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Mechanical Ventilation in Traumatic Brain Injury

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Abstract:

Background: Traumatic brain injury (TBI) is one of the leading causes of mortality and disability worldwide and frequently necessitates mechanical ventilation because of impaired consciousness, airway protection failure, respiratory insufficiency, and prevention of secondary brain injury. Mechanical ventilation plays a crucial role in maintaining adequate cerebral oxygenation and carbon dioxide balance; however, inappropriate ventilatory strategies may aggravate intracranial hypertension, impair cerebral perfusion, and contribute to pulmonary complications such as acute respiratory distress syndrome and ventilator-associated pneumonia. Lung-protective ventilation strategies, including low tidal volume, careful adjustment of positive end-expiratory pressure, and controlled oxygen supplementation, are increasingly recommended to optimize neurological and respiratory outcomes in TBI patients. In addition, strategies such as tracheostomy, prone positioning, and structured weaning protocols may influence duration of mechanical ventilation, ICU stay, and overall patient recovery. This review highlights current concepts and recent evidence regarding mechanical ventilation strategies, indications, settings, complications, and weaning approaches in traumatic brain injury patients managed in the intensive care unit.

Keywords: Traumatic brain injury; Mechanical ventilation; Hyperoxemia; Lung protective ventilation; Positive end-expiratory pressure; Tracheostomy; Weaning; Intensive care unit.

Introduction:

In the first 24 hours following ICU admission, about 50% of patients require mechanical ventilation, mostly as a result of severe respiratory failure, inability to secure their airway, unconsciousness, etc. Intensive care unit (ICU) admission and the start of mechanical ventilation are frequently caused by severe TBI, cerebral hemorrhage, or stroke. Mechanical ventilation is usually indicated in TBI patients with altered consciousness in order to secure the airway preventing aspiration and avoid severe secondary brain injuries related to hypoxemia and hypercapnia **(1).**

Extracranial consequences, such as respiratory, cardiac, renal, lymphatic, and hepatic injuries, can result from brain injury that also affects the distal organ **(2).** TBI patients commonly develop respiratory failure, either as a result of a reduced respiratory drive or a loss of the airway protective reflex. These patients are therefore at a greater risk of respiratory complications, such as ARDS and pneumonia **(3).**

Mechanical ventilation in TBI, regulates the arterial carbon dioxide tension (CO2) and supplies the brain with a proper oxygen levels. However, because of the complicated physiological relationships between the intrathoracic, central venous, and cerebral compartments, it might be detrimental to the brain. Because TBI patients are not included in the majority of clinical studies, most effective ventilatory processes for head injury patients have not been developed. For TBI patients to have desirable outcomes, mechanical ventilation processes must be carefully applied **(4).**

Pathophysiology Of Lung Injuries in TBI

The lung seems to be the organ most impacted by TBI out of all the extracranial problems **(5).** In individuals with head injuries, thoracic injuries are frequently observed **(6).** In addition to local and systemic effects such increased elastance and airway resistance, pulmonary inflammation, and elevated pulmonary hydrostatic pressure, head traumas also alter the mechanisms of the respiratory system **(7).** The brain and the lungs interact together; the brain needs an adequate supply of oxygen to function properly, and the respiratory system needs regular brain signals to function.

Pneumothorax, haemothorax, rib fractures, lung contusions, and flail chest are examples of respiratory disorders that can be due to direct chest trauma. One of the most prominent causes of the need for mechanical ventilation is respiratory failure caused on by severe brain injury or cervical spine injury. Patients with head trauma often develop ARDS/Acute Lung Injury (ALI), pulmonary embolism, neurogenic pulmonary oedema, and ventilator-associated pneumonia **(8).**

Various mechanisms have been described for pulmonary complications in TBI, including neuroinflammation, neurotransmitter-mediated injuries, and complication associated with mechanical ventilation **(9).** Sympathetic storm; a sudden sympathetic discharge immediately after injury increases plasma adrenaline level. This rise in adrenaline level increases blood pressure which damages the endothelium and produces pulmonary edema **(Godoy et al., 2023).** In addition to sympathetic storm or blast, a systemic inflammatory response also plays a crucial role in pulmonary injury in TBI **(8).**

