Who Is Safe to Extubate in the Neuroscience Intensive Care Unit?

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Abstract

Patients admitted to the neuroscience intensive care unit (NICU) may have respiratory compromise from either central or peripheral neurological pathology, and may hence require intubation and mechanical ventilation for very diverse reasons. Liberation from invasive ventilation, that is, extubation, at the earliest possible time is a widely accepted principle in intensive care. For this, classic extubation criteria have been established in the general critical care setting, mainly targeting pulmonary function and cooperativeness of the patient. However, classic extubation criteria have failed to predict successful extubation in many studies on NICU patients, and extubation failure (EF) rates range between ∼20 and 40% in these. Not necessarily impaired consciousness, but neurological impairment of securing the airway and handling secretions (dysphagia, low pharyngeal muscle tone, weak cough, etc.) may be mainly responsible for this dilemma. Attempts have been made to identify predictors of EF or success, and to establish extubation scores for the NICU, but results have been partially controversial and the database is still weak. It is very important to have a stepwise protocol to approach extubation in the NICU patient and to be prepared for reintubation (at times in a difficult airway) and alternatives (such as tracheostomy). The particular challenges of safely extubating the NICU patient will be the focus of this review, including a suggestion for a standardized approach.

Keywords
- neurocritical care
- neuroscience intensive care unit
- extubation
- reintubation
- weaning
- airway

The need to secure the airway and mechanically ventilate a patient with a severe neurological disorder is among the main reasons to admit and keep a patient on a neuroscience intensive care unit (NICU). For these severely afflicted neurological or neurosurgical patients, invasive mechanical ventilation (MV) is probably the main distinguishing feature between NICUs and intermediate care or stroke units. Several publications in the 1980s and 1990s suggested that neurological, particularly cerebrovascular, patients requiring MV have a very poor prognosis and questioned the usefulness of such ventilation,[1–4] while other studies indicated that a considerable part of these even long-term ventilated patients can have a good outcome.[5,6] Today, with evidence that treatment on specialized NICUs improves outcome, new endovascular and neurosurgical options, progress in neuromuscular disease, and considerable advances in modern ventilation techniques, withholding respiratory procedures can hardly be justified unless the situation is clearly futile from the outset. Since respiratory failure is the most frequent extracerebral organ complication in NICU patients, the airway and lungs are clearly important treatment targets in these patients.[7,8]

Although initially lifesaving and potentially useful as a tool to influence cerebral oxygenation and hemodynamics, invasive mechanical positive pressure ventilation is nonphysiological, carries the risk of side effects such as ventilation-associated

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pneumonia (VAP), and should be discontinued as soon as possible.[9] Timely liberating the NICU patient from ventilation not only helps prevent or ameliorate those pulmonary side effects but also enables neurological assessment, the patient's better environmental participation and stepping down from intensive care and into rehabilitation. Liberation from MV in its simplest and most desirable form means extubation. The readiness, timing, prognostication, management, and safety of extubating the NICU patient are the topic of this review. It will only briefly touch on general principles of ICU extubation and (re)intubation, and focus on the particular challenges in the NICU patient. It will hardly address modes or details of maintaining or weaning MV. It will not give a one-size fits of all answer to the title question, but rather suggest a systematic approach to this difficult but everyday dilemma to base individual decisions on.

Respiratory Failure in Neurological Disease

Although patients admitted to the NICU can certainly acquire respiratory compromise by ways not directly related to their neurological disease, there are distinct disease-related causes to be aware of. These can be grouped into central or peripheral causes of failure.

Central Respiratory Failure

Very different types of severe damage to the central nervous system, that is, supra- and infratentorial brain or spinal cord lesions due to traumatic, vascular, infectious/inflammatory, metabolic, neoplastic, or seizure-related disorders, can cause respiratory failure. The central respiratory centers, that is, those in the cortex and the autonomic centers in pons and medulla, as well as their connections between each other and to the phrenic nerve and the upper motor neurons, can be affected at every level. This does not necessarily only result in loss of respiratory drive or respiratory rhythm but might also cause loss of protective airway reflexes and airway patency and thus impair ventilation. Specific patterns of pathologic breathing (e.g., Cheyne–Stokes, Cluster, and Biot) have been suggested for topographic diagnosis of lesion levels, although that correlation appears somewhat unreliable in clinical practice.

