reduces length of hospital stay and duration of cannulation while increasing speech valve usage compared to those who do not receive tracheostomy review and management in acute SCI patients.***

***There is level 2 evidence (from one cohort study; Vitaz et al. 2001) that the use of a clinical care pathway reduces length of hospital stay and results in fewer complications compared to those who received regular care in acute SCI patients.***

***There is level 3 evidence (from one case control study; Richard-Denis et al., 2018) that early admission to a level-1 trauma center results in lower rates of tracheostomies, as well as fewer ventilator days for acute SCI patients, compared to late admission.***

***There is level 4 evidence (from one pre-post test; Romero-Ganuza et al., 2015) that specialized respiratory care results in a high number of community discharges in acute SCI patients.***

<p>Respiratory management hospital programs overall may lead to reduced procedures, ventilator days, and hospital length of stay, and improved respiratory and patient discharge status, in the acute phase post SCI.</p>
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## **8.0 Summary**

***There is level 2 evidence (from one cohort study; Iwashita et al., 2006) that acute SCI patients who are intubated may have reduced ratios of arterial oxygen partial pressure to fractional inspired oxygen compared to no intubation.***

***There is level 2 evidence (from one RCT; Sustic et al., 2002) that percutaneous dilational tracheostomies are a significantly shorter procedure and have fewer pulmonary complications compared to surgical tracheostomies for individuals with acute SCI.***

***There is level 2 evidence (from one cohort study; Leelapattana et al., 2012) that tracheostomies can reduce the number of pulmonary complications in individuals with acute SCI compared to late or no tracheostomy.***

***There is level 2 evidence (from one cohort study; Romero-Ganuza et al., 2011a) that tracheostomies performed directly after spinal fixation surgery do not increase the rate***

***of surgical wound infection compared to non-immediate tracheostomies in acute SCI individuals.***

***There is level 3 evidence (from one case control study; McCully et al., 2014, and one case series; Kornblith et al., 2014) that acute SCI individuals who receive a tracheostomy may spend more days on a ventilator than those who do not.***

***There is level 3 evidence (from one case control study; Berney et al., 2011) that acute SCI individuals who receive a tracheostomy, compared to those who are extubated, may have more pulmonary secretions, lower gas exchange, and lower forced vital capacity.***

***There is level 4 evidence (from one case series; O’Keeffe et al., 2004) that tracheostomies in acute SCI individuals may not increase the risk of neurologic deterioration or surgical site infection.***

***There is level 2 evidence (from one prospective controlled trial; Gregoretti et al., 2005) that endotracheal invasive ventilation may lower partial pressure of carbon dioxide compared to transtracheal open ventilation in acute SCI individuals.***

***There is level 3 evidence (from one case control study; Watt et al., 2011) that diaphragm pacing in combination with mechanical ventilation may result in higher survival than mechanical ventilation alone in acute SCI populations.***

***There is level 3 evidence (from one case control study; Romero-Ganuzza et al., 2011b) that percutaneous tracheostomies may result in fewer cases of pneumonia compared to surgical tracheostomies in acute SCI individuals.***

***There is level 3 evidence (from five case control studies; Beom and Seo, 2018; Flanagan et al., 2018; Choi et al. 2013; Romero-Ganuzza et al. 2011b; Romero et al. 2009) that early tracheostomies may result in fewer ICU days than late tracheostomies in acute SCI patients.***

***There is level 3 evidence (from four case control studies; Flanagan et al., 2018; Choi et al. 2013; Romero-Ganuzza et al. 2011b; Romero et al. 2009) that early tracheostomies may result in fewer ventilation days compared to late tracheostomies in acute SCI patients.***

***There is conflicting level 3 evidence (from six case control studies; Flanagan et al., 2018; Choi et al., 2013; Babu et al., 2013, Romero-Ganuzza et al., 2011b; Romero et al., 2009; Kornblith et al. 2014) as to whether or not early tracheostomies decrease the risk of medical complications compared to late tracheostomies in acute SCI patients.***

***There is level 3 evidence (from 3 case control studies; Flanagan et al., 2018; Romero-Ganuzza et al., 2011b; Romero et al., 2009) that the timing of tracheostomy may not influence in-hospital mortality rates in acute SCI individuals.***

***There is level 3 evidence (from one case control study; Kornblith et al. 2014) that acute SCI patients who do not require tracheostomies have a higher success rate of mechanical ventilation weaning compared to those who do require this procedure.***

***There is level 3 evidence (from two case control studies; Nakashima et al. 2013; Call et al. 2011) that higher level SCI correlates with lower rates of decannulation and extubation in acute SCI patients.***

***There is level 2 evidence (from one cohort study; Peterson et al. 1999) that higher ventilator tidal volumes may speed up the mechanical ventilation weaning process compared to lower ventilator tidal volumes in acute SCI patients.***