Different mechanisms as neuroinflammation, neurotransmitter-mediated damage, and problems related to mechanical ventilation, are responsible for pulmonary problems following TBI **(9).** After an injury, a rapid sympathetic discharge raises the plasma adrenaline level, a phenomenon known as "sympathetic storm." An increase in blood pressure due to this adrenaline surge affects the endothelium and results in pulmonary edema **(10).** Pulmonary complications in TBI can be explained by a systemic inflammatory response as well as sympathetic storm **(8).**

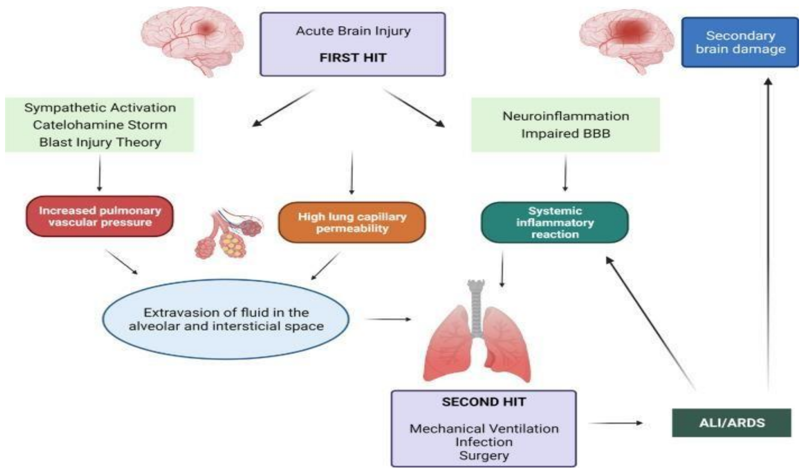

Fig (1): Pathophysiology of lung injury in patients with isolated acute brain injury. ALI, Acute Lung Injury; ARDS, Acute Respiratory Distress Syndrome **(8).**

Indications for endotracheal intubation and mechanical ventilation Twenty percent of traumatic brain injuries need endotracheal intubation and ventilation **(11).** Indications for mechanical ventilation and intubation could be to either neurological or respiratory causes **(12).**

- **Neurological indications such as:**
  1- disturbance in level of consciousness.
  2- airway protection.

3- brainstem dysfunction.

4- elevated intracranial pressure.

5- expected neurologic impairment.

- **Pulmonary indications are:**

hypoxemic respiratory failure caused by

1- aspiration.

2- Pneumonia.

3- Atelectasis.

4- pulmonary oedema.

5- acute lung injury (ALI).

6- ARDS.

7- neurogenic pulmonary dysfunction oedema.

In patients with Glasgow coma scale (GCS) ≤ 8, severe agitation and aggressive behaviors, poor airway protective reflex, serious ICP elevation, and clinical signs of brain herniation, ESICM recommends considering endotracheal intubation and mechanical ventilation **(13).**

Mode OF Ventilation

The ICU typically uses either invasive (ventilation with endotracheal tube in situ) or non-invasive (BiPAP, CPAP, and HFNC) mechanical ventilation. Unfortunately, there isn't a definitive clinical trial that can demonstrate which is better than the other. High-flow nasal cannula (HFNC) oxygen therapy is not recommended by ESICM, and there is insufficient evidence to support noninvasive positive pressure ventilation. Ventilation in TBI can be started using a variety of invasive mechanical ventilation options **(2).**

Mechanical Ventilation Settings

The goal of mechanical ventilation for TBI patients is to reduce intracranial hypertension by maintaining normocapnia and optimal oxygenation. In order to avoid ventilation-induced barotrauma, volutrauma, atelectasis, and biotrauma, lung-protective strategies are now employed for mechanical ventilation **(10).**

Tidal volume (TV): It is now established that a high TV (10 ml/kg) ventilation is linked to an increased risk of ARDS and ventilator-induced lung injury (VILI) **(14).** According to the latest guidelines, lung-protective ventilation should be used with a low tidal volume of 6–8 ml/kg of ideal predicted body weight **(15).** As long as $PaCO_2$ levels was monitored and kept within normal ranges, low tidal protective ventilation had no effect on outcomes or intracranial pressure **(16).** adjusting the respiratory rate instead of the tidal volume will result in the ideal $PaCO_2$.