Mechanisms of respiratory failure depend on types and location of pathology, listed incompletely in the following. Impaired respiratory drive may be caused by lesions to pons or medulla, such as after basilar artery occlusion or brain stem intracerebral hemorrhage (ICH), by brain stem compression via raised intracranial pressure (ICP) in brain edema, by neurotransmitter imbalance/diffuse brain dysfunction in encephalopathy, encephalitis, or status epilepticus, or by sympathetic overdrive as in subarachnoid hemorrhage (SAH) or the early phase of developing brain death. Impaired airway and ventilatory control may be caused by lesions to the brain stem swallowing centers, dysphagia, loss of glossopharyngeal muscle tone such as in brain stem stroke or traumatic brain injury (TBI), by lesions to the reticular formation or bilateral thalami, large areas hemispheric lesions/hydrocephalus with subsequent coma and loss of protective airway reflexes in many sorts of etiologies, by vomiting, dysphagia, aspiration, and by neurogenic pulmonary edema as in SAH. Impaired ventilation mechanics may be caused by high (above C3–5) spinal cord lesions that reduce the ventilatory force to accessory neck muscles as in trauma, ischemia, or myelitis.

Peripheral Respiratory Failure

The connections (phrenic nerve, lower motor neurons) to the respiratory muscles, that is, diaphragm (80% of ventilatory force), intercostal, and accessory muscles, can be affected by inflammatory, toxic, or degenerative disorders. Inflammatory neuromuscular diseases and myopathies are other causes of peripheral respiratory failure. It has to be kept in mind that the control of respiration is intact, while the efferent part of the system is compromised, which has implications for the type and setting of MV, as well as for strategies to discontinue it.

Peripherally impaired ventilation mechanics may be caused by lesions to anterior horn cells as in degenerative anterior horn cell disease, or by lesions to the phrenic nerve or other lower motor neurons, as in trauma, tumor, motor neuron disease (e.g., amyotrophic lateral sclerosis [ALS]), Guillain–Barré's syndrome (GBS), and critical illness myopathy/polyneuropathy (CIM/CIP).

Principles of General ICU Airway Management to Discontinue Ventilation

General principles for airway management in nonneurological ICU patients have been presented in several instructive reviews.[10,11] Safe extubation can only be tried if intubation even under difficult and ICU conditions can be mastered. This means that (re)intubation has to be addressed before extubation is considered or tried.

Managing the (Difficult) Airway in the ICU

Problems of intubation and extubation most often arise if the patient has a difficult airway. The reader is further directed to reviews on this particular topic,[12] including the recommendations of the American Society of Anesthesiologists[13] and the Difficult Airway Society that contain very helpful algorithms.[14,15] Since these guidelines primarily refer to the operation room (OR) situation, they have to be adapted to fit the ICU scenario. Airway management in the ICU or the emergency room (ER) is different from the OR situation. Twenty percent of all critical incidents in the ICU are airway related,[12] and difficult (re)intubation is encountered in the non-OR setting in approximately 10% (about twice as often as in the OR setting).[11] Relevant complications associated with difficult airway management are severe hypoxemia, severe hypotension, esophageal intubation, aspiration, cardiac arrest, and death, reported at rates between 5 and 40%.[11] A prospective registry for England and Wales between 2005 and 2007 revealed more than 1,000 reported airway incidents in the ICU, 18% at intubation, 5% during tracheostomy placement, and 82% as postprocedural problems.[16] Implementations of difficult airway algorithms were shown to half the number of intubation-related cardiac arrest[17] or substantially reduce the number of overall complications.[18] If a patient is to be extubated, the treating physician has to strive for information on whether that particular patient has a known difficult airway and/or presented difficulties on intubation previously.

Optimally, every airway should be regarded difficult in the ICU setting, and the situation "can't ventilate, can't intubate" anticipated, avoided, or at least managed adequately. The following environmental factors can make ICU/ER airway management a particular challenge: time pressure, a changing team of caregivers that might not have worked together often before, insufficient lighting, suboptimal patient position in the ICU bed, limited physiologic reserve of the patient, or an uncooperative patient, for example, with a reduced level of consciousness. Patient factors predicting a difficult airway are obesity, small mouth, large tongue, prognathia or dental abnormalities, mandibular joint dysfunction, facial burns, facial trauma, cervical trauma, cervical immobility/abnormality, short neck, high/anterior larynx, deep vallecula, or abnormal epiglottis/subglottis.