***There is level 3 evidence (from one case control; Peterson et al. 1994) that progressive ventilator-free breathing is a more successful method of weaning acute cervical SCI patients from mechanical ventilation than intermittent mandatory ventilation.***

***There is level 2 evidence (from one RCT; Pillastrini et al. 2006) in support of mechanical insufflation/exsufflation as an effective adjunctive therapy to the use of respiratory kinesitherapy for bronchial clearance in acute SCI patients.***

***There is level 1b evidence (from two RCTs; Postma et al., 2014; Derrickson et al., 1992, and one case control study; Raab et al., 2018)) in support of inspiratory muscle training as an effective means to improve respiratory muscle function compared to usual care in acute SCI patients regardless of AIS status.***

***There is level 3 evidence (from one case control; Berney et al. 2002) that extubation and intensive physiotherapy reduces length of stay in intensive care in acute SCI patients.***

***There is level 3 evidence (from one case control study; Kerwin et al., 2018) that diaphragm pacing may not increase the risk of ventilator associated pneumonia or reduce the number of ventilator days compared to no implantation for acute SCI patients.***

***There is level 4 evidence (from one pre-post study; Stiller et al., 1992) that intermittent positive pressure breathing may increase lung volume as well as vital lung capacity in acute SCI individuals.***

***There is level 1b evidence (from one RCT; Barratt et al. 2012) that bronchodilator therapy with salbutamol may improve pulmonary function compared to placebo in acute SCI patients.***

***There is level 1b evidence (from one RCT; Li et al. 2012) that high-dose ambroxol may reduce postoperative respiratory complications and increase blood oxygenation following surgery compared to placebo in acute cervical SCI patients.***

***There is level 4 evidence (from one post test; Wong et al., 2012) that the implementation of specialized respiratory management results in stabilization and improvement of respiratory status in acute SCI patients.***

***There is level 2 evidence (from one cohort study; Cameron et al. 2009) that the tracheostomy review and management service reduces length of hospital stay and duration of cannulation while increasing speech valve usage compared to those who do not receive tracheostomy review and management in acute SCI patients.***

***There is level 2 evidence (from one cohort study; Vitaz et al. 2001) that the use of a clinical care pathway reduces length of hospital stay and results in fewer complications compared to those who received regular care in acute SCI patients.***

***There is level 3 evidence (from one case control study; Richard-Denis et al., 2018) that early admission to a level-1 trauma center results in lower rates of tracheostomies, as well as fewer ventilator days for acute SCI patients, compared to late admission.***

***There is level 4 evidence (from one pre-post test; Romero-Ganuza et al., 2015) that specialized respiratory care results in a high number of community discharges in acute SCI patients.***

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## Abbreviations

%VC	Percentage of Vital Capacity
AbWts	Abdominal Weights
AIS	ASIA Impairment Scale
ALI	Acute Lung Injury
APACHE II	Acute Physiology and Chronic Health Evaluation II
ARDS	Acute Respiratory Distress Syndrome
ASIA	American Spinal Injury Association
BiPAP	Biphasic Positive Airway Pressure
CPAP	Continuous Positive Airway Pressure
EIV	Endotracheal Invasive Ventilation
FEV <sub>1</sub>	Forced Expiratory Volume in One Second
FVC	Forced Vital Capacity
GCS	Glasgow Coma Score
HAP	Hospital Acquired Pneumonia
HTV	High Tidal Volume
IC	Inspiratory Capacity
ICU	Intensive Care Unit
RIMT	Resistive Inspiratory Muscle Training
IMV	Intermittent Mandatory Ventilation
IPPB	Intermittent Positive Pressure Breathing
ISS	Injury Severity Score
LTV	Low Tidal Volume
MVV	Maximal Voluntary Ventilation
PaCO <sub>2</sub>	Partial Pressure of Carbon Dioxide in Arterial blood
PaO <sub>2</sub>	Partial Pressure of Inspired Oxygen in Arterial blood
PaO <sub>2</sub> /FiO <sub>2</sub>	Ratio of Arterial Oxygen Partial Pressure to Fractional Inspired Oxygen
PEF	Peak Expiratory Flow
Plmax	Increased Inspiratory Mouth Pressure
PDT	Percutaneous Dilational Tracheostomy
PVFB	Progressive Ventilator-Free Breathing
RCT	Randomized Controlled Trial
SaO <sub>2</sub>	Saturation of Oxygen
SCI	Spinal Cord Injury
ST	Surgical Tracheostomy
TOV	Transtracheal Open Ventilation
TRAMS	Tracheostomy Review and Management Services
VAP	Ventilator-Associated Pneumonia