Positive end-expiratory pressure (PEEP): Lung disorders such as ARDS, atelectasis, and Ventilation/Perfusion (V/Q) mismatch, which results in hypoxemia and hypercapnia, are more common in brain-injured individuals. PEEP recruits an atelectatic lung unit, which helps to increase oxygenation. It also contributes to the enhancement of lung compliance and Functional Residual Capacity (FRC). Conversely, PEEP lowers cerebral perfusion pressure by increasing intrathoracic pressure, decreasing venous return to heart, decreasing cardiac output, and decreasing mean arterial pressure (MAP). Even though PEEP is associated with an increase in ICP and a decrease in cerebral venous return, recent research indicates that mild to moderate PEEP levels have no clinically significant effects on ICP **(17).**

ESICM highly recommends the application of PEEP for all individuals suffering from TBI with no significant increase in ICP, regardless of the presence of ARDS. However, they are unable to suggest lung-protective mechanical ventilation for TBI patients experiencing clinically significant ICP elevation, whether or not ARDS is present **(13).**

Adjustment of PEEP is an important strategy to improve oxygenation in patients with ARDS. Although no single PEEP strategy has proven to be ideal, several well-known trials have outlined various PEEP titration strategies with the underlying consensus surrounding the idea of limiting over-distention of lung parenchyma. In the ARMA trial, PEEP and FiO2 were titrated to target an oxygen saturation of 88 to 95 percent or PaO2 of 55 to 80 mmHg. Although PEEP levels ranging from 5 to 24 cm H2O were used, the trial outlined the need for dynamic changes to PEEP in combination with FiO2 as shown in figure (2). In addition to achieving target O2 saturation and PaO2 levels, this PEEP strategy also involves ensuring low plateau pressures, a fundamental part of classical lung protective ventilation **(18).**

PEEP tables from ARDSnet

FiO2	Standard PEEP*	High PEEP
0.3	5	5-14
0.4	5-8	14-16
0.5	8-10	16-20
0.6	10	20
0.7	10-14	20
0.8	14	20-22
0.9	14-18	22
1.0	18-24	22-24

*Used in the origional ARDSnet trial.
-The Internet Book of Critical Care, @PulmCrit

Figure (2): Peep tables form ARDSnet **(18).**

Inspired oxygen concentration (FIO2):

According to recommendations from the American College of Chest Physicians and the National Heart, Lung, and Blood Institute, oxygen therapy should be initiated under the following clinical conditions **(13):**

- Cardiac or respiratory arrest
- Hypoxemia, defined as:
  - $PaO_2 < 60$ mmHg
  - $SaO_2 < 90\%$
- Hypotension, with systolic blood pressure < 100 mmHg
- Low cardiac output or metabolic acidosis, indicated by bicarbonate < 18 mmol/L
- Respiratory distress, characterized by a respiratory rate > 24 breaths/min

These criteria emphasize the importance of timely oxygen supplementation to prevent tissue hypoxia and support vital organ function.

100% FIO2 is typically administered when mechanical ventilation is started, but it should be gradually down to the level needed to reach the desired level of PaO2; otherwise, oxygen-free radical injury may result. The ideal target range for PaO2 in TBI patients, whether or not there is a clinically significant increase in intracranial pressure, is 80–120 mmHg, according to ESICM**.** TBI patients can benefit from lung protective ventilation as shown in table (1) with low tidal volume (6–8 ml/kg ideal body weight), keeping low mean airway pressures ≤ 30 cmH2O, careful use of positive end-expiratory pressure (PEEP), and higher respiratory rates without impairing neurological outcome or minimizing lung damage during mechanical ventilation **(12).**