There are multiple means, techniques, and devices for securing an airway, the choice of which depends on the severity of the situation, the setting, the skills of the team, and on patient factors.[10,11] Most importantly, the techniques by which the airway is secured need to be practiced under supervision, and the care team needs to familiarize itself with the devices present in the ICU/ER. For extubation and reintubation, this includes bridging devices such as exchange catheters. Some traditional customs of airway management have recently been questioned. The so-called sniffing position for (re)intubation that is meant to align oral, pharyngeal, and laryngeal axes did not appear to be superior to simple head extension in magnetic resonance imaging and clinical randomized studies. The "sniffing position" might have advantages in obese and neck-fixed patients, but optimal positioning has not been clarified for ICU airway management. Among the many techniques and devices available, noninvasive mask ventilation might be the most important one. At least one supraglottic airway device should also be present and familiar, in case (re)intubation fails and has to be bridged by these devices (for instance, a laryngeal mask) that can later be used as a conduit for endotracheal (re)intubation. Laryngoscope blades for tube loading, augmented by video-/fiberscopic or patented lens systems can also be helpful and should be at hand.[11]

Discontinuing Airway Protection

After re-establishment of spontaneous breathing (see later), sufficient swallowing, and brain stem reflexes, that is, with the patient's regained ability to protect their own airway unaided, airway protection can be discontinued.[19] Extubation is the procedure to be aimed for as soon as possible, but it can be risky and its timing is very difficult in the ICU, particularly if the patient had presented a difficult airway before (see earlier). Between 5 and 10% of extubated general ICU patients require reintubation.[10,12] Reasons comprise dysfunctional airway reflexes, prolonged effects of analgesics and sedatives, reduced pharyngeal tone, occluded airway, reduced oxygen stores, laryngeal edema, respiratory exhaustion, etc. Both reintubation after failed extubation and delayed extubation are associated with a longer ICU length of stay (ICU-LOS), more infections, and higher mortality.[20] Removal of the orotracheal tube to allow spontaneous breathing and airway protection requires a successful weaning process and spontaneous breathing trials (SBTs) (see later), a back-up strategy for reintubation and at best the following parameter targets (►**Table 1**).

A cuff-leak test demonstrating the absence of air leak on deflation of the tube cuff can indicate laryngeal edema and subsequent extubation failure (EF),[21,22] although some studies have not confirmed this. It is probably a useful additional criterion to guide the extubation decision. Laryngeal edema has been subjected to pre-extubation treatment with steroids. After decades of controversy on this practice, a recent systematic review and a Cochrane analysis have confirmed that short-term prophylactic corticosteroids reduce EF in adult critical care patients.[23,24] Another safety practice is to apply an exchange catheter and leave it in place for a while after extubation to allow for easier reintubation.

Principles of Mechanical Ventilation Related to Airway Discontinuation

Few of the basic principles of modern ICU ventilation have a relation to extubation. Although lifesaving and indispensable in most cases, positive pressure MV is a nonphysiological procedure that carries risks such as shear stress and barotrauma to the lung, VAP, atrophy of respiratory muscles, and stress and agitation in the patient. Its duration should hence be kept as short as possible. The option to discontinue MV has to be evaluated every day.[19]

No particular mode of ventilation has proven superior over another in studies on patient outcomes. However, being able to choose from different modes can be helpful in addressing the individual patient's ventilation needs. One

Table 1 Classical criteria for the general ICU suggesting a successful extubation

Patient awake and cooperative, high Glasgow coma scale ($>$ 8)
Good coughing and swallowing
Tube intolerance
Spontaneous breathing (30 minutes) with $PaO_2 > 60$/increase $PaCO_2 < 15$ mm Hg
Low respiratory rate (RR $<$ 30/min)
Adequate tidal volume (Vt $>$ 5 mL/kg)
Rapid shallow breathing index (RSBI $<$ 105)
Minute volume (MinV ca. 10 L)
PaO_2/FiO_2 ratio 150–200

Abbreviations: ICU, intensive care unit; MinV, minute volume; RR, respiratory rate; RSBI, rapid shallow breathing index; Vt, tidal volume.

should aim for letting the patient take part actively in the ventilation process, that is, establish an assisted (as opposed to a fully controlled) ventilation mode as soon as possible. The reasons are that on fully controlled ventilation, more sedation and at times neuromuscular blockers are needed, and respiratory muscle atrophy and CIM/CIP start to develop within the first day of ventilation.[25]

Noninvasive ventilation can help avoid endotracheal (re) intubation but is largely reserved for cooperative patients with respiratory compromise by exacerbated chronic obstructive pulmonary disease (COPD), asthma, or cardiogenic pulmonary edema. It may well serve to facilitate liberation from MV and stabilization of spontaneous breathing after extubation,[26] and may hence be planned as a transition phase before permanent spontaneous breathing. It can be an effective strategy in myasthenia gravis (MG), cautious application provided, but may be less successful in GBS.[27] Extubation to noninvasive ventilation in chronic neurodegenerative or neuromuscular disease is beyond the scope of this article.

Weaning

Liberating the patient from the respirator (weaning) can be very challenging, especially in patients with underlying pulmonary disease and after prolonged ventilation periods.[19,28–31] The weaning period is often exhausting for the patient both physically and mentally, and is associated with a high incidence of delirium. The optimal method of weaning has not been clarified. Principally, patients can be put on an assisted ventilation mode and the support from the respirator be gradually reduced (continuous mode of weaning), or MV can be interrupted by phases of spontaneous breathing and the intervals extended over time (discontinuous mode of weaning). Of two randomized trials, one supported the first[32] and the other the latter;[33] the ventilation mode appearing the least helpful in weaning was the (synchronized) intermittent mandatory ventilation mode in both trials. The question might have to be clarified in particular subgroups of patients.[34]

Principles of NICU Airway Management to Discontinue Ventilation

Although many of the general ICU principles described earlier may be adopted for the neurological or neurosurgical ICU patient, some particularities have to be emphasized. A lot of patients with centrally caused respiratory failure do not primarily have a problem with lung mechanics but with respiratory coordination and airway protection, the latter by way of reduced voluntary clearing of the airways in stupor or coma, loss of pharyngeal and glossal muscle tone, or dysphagia and/or loss of protective reflexes. Peripheral, that is, neuronal or neuromuscular disease such as GBS, ALS, or MG crisis, can cause severe impairment of lung mechanics, but may also cause airway compromise by way of reduced capacity to cough, swallow, and thus handle saliva and secretions. In a NICU patient planned for extubation, these compromises have to be prepared for but may be difficult to predict.

Weaning

Weaning from the respirator should certainly not be delayed in NICU patients, be they comatose or not, although it seems to be often delayed in the former.[8] The best method of weaning, that is, continuous versus discontinuous, is unclear (as in general ICU patients). Discontinuous weaning methods, however, involve successive SBTs and thus wake-up trials. These have been associated with a release of stress hormones[35] and rises in ICP[36,37] in brain-injured patients, particularly those with a higher ICP from the outset.[38] In a small randomized pilot study in ventilated patients with severe stroke, patients weaned by a gradual (continuous) weaning method had a shorter duration of ventilation.[39] It may be reasonable to try SBTs in patients fulfilling the general criteria allowing these (see later), but refrain from further SBTs if they are accompanied by ICP crises or other physiological derangements, and in that case, it might be best to change to a continuous weaning method. In a subgroup of NICU patients, such as those with advanced ALS or extensive brain stem injury, weaning will not be successful. In those cases, tracheostomy and long-term ventilation might be adequate, if this is the patient's or family's will.

The application of weaning protocols appeared superior compared with unsystematic weaning in different subgroups of ICU patients over the past 10 years. Predictors of a successful weaning in the general ICU population have been identified, among these the rapid shallow breathing index (RSBI, RR/Vt), maximal inspiratory pressure (Pi max), and minute volume,[40] as well as a passed SBT.[31] These parameters have not been established in the NICU population but may be adapted and tried for a first orientation. The weaning process has to go hand-in-hand with de-escalation of sedation, optimally according to a sedation protocol. The steps in ►**Table 2** can help successfully wean an ICU patient from the respirator and eventually extubate or tracheostomize him/her.

Reintubation

Since extubation in NICU patients fails more often than in general ICU patients (see later), there has to be a high awareness and adequate preparation for reintubation. Principally, the general ICU criteria for (re)intubation listed earlier apply to neurocritically ill patients as well. Details of (re)intubation in these patients have hardly been studied systematically. Some considerations on certain subgroups, situations, and pathophysiology deserve mention.

The need to continue invasive MV in the NICU patient with central respiratory failure may become obvious rapidly, with fast emergence of indicators of respiratory failure. It may be less obvious, however, in peripheral neuronal or neuromuscular disease, where respiratory failure can evolve in a more gradual fashion and then suddenly turn into an emergency situation.[41] Patients with GBS, botulism, MG, Lambert–Eaton myasthenic syndrome, ALS, or CIP/CIM need to be monitored very closely after extubation. The following are warning signs of peripheral respiratory failure (►**Table 3**).

In these patients, noninvasive ventilation may help compensate a respiratory crisis and avoid (re)intubation. This has

Table 2 Suggested steps in discontinuation of (N)ICU ventilation and airway protection

Systemic and respiratory criteria for readiness to wean	Improvement of underlying disease	
	No indication for mechanical ventilation	
	No invasive procedure planned in near future	
	No fever, no raised ICP	
	No or little sedation	
	No delirium	
	No metabolic/electrolyte derangements	
Application of a weaning protocol	Continuous weaning mode OR discontinuous weaning mode (controlled or control/assist mode + SBTs)	
Criteria for initiating a spontaneous breathing trial	Respiratory criteria	$SatO_2 > 90\%$
		$PaO_2 > 60$ mm Hg on $FiO_2 < 0.4$ ($PaO_2/FiO_2 > 150–200$)
		$PaCO_2$ normal or baseline
		PEEP < 8 cm H_2O
		P insp < 20 cm H_2O
		Pi max > − 20 cm H_2O
		RSBI (RR/Vt) < 105
		RR < 35/min
		Vt > 5 mL/kg
		MV < 10 L/min
	Cardiovascular criteria	No signs of cardiac ischemia or arrhythmia
		HR < 140 beats/min
		SBP 90–160 mm Hg on no or minimal vasopressors
	Neurological criteria	Ideally, patient awake (RASS 0 or −1, GCS > 8)
		Ideally, patient cooperative
		Cough and gag reflexes present
		No excessive saliva/secretions
Spontaneous breathing trial for 30 min	Documentation of events at 5, 10, 20, and 30 min	
	Settings on respirator	Ventilation mode PSV (or similar)
		PEEP < 8 cm H_2O
		No ATC
		Tube diameter > 7 mm
		Flow trigger < 3 L/min
	OR patient off respirator and application of T-piece	
	Criteria to abandon SBT	Anxiety and/or agitation (RASS > +2), sweating
		Decline in level of consciousness (RASS < − 2)
		Markedly increased work of breathing (use of accessory muscles)
		Rapid breathing with decreasing Vt and without decreasing $PaCO_2$
		Cyanosis
		Hemodynamic instability
		HR 140 beats/min or increase 20% from baseline
		SBP > 180 mm Hg or increase 20% from baseline
		Ventilation and oxygenation
		RSBI (RR/Vt) > 105
		RR < 7/min OR > 35/min or increase 50% from baseline
		$SatO_2 < 85\%$
		$PaO_2 > 50–60$ mm Hg on $FiO_2 > 0.5$
		$PaCO_2 > 50$ mm Hg or increase > 15 mm Hg

Table 2 (*Continued*)

Spontaneous breathing trial for a longer period	
Extubation (criteria see above) if SBT was passed	
Return to weaning protocol if extubation failed	
Another extubation trial OR tracheostomy	
Weaning after tracheostomy, applying the previous steps	
Criteria for decannulation	Same as for extubation
	Ensure intact swallowing, e.g., by endoscopic swallowing test
Decannulation	

Abbreviations: ATC, automatic tube compensation; FiO_2, inspiratory fraction of oxygen; GCS, Glasgow coma scale; HR, heart rate; ICP, intracranial pressure; MV, minute volume; (N)ICU, (neuroscience)intensive care unit; $PaCO_2$, arterial pressure of carbon dioxide; PaO_2, partial arterial pressure of oxygen; PEEP, positive end-expiratory pressure; P insp, inspiratory pressure; Pi max, maximal inspiratory pressure; PSV, pressure support ventilation; RASS, Richmond agitation sedation scale; RR, respiratory rate; RSBI, rapid shallow breathing index; $SatO_2$, arterial saturation of oxygen; SBP, systolic blood pressure; SBT, spontaneous breathing trial; Vt, tidal volume.

been shown particularly in patients with MG crisis. Case reports and series on noninvasive ventilation in GBS also exist. However, most severe GBS cases require long-term invasive ventilation. Noninvasive ventilation is very time consuming, requires a higher therapist–patient ratio, wakefulness, and cooperation on the side of the patient, as well as fairly compensated blood gas and acid–base parameters and the presence of airway protective reflexes. Other than in MG crisis, it might be applicable in ALS, intoxications, as a support in weaning (see later) and to treat mild exacerbations of COPD and cardiogenic pulmonary edema. It can also be used in some less severely afflicted stroke patients, but outside these situations, it plays a minor role in neurocritically ill patients.[27] In a recent multicenter study on ventilation management in ~4,968 ICU patients, noninvasive ventilation was used in only 1% of the 938 neurological patients, compared with 12% in the others.[8]

(Re)Intubation almost always involves an episode of hypotension, or at least variance in blood pressure. This can be detrimental in cerebrovascular disease, where cerebral autoregulation is impaired and systemic hypotension translates directly into decreased cerebral perfusion pressure. Such hypotension during pharmacological induction for intubation has been found to be more common in patients with more severe underlying disease, a baseline MAP $<$ 70 mm Hg, age $>$ 50 years and with the use of propofol or increasing doses of fentanyl as inductor drugs.[42] Thiopental is another agent often causing hypotension. Therefore, the less vascular-active etomidate may be more appropriate for induction in cerebrovascular patients; it can be accompanied by fasciculations that should not be mistaken for seizures. Ketamine as an alternative induction agent was suggestedly associated with increases in ICP, but this was not confirmed in several subsequent studies. In fact, it decreased ICP in many of these. Contrary to other sedatives, ketamine does not have depressing but rather activating circulatory effects. It can thus cause tachycardia and hypertension and should not be used in patients already in the upper ranges of these parameters.

(Re)Intubating head trauma patients can be very challenging, not only in the case of facial trauma with direct airway involvement but because ~10% have associated cervical spine injury. Airway management in all trauma patients in which ruling out cervical injury by imaging has not taken place in the ventilation period (i.e., after inadvertent or self-extubation) must involve in-line traction and stabilization of the neck (by hands of an assistant and then by stiff neck device/cervical collar). As conventional laryngoscopy and intubation might be difficult or impossible in that situation, fiberoptic intubation, if feasible, should be preferred. Alternatively, one should soon proceed to cricothyroidotomy, particularly if major facial or airway trauma is present.

Extubation

The question of when a NICU patient is ready to be safely extubated is very difficult to answer. It is clear that extubation can only be considered in patients who are respiratorily reconstituted, sufficiently oxygenated, and cardiocirculatorily stable. One relevant problem, however, is that the above-named classic extubation criteria from the general ICU apply to an awake and cooperative patient, something rarely encountered in the NICU where patients might present with aphasia, anarthria, apraxia, agitation, delirium, or a reduced level of consciousness, depending on their brain lesion. Even patients with neuromuscular disease or CIP/CIM that should principally have the cerebral capacity to fulfill these criteria, can develop delirium, psychosis, mutism, cranial nerve-

Table 3 Warning signs of neuromuscular respiratory failure

Decreased VC (critical VC < 20 mL/kg)
Prolonged exhalation time
Interrupted speech, dyspnea at low levels of exertion
Attempted compensation by increased RR (RR > 20/min)
Inability to count to 20 on one breath (approx. 1 L VC)
Loss of strength in neck flexors and proximal muscles
Abdominal paradox breathing (abdomen retracts on inspiration)
Weak cough
Lost intrinsic sigh
Decreased maximum inspiratory pressure (< −30 cm H_2O)
Decreased maximum expiratory pressure (< 40 cm H_2O)
Increased work of breathing
Restlessness
Tachycardia (> 100 beats/min)
Forehead sweating
Use of accessory respiratory muscles (sternomastoid)
Sitting upright to breath
Hypoventilation with hypercapnia (late sign of decompensation)
Hypoxia

Abbreviations: RR, respiratory rate; VC, vital capacity.

related communication deficits, agitation, and especially anxiety (at times a kind of ventilator dependency), making the extubation decision similarly challenging. Extubation therefore is often delayed in NICU patients.[8] Another problem is the difficulty in predicting neurological compromise of airway functions.

Classical extubation criteria have not reliably predicted EF in NICU patients in several studies, and EF occurs far more often than in nonneurological ICU patients, that is, at a rate of 15 to 35% in patients with brain lesions[8,43–46] and 30 to 40% in patients with neuromuscular disease such as MG.[47] A selection of these studies will be presented in more detail in the following.

Regarding pathologies with predominantly centrally caused respiratory failure, Anderson et al prospectively studied 285 extubations in 378 NICU patients with predominantly cