# Weaning of mechanical ventilation in neuro critical care

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**Abstract (100 words)**

In the intensive care unit (ICU), weaning from mechanical ventilation follows a step by step process that has been well established in the general ICU population. However, little data is available in brain injury patients, who are often intubated to protect airways and prevent central hypoventilation. In this narrative review, we describe the general principles of weaning and how these principles could be adapted to brain injury patients. We focus on three major issues regarding weaning from mechanic ventilation in brain injury patients: 1) sedation protocol, 2) weaning and extubation protocol and criteria, 3) criteria, timing and technique for tracheostomy.

**Keywords:**

Mechanical ventilation; Brain injury; Weaning; Extubation

## 1. Introduction

Although artificial ventilation is a life-saving therapy, it is associated with risks and complications. For instance, longer duration of mechanical ventilation (MV) is associated with higher intensive care unit (ICU) mortality [1]. In order to avoid complications related to MV, physicians should put important effort on the reduction of the duration of MV, which involves to wean as soon as possible patients from MV.

Along the past decades, various changes in ICU practice have contributed to a reduction of duration of MV: lighter sedation, individualised choice of substances, importance of analgesia, daily attempts of sedation interruption, weaning and extubation protocols. Neurocritical care is a subspecialty of intensive care that focuses on the management of acutely ill patients with life-threatening neurologic and neurosurgical diseases or with life-threatening neurologic manifestations of systemic disease.

One may ask if the general principles of weaning from MV can be extrapolated to this specific population. While the amount of data on weaning and extubation is steadily increasing, data on neurocritical care patients are lacking. Indeed, these patients are frequently excluded from randomised controlled trials. In this article we will review the current clinical literature and discuss the principles of weaning from MV in neurocritical care patients. Because it involves a very large variety of diseases, we will focus on patient with acute brain injury and will exclude from the present review article acute and acute-on-chronic peripheral nerve injury.

## 2. Weaning from mechanical ventilation: toward a systematic approach

Successful weaning is defined as the ability to maintain spontaneous ventilation without the need for MV for 48 hours after extubation [2]. This time frame is debated and some authors suggest to extend this period to 72 hours and even 7 days after extubation [3].

To avoid complications of MV, patients should be weaned from MV as soon as possible. However, extubation failure and subsequent reintubation is as high as 20% [4, 5] and is associated with an increased mortality [6]. Therefore, the challenge of weaning is to identify the right moment to avoid both the complications associated with unnecessarily delayed extubation and those associated with the need for reintubation because of weaning failure.

A body of literature has identified factors that are associated with successful extubation: young age [7], low severity on ICU admission, short duration of MV prior to extubation [8], normocapnia [9], negative fluid balance immediately prior to extubation [10]. However, in a given patient, these factors do not allow to predict whether weaning will be successful or not [11, 12]. For this reason, a consensus conference held in 2006 has proposed a systematic approach based on a step by step management of the weaning process [13].

**Step 1:** Search every day for readiness to wean criteria. The criteria are shown in Figure 1. When present, these criteria indicate that it is worth to assess whether the patients can tolerate unassisted breathing. Indeed, it would not make sense to impose step 2 (see below) to patients with a too low pre-test probability of successful weaning.

**Step 2:** If readiness to wean criteria are present, initiate a spontaneous breathing trial (SBT). The aim of the SBT is to determine a priori the patient ability to tolerate unassisted breathing. Various methods have been proposed to mimic unassisted breathing: T-tube (the patient receives only supplemental oxygen through a T-tube connected to the endotracheal

tube), continuous positive airway pressure (mostly with a pressure support level of 5 $cmH_2O$) and pressure support (with a pressure support level between 0 and 8 $cmH_2O$). The conditions in which the SBT is performed is extremely important. For instance, if breathing is too much assisted during SBT (i.e. pressure support level 7 $cmH_2O$ and PEEP 5 $cmH_2O$), the risk is that more patients will qualify, but with a high rate of failure. On the contrary, with a too low level of assistance (i.e. pressure support 0 $cmH_2O$ and PEEP 0 $cmH_2O$), less patients will succeed, but those who will succeed will have a low rate of extubation failure and subsequent re intubation. Finally, the duration of the SBT is also important. A longer SBT will be more demanding. Subsequently, patients who qualify will be at low risk of extubation failure. However, some patients who could succeed extubation will not qualify. A recent study has suggested that a 30 minutes SBT with a pressure support level of 7 $cmH_2O$ and a PEEP 5 $cmH_2O$ is the best compromise [14]. It increases the proportion of patients who are extubated, without increasing the proportion of extubation failure. Criteria for SBT failure are shown in Figure 1. In the absence of these criteria, SBT is successful.

**Step 3:** In case of a successful SBT, then search for extubation criteria. Indeed, a successful SBT means that the patient can breathe unassisted (i.e. without a ventilator). However, it does not mean that the intubation probe can be safely removed. Indeed, to tolerate extubation, adequate level of consciousness, swallowing and cough are needed.

**Step 4:** Once the patient is extubated, consider prophylactic non-invasive ventilation or high flow nasal cannula to prevent post extubation acute respiratory failure and subsequent reintubation in at risk patients (age > 65 years, chronic cardiac disease, chronic respiratory disease).

According to the 2006 consensus conference, simple weaning is defined as successful extubation after one attempt whereas difficult weaning is defined as requiring up to three SBT

attempts within seven days of the first SBT. Prolonged weaning is defined as failure of at least three SBT attempts or the need for more than 7 days of weaning after the first SBT. [13].

## 3. Specificities of weaning in neuro-critical care patients

The potential obstacles to the completion of the classical steps of weaning from MV in brain injury patients are presented in figure 1.

### 3.1. Weaning and brain injury

Brain injury is defined by a Glasgow Coma Scale (GCS) ≤ 12 associated with at least one anomaly related to an acute process on head tomographic tomodensitometry (extradural hematoma, subarachnoid haemorrhage, brain contusion, hematoma, brain edema, skull fracture, stroke, and abscess). Brain injury is a major cause of respiratory failure and a frequent cause of prolonged MV [15]. In brain injury patients, respiratory failure is the most common non-neurologic organ system failure. It is associated with poor neurological recovery and death in this population [16-18].

Brain injury patients require intubation and MV to protect airways from aspiration and to prevent secondary brain damage by modulating oxygen and carbon dioxide levels [19]. Application of protective MV including low tidal volume in conjunction with early extubation reduces the risk of pulmonary complications [20]. Protective MV with low tidal volume (6-8 ml/kg of predicted body weight) has specific requirements in brain injury patients, its goal being to avoid hypercapnia and respiratory acidosis, which increase the intracranial pressure with subsequent risk of secondary brain injury and hospital mortality. Protective ventilation should be applied to brain injury patients, with close monitoring of the minute ventilation, continuous monitoring of end tidal $CO_2$, and close biological monitoring of blood gases. [21].

In brain injury patients, weaning from MV can theoretically follow the step-by-step process previously described. A successful SBT is required to extubate. However, because of impaired breathing control and altered respiratory drive, 5% to 20% of brain injury patients cannot pass SBT [22]. Indeed, as compared to non-brain injury patients anomalies of the breathing pattern due to brainstem involvement and the need to protect the airways from inhalation are more common [23-25]. The decision to extubate is particularly difficult in comatose patients [4]. On the one hand, extubation failure is associated with increased length of hospital stay and mortality like in every patients [26]. On the other hand in brain injury patients, late extubation is associated with unplanned extubation and impaired outcomes [27]. Therefore, the prediction of successful extubation is a major challenge, as up 10% to 35% of neurocritical care patients require reintubation [24, 28].

It has been suggested that prolonged intubation should be avoided when the only concern is an impaired neurological state [27]. Discriminating patients who can be safely extubated from those who cannot is very difficult. In a prospective cohort study of 192 consecutive brain injury patients, extubation success was predicted by younger age, presence of cough, and negative fluid balance [29, 30].

Finally, non-invasive ventilation is generally not recommended for brain injury patients [13] due to inherent limitations, such as severe neurogenic dysphagia or disorders of consciousness. Post-extubation prophylactic non-invasive ventilation is therefore not a useful tool in this population.

### 3.2. Specificities of weaning according to structural lesions

Extubation failure in patients with intracerebral hemorrhage is about 15% [31]. In patients with subarachnoid hemorrhage, extubation failure rate averages 29%, consistent with other stroke subpopulations [32]. Dysphagia associated with acute ischemic stroke is a

major determinant of readiness for extubation. A study of acute ischemic stroke patients close to weaning and extubation found that dysphagia was the main factor for extubation failure in half of them, and the reintubation rate was 21%. After extubation, dysphagia was observed in 69% of the general ICU population and in 93% of patients in acute ischemic stroke [33].

In traumatic brain injury, predictive factors of extubation failure include female gender, GCS <5, moderate to large secretion volume, absent or weak cough, and MV for more than 10 days [34].

## 4. How to adapt weaning from mechanical ventilation to brain injury patients?

### 4.1. Management of sedation

Avoidance and/or discontinuation of unnecessary sedation appears essential [35]. In the ICU, sedation protocols reduce the length of hospital stay [36]. However, these protocols have been poorly studied in brain injury patients.

Historically, the first sedation protocol developed was the daily interruption of sedation, which reduces duration of MV and improves survival, all the more so it is associated with a weaning protocol [37, 38].

In brain injury patients, daily interruption of sedation is debated. Criticism is based on uncontrolled variations in blood pressure associated with intra cranial pressure variations as well as systemic stress responses, which may cause neurological worsening [39, 40]. In an observational study in patients with subarachnoid haemorrhage and traumatic brain injury, daily interruption of sedation was associated with an increase in stress hormone and in intracranial pressure (up to 22 mmHg). As mean arterial pressure also increased, cerebral

perfusion pressure drops were rare and only transient. The authors concluded that most of these risks did not outweigh the benefits of sedation interruption, excepted in patients with severe intracranial pressure or cerebral perfusion pressure disturbances [39, 41]. A recent review identified a total of one retrospective and four prospective observational trials of daily interruption of sedation in brain injury patients [42]. In these five studies, daily sedation reduction was associated with a worsening of neuromonitoring parameters (increases in intracranial pressure and changes in cerebral perfusion pressure) that motivated its discontinuation. In summary, there is no evidence to support the indiscriminate use of daily sedation reduction in brain injury patients. When daily interruption of sedation reduction is decided, an appropriate monitoring is required and it could only be performed in patients with controlled intracranial pressure for more than 24 to 48 hours without the need of pentobarbital administration or therapeutic hypothermia, and in the absence of any acute neurologic complications (like cerebral vasospasm or seizures) or systemic complications (like sepsis, ventilated associated pneumoniae with hypoxemia).

An alternative to daily interruption of sedation is goal-directed analgesia and sedation protocol. In the ICU, the benefit of these protocols is clearly established [43] and guidelines recommend their systematic use [44]. Few data are available in brain injury patient. In a prospective study of 215 patients admitted to the ICU for acute brain injury, the application of a sedation and analgesia protocol resulted in a decrease in the total amount of sedation used, the number of painful episodes and the number of painful days [45]. In a randomised controlled trial that included 162 patients with acute brain injury or after neurosurgery, a remifentanil-based protocol achieved the same feasibility and safety than a conventional sedative-based regime, but with earlier and more reliable neurological assessment [46]. In a

prospective study performed in 67 brain injury patients, the bispectral index was able to reduce sedative drug consumption [47].

Goal-directed analgesia and sedation protocols require tools to monitor analgesia and sedation. Clinical scores and scales that are commonly used in the ICU have been poorly studied in brain injury patients [48]. The Richmond Agitation Sedation Scale (RASS) [49] has been evaluated in 34 brain injury patients and showed a good correlation with other sedation assessment scales such as the Sedation-Agitation Scale [50], the measurement of depth of sedation based on electroencephalogram and the bispectral index [51].

Delirium is associated with prolonged MV and increased ICU mortality [52-55]. In ICU patients with acute brain injury, the prevalence of delirium is 19% to 70% [56, 57]. In the general ICU population, the only evidenced benefit of dexmedetomidine is an increase in the number of days without delirium or coma [58]. Dexmedetomidine may have attractive features for patients with acute brain injury, such as the lack of respiratory depression, an ease of sensorium and neurological assessment with ongoing infusion and sympatholysis [59]. However, dexmedetomidine is in the early stages of evaluation in brain injury patients and there is little evidence in the literature. A study in brain injury patients demonstrated the safety and feasibility of using dexmedetomidine, although in many cases the sedative power of dexmedetomidine alone was insufficient [60]. A single institutional series demonstrated that initiation of dexmedetomidine infusion is not associated with a decline in neurological functioning in adults with severe traumatic brain injury [61]. A retrospective analysis of prospectively collected data on the main clinical features and adverse events observed during light sedation with dexmedetomidine in brain injury patients suggested that when used to target light sedation, dexmedetomidine was safe and enabled the weaning from MV and the

maintenance of spontaneous breathing [62]. Rigorous studies are needed to confirm these hypotheses.

### 4.2. Weaning and extubation

In general ICU patients, weaning and extubation follow the four steps protocol that has been previously detailed (see above). Nothing suggests that this strategy could not be used in brain injury patients. However, very few studies have evaluated weaning and extubation strategies and protocols in brain injury patients.

In a prospective multicenter before-and-after trial [20] that included 744 patients with acute brain injury requiring MV for more than 48 hours, a ventilation and extubation protocol was implemented. Extubation was recommended when the following three criteria were met and carried out within 48 h: (1) weaning from ventilation support defined as a successful spontaneous breathing trial (30 min T-tube trial or total pressure support level <10 $cmH_2O$), (2) effective cough [63] and (3) GCS ≥10 . Ninety days after inclusion, the number of days free of invasive ventilation was higher in the 60 patients (8%) whose care was compliant to the protocol than in the 684 (92%) patients whose care deviated from the protocol (77 [66-82] and 71 [0-80] days, respectively, P=0.03). The mortality rate was 10% in the compliant group and 26% in the non-compliant group (P=0.023). Multivariate analysis and propensity score-adjusted analysis revealed that compliance to the ventilation and extubation protocol was an independent factor associated with shorter duration of MV.

It is of note that, in brain injury patients, a dissociation between consciousness and respiratory function may persist. Therefore, persistent impairment of alertness due to brain injury is not a contraindication to initiate the weaning process. Extubation success was predicted by younger age, presence of cough, and negative fluid balance, rather than GCS at extubation [29, 30]. These results do not support prolonging intubation solely for low GCS in

brain-injured patients [29]. Extubation of patients without full neurological recovery can be safe [27, 63], can reduce the risk of unplanned extubation [63, 64] and can decrease the ICU length of stay [27]. Several studies have reported a low risk of extubation failure in patients with a GCS between 8 and 10, provided that patients are able to cough [63, 65]. In a large interventional study, the rate of reintubation decreased in the intervention group in which criteria for readiness included a GCS $\geq 8$ and associated with presence of clearly audible cough during suctioning followed by a 1-hour spontaneous breathing trial for the patients who passed the screening [64].

Generic scores for predicting extubation failure have been recently developed. The most commonly applied in the general ICU population is the VIsual pursuit, Swallowing, Age, Glasgow for Extubation score (VISAGE), which considers gag reflex, cough, swallow and neurological status as assessed by the visual subscale of the revised coma recovery scale [66]. This score predicts extubation failure in the general ICU patients, but also in patients with traumatic brain injury and subarachnoid haemorrhage patients to [32]

Prior to extubation, chest physiotherapy is recommended for critically ill MV patients, as reduces the incidence of respiratory complications, promotes weaning from MV, facilitates physical function in ICU survivors and reduces length of stay [67]. A study on manual and mechanical chest percussion techniques in patients with traumatic brain injury found that the manual technique was associated with an increase in intracranial pressure and impaired hemodynamic. However, this increase was transient and not clinically relevant in moderate to severe traumatic brain injury without intracranial hypertension [68].

Table 2 lists the readiness to wean criteria that are commonly retained for brain injury patients [20, 27, 29, 30, 39, 41, 63, 65].

## 5. Tracheostomy

Tracheostomy has several potential advantages over endotracheal intubation. It reduces the risk of accidental extubation, airway trauma, sinusitis, airway resistance and therefore work of breathing [69]. Tracheostomy is better tolerated by patients, resulting in a potentially lower need for sedation [37, 70]. The procedure, however, is not without risk, and potential complications include surgical site infection, bleeding, pneumomediastinum, pneumothorax and death [71].

Extubation failure in brain injury patients is about 38%, while tracheostomy is required in 32% to 45% of patients [29, 30]. In brain injury patients, tracheostomy is performed in most patients who failed weaning or extubation. However, a tracheostomy is performed in up to 79% of brain injury patients without any weaning attempt [29].

In patients with unstable intracranial pressure or cerebral perfusion pressure, it is reasonable to postpone tracheostomy [72].

### 5.1. Factors associated with the need for tracheostomy

A study of tracheostomy practices after severe acute brain injury in the US found that, in patients with stroke, traumatic brain injury and hypoxic ischemic encephalopathy after cardiac arrest, performing a tracheostomy was associated with younger age, male gender and non-white race [30]. It was also strongly and independently associated with large, urban and university hospitals. These results may suggest either that two different standards of care have evolved for severe acute brain injury in different types of hospitals, or that patients whose families demand aggressive care tend to be transferred to high volume centers, or that patients in these centers have more severe disease and require tracheostomy more often [73].

Factors associated with the need for tracheostomy depends on the nature of brain injury. In a cohort of 1358 patients with acute traumatic brain or cerebrovascular injury , age,

GCS ≤8, associated thoracic trauma, hypoxemia and unreactive pupil were identified as predictive factors for tracheostomy [74].

In patients with severe traumatic brain injury, a cohort of 120 patients found that factors associated with the need for tracheostomy were the Corticosteroid Randomisation After Significant Head injury score (CRASH), International Mission for Prognosis and Analysis of Clinical Trials score (IMPACT), Simplified Acute Physiology Score II (SAPS II) and Acute Physiology And Chronic Health Evaluation II score (APACHE II), age, revised trauma score, general state of consciousness, presence of a subdural, pupillary reactivity and basal cistern collapse [75]. In another cohort of 209 adult traumatic brain injury patients requiring ICU admission for ≥72 hours and MV for ≥24 hours, admission factors associated as predictors of tracheostomy were the GCS, Marshall score, chest tube and injury severity score [76].

In patients with stroke, dysphagia and GCS <10, hydrocephalus, brainstem lesion, intracranial hemorrhage, surgical procedure and general organ function (additional respiratory disease, $PaO_2/FiO_2$ <150, sepsis, lung injury score >1, acute physiology score > 20) have been identified as possible predictive factors to identify patients who may require tracheostomy by the stroke-related early tracheostomy (SET) score [77].

In intracranial hemorrhage, low GCS, chronic obstructive pulmonary disease, intracranial hemorrhage volume and location, midline shift, intraventricular blood and hydrocephalus are predictive factors for the need for tracheostomy [78].

In a retrospective cohort study of patients with 150 patients with supratentorial intracranial hemorrhage, the Clinical and Radiological Predictors of Tracheostomy score (TRACH score) was developed to easily identify patients who may require tracheostomy [79]. GCS was the most significant clinical predictor, radiological predictors were presence of hydrocephalus, displacement of the septum pellucidum and location of intracranial

hemorrhage in the thalamus. The TRACH score has been defined from a formula taking into account the GCS and the presence or absence of the three radiological predictors and was very predictive of tracheostomy needs (ROC = 0.92) [79].

Table 2 lists the factors that are associated with the need for tracheostomy in brain injury patients.

### 5.2. Early versus late tracheostomy

In the general ICU population, the timing of tracheostomy is still a matter of debate [80, 81]. Recent guideline recommend to avoid performing tracheostomy before the fourth day of MV [82].

In an international observational cohort study, patients with acute hemorrhagic or ischemic stroke or subarachnoid hemorrhage, ICU length of stay was similar with early (within three days) or late (between 7 and 14 days) tracheostomy [77]. In a prospective, randomized, parallel-group trial performed in neurological and neurosurgical ICUs, patients with severe ischemic or hemorrhagic stroke and an estimated need for at least 2 weeks of MV were randomized to either early tracheostomy (within 1 to 3 days from intubation) or standard tracheostomy (between 7 and 14 days from intubation, if extubation could not be achieved or was not feasible). ICU mortality and 6-months mortality were lower in the early tracheostomy group [83].

In subarachnoid hemorrhage, tracheostomy is performed in 17% of patients [84]. Longer time to tracheostomy was associated with more frequent pulmonary complications (pneumothorax, acute respiratory distress syndrome, post-procedural pulmonary complications), venous thromboembolism and pneumonia [85], while shorter time to tracheostomy was associated with a shorter length of stay [85, 86].

In a cohort of 433 patients with traumatic brain injury, tracheostomy within 7 days from admission seemed to be associated with better neurological outcome, lower mortality, lesser neurological sequelae and shorter length of stay than late tracheostomy (more than 7 days from admission) [74]. In a meta-analysis based on eight trials of early (within 10 days of injury) versus late (more than 10 days) tracheostomy in patients with traumatic brain injury, early tracheostomy was associated with a shorter duration of MV and lower incidence of ventilator-acquired pneumonia [87].

Very early (within 3 days of admission) and early tracheostomy (after 3 days of admission) were also compared in a retrospective cohort study of patients with traumatic brain injury. Thirty-day mortality was 3% in the very early group vs. 8% in the early groups, ($p = 0.38$). The duration of MV and ICU length of stay were lower in the very early group than in the early group. There was no difference between the two groups in term of incidence of adverse events and pneumonia [88]. In another cohort of 98 patients with traumatic brain injury, very early tracheostomy was associated with a reduction of ICU length of stay, antibiotic use, cost of hospitalization and rate of ventilator-acquired pneumonia rate Mortality was not different between groups. [89].

## 5.3. Technique

Guidelines recommend bedside percutaneous tracheostomy as the standard method in the ICU [90] since this technique is associated with a shorter operative time and a decreased incidence of stoma infection and inflammation [91]. In brain injury patients, when tracheostomy was performed at bedside by intensivists rather than in the operating room by surgeons, tracheostomy was performed earlier and duration of MV was shorter [92].

## 5.4. Rehabilitation and decannulation

Once tracheostomy is performed, it remains necessary until airway protection reflexes, pharyngeal tone, level of consciousness and cognition improve sufficiently to clear secretions and to efficiently control upper airway [77, 93].

Prompt and safe decannulation of tracheostomy appears to improve the outcome [94]. Various decannulation protocols have been described, mainly for general ICU population where tracheostomy tubes are usually removed after a short period of time [95]. A cross-sectional study examined criteria for decannulation after tracheostomy in brain injury patients. First, subjects underwent the original assessment for decannulation. Second, they underwent an experimental decannulation protocol including: voluntary cough, reflex cough, tracheostomy tube capping (≥72 h), swallowing instrumental assessment, blue dye test, number of trachea suctions, endoscopic assessment of airway patency, saturation ($SpO_2$ >95%), and level of consciousness evaluation (GCS ≥8). The best clinical prediction rule for decannulation was a combination of the following assessments: tracheostomy tube capping, endoscopic assessment of patency of airways, swallowing instrumental assessment, and blue dye test [96].

## 6. Conclusion

Weaning from MV is a step by step process that is well standardized for the general ICU population. However, little data is available in brain injury patients. First, goal-directed analgesia and sedation seems beneficial in brain injury patients, while daily interruption of sedation in debated. Second, weaning protocol can be adapted to brain injury patients, assuming that brain injury patients can be extubated with a lower level of consciousness than what is recommended is for other patients. Third, based on given criteria, physicians can select patients who will benefit from tracheostomy.

Further studies are needed to assess the pathophysiology of extubation failure in brain injury patient, to improve the detection of patients who are ready for extubation, and to prevent re intubation. Patient selection and the timing of tracheostomy are still debated.

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## Tables and figure

**Table 1. Readiness to wean criteria, criteria for spontaneous breathing trail failure and extubation criteria**

| **Readiness to wean criteria**<br>If present, the spontaneous breathing trial should be initiated | **Criteria for failure of the spontaneous breathing trial**<br>If present, mechanical ventilation should resumed | **Extubation criteria**<br>If present, extubation can be performed |
|---|---|---|
| - Resolution of the cause of mechanical ventilation<br>- Effective cough<br>- Low bronchial congestion<br>- State of consciousness: patient awake, not agitated<br>- Hemodynamic stability : heart rate < 140 beats per minute, systolic blood pressure between 90 and 160 mmHg without vasopressor<br>- Gas exchange<br>  ○ $PaO_2/FiO_2$ > 150 mmHg with $FiO_2$ < 40% and PEEP ≤ 8 $cmH_2O$)<br>  ○ RR < 35 / min.<br>  ○ pH > 7.35<br>  ○ rapid shallow breathing index ($RR/V_T$) ≤ 105/min/l | **Objective criteria**<br>Respiratory<br>- Polypnea > 35/minute<br>- RR/ $V_T$ > 105 cycles/minute per litre<br>- Involvement of accessory respiratory muscles<br>Gas exchange<br>- $PaO_2$ ≤ 50-60 mmHg with $FiO_2$ 50% or $SaO_2$ < 90%<br>- $PaCO_2$ > 50 mmHg or increase of $PaCO_2$ > 8 mmHg<br>- pH < 7.32<br>Hemodynamics<br>- Tachycardia > 140/minute<br>- Hypertension : systolic blood pressure ≥ 180 mmHg<br><br>**Subjective criteria for failure**<br>Respiratory<br>- Signs of respiratory distress<br>- Visible increased accessory muscle activity<br>Neurological<br>- Agitation and anxiety | SBT success<br>Adequate swallowing<br>Effective cough<br>GCS >10<br>Negative fluid balance |

RR, respiratory rate; $V_T$, tidal volume; PEEP, positive end expiratory pressure; $PaO_2$, partial pressure of oxygen; $PaCO_2$, partial pressure of carbon dioxide; $FiO_2$, inspired fraction of oxygen; SBT spontaneous breathing trial; GCS, Glasgow Coma Scale.

**Table 2. Proposition of readiness to wean criteria and of criteria for tracheotomy in brain injury patients**

| **Proposition of readiness to wean criteria in brain injury patients** |
|---|
| *Respiratory*<br>• Resolution of the cause of mechanical ventilation<br>• Low bronchial secretion<br>• Gas exchange:<br>  ○ $PaO_2/FiO_2$ >150 mmHg with $FiO_2$ <40% and PEEP ≤8 $cmH_2O$<br>  ○ RR <35 breaths/min.<br>  ○ pH >7.35<br>  ○ Rapid shallow breathing index ($RR/V_T$) ≤105 cycles/min/l<br>*Neurological*<br>• Stable neurological condition<br>• Intracranial pressure <20 mmHg, cerebral perfusion pressure ≥60 mmHg<br>• GCS ≥8, no agitation<br>*Hemodynamics*<br>• Hemodynamic stability:<br>  ○ Heart rate <140 beats/min<br>  ○ Systolic blood pressure between 90 and 160 mmHg<br>  ○ No vasopressor<br>• Negative fluid balance<br>*Otolaryngology*<br>• Adequate swallowing<br>• Gag reflex<br>• Patient able to cough effectively<br>• Adequate secretion clearance (cough strength) |
| **Proposition of criteria for early tracheotomy** |
| • Failure of a first spontaneous breathing trial with<br>  ○ GCS < 10<br>  ○ Neuroimaging : hydrocephalus and/or displacement of the septum pellucidum and/or location of intracranial hemorrhage in the thalamus<br>  ○ Dysphagia |

RR, respiratory rate; $V_T$, tidal volume; PEEP, positive end expiratory pressure; $PaO_2$, partial pressure of oxygen; $PaCO_2$, partial pressure of carbon dioxide; $FiO_2$, inspired fraction of oxygen; GCS, Glasgow Coma Scale.

**Fig. 1 Timeline of impediments to weaning from mechanical ventilation in brain injured patients**