Table (1): Lung protective ventilation strategies can be summarized as follows **(18).**

Mode	**Setting**
Tidal Volume	6-8 ml /kg ideal body weight.
Respiratory rate	8 – 35 / minute
Plateau pressure	25-30 cm H2O
PEEP	3 to 5 cmH2O max up to 10 to 12 cm H2O
Inspiration and expiration time ratio	1:1 to 1:3
Target PaO2	80–120 mmHg

Tracheostomy in TBI Patients

Tracheostomy is typically taken into consideration for patients who are anticipated to need prolonged mechanical ventilation in order to enable early ventilator weaning. lot of advantages of tracheostomy include better pulmonary mechanics, fewer nociceptive stimulation in the larynx or trachea, a reduced need for sedatives and analgesic drugs, simpler nutrition and oral hygiene, and enhanced communication. Pneumothorax, oesophageal perforation, airway hemorrhage, and surgical site infection are some of the complications that may be linked to its surgical method **(19).**

The indications for tracheostomy and the appropriate timing for its placement remains a subject of debate. Historically, tracheostomy is indicated when patients need mechanical ventilation for over 21 days. Certain research also indicates that performing tracheostomy earlier, within a window of 7 to 15 days after intubation, might be beneficial. Nevertheless, there is no definitive distinction established between early and late timing for tracheostomy; however, a Cochrane Review of randomized controlled trials from 2015 categorized tracheostomies completed within ten days post-intubation as early, while those conducted afterwards were labeled late **(19).**

Implementing early tracheostomy in patients with traumatic brain injury may aid in decreasing the length of mechanical ventilation, shorten ICU admissions, reduce the incidence of VILI, cut down on sedative needs, and minimize the risk of ARDS and VAP. However, it does not significantly influence overall mortality rates among individuals with head injuries **(19).**

The ESICM emphasizes that patients who experience one or more failed extubation attempts should be evaluated for the possibility of tracheostomy. However, they cannot give recommendations concerning the ideal timing for tracheostomy in TBI patients **(19).**

Prone Position Ventilation in TBI

Early initiation of ventilation sessions in the prone position has notably lowered mortality rates at both 28 and 90 days **(Guérin et al., 2013).** Recently, it is found that prone positioning during ventilation sessions enhances oxygen levels owing to better lung perfusion, decreased compression in the dorsal area of the lungs, and improved gas exchange by enhancing the difference in transpulmonary pressure from the front to the back. This method can also be beneficial for increasing oxygen supply to the brain and elevating cerebral perfusion pressure in cases of traumatic brain injury and subarachnoid hemorrhage. However, there is a notable association with a considerable increase in ICP **(20).**

The European Society of Intensive Care Medicine strongly advocates for the use of prone positioning in patients with traumatic brain injury and acute respiratory distress syndrome, provided that there is no significant rise in intracranial pressure **(13).**

Weaning from Mechanical Ventilation IN TBI

Weaning denotes the method of Removing mechanical ventilatory - Support and Changing the work of breathing from the ventilator to the patient. This process is continuous and should Start as soon as a suitable level of medical and respiratory stability is reached. The weaning procedure consists of two phases: the initial phase involves removing ventilator pressure - Support, while the subsequent phase pertains to freeing the airway from the endotracheal tube. Extubation in patients with TBI poses significant difficulties; the elevated failure rate of extubation in individuals with head trauma is primarily linked to the severity of their initial critical condition, emergency situations, and often, prehospital intubation of the trachea **(21).**

The weaning process necessitates regular evaluations of the patient and a meticulous balance between the advantages of Sustained ventilatory support and the potential risks such as VILI and muscle wasting. Criteria for weaning as shown in figure (3) are Applied to assess a patient's Readiness for a weaning trial and the probability of successful weaning. This includes clinical criteria, ventilatory parameters, oxygenation standards, and evaluations of pulmonary reserves and Indicators **(19).**

Process of weaning from mechanical ventilation begins with gradually decreasing the concentration of inspired oxygen (FIO2) and pressure support levels. A spontaneous breathing trial (SBT) may serve as the primary diagnostic assessment to evaluate successful extubation and the process of weaning off mechanical ventilation. SBT can be administered using continuous positive airway pressure (CPAP) with minimal pressure support to counteract the resistance posed by the endotracheal tube, or through T-piece trials where the patient breathes spontaneously via the endotracheal tube connected to an oxygen flow **(21).**

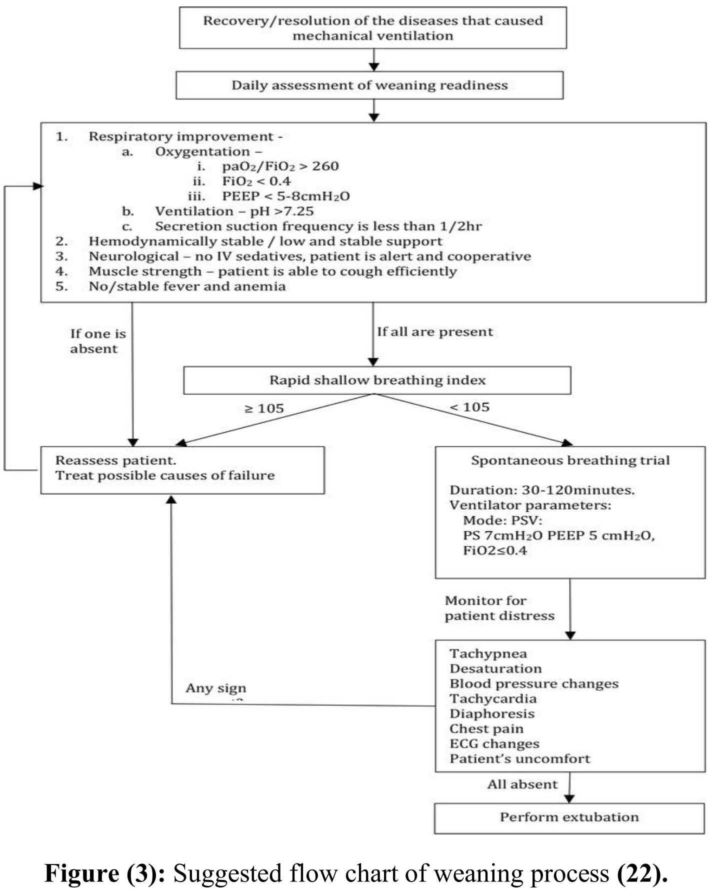

Figure (3): Suggested flow chart of weaning process **(22).**

Weaning may also be accomplished through pressure support ventilation (PSV) and Synchronized Mandatory Intermittent Ventilation (SIMV) (90. An altered level of consciousness or changes in mental status are significant considerations in determining the appropriate timing for extubation in patients suffering from head injuries **(19).**

Recenly, there is no definite protocol for weaning or extubating TBI patients. Delaying extubation in order to wait for adequate neurological recovery did not ensure successful extubation and is linked to higher rates of nosocomial pneumonia, lengths of stay in the intensive care unit, and hospital expenses **(19).**

ESICM is unable to suggest a specific GCS level to be taken into consideration when deciding whether to extubate patients with acute brain damage, but it strongly advises that the choice should take airway protection measures (coughing, gaging, and swallowing) into consideration **(13).**

Four criteria were used to create the VISAGE score as shown in figure (4) following a multicentric investigation of more than 437 patients **(16).**

Extubation Success Score	Assigned Points According to Items
Age < 40 yr old (yes/no)	1/0
Visual pursuit (yes/no)	1/0
Swallowing attempts (yes/no)	1/0
Glasgow coma score > 10 (yes/no)	1/0

VISAGE = visual pursuit, swallowing, age, Glasgow for extubation.

Figure (4): VISAGE Score.

When Score = / <3, they discovered that at least 90% of extubation episodes were successful **(16).** The following clinical characteristics can be summed up as indicators of effective extubation: swallowing, visual pursuit, age <40, GCS >10, coughing and gag reflex, and negative fluid balance **(23).**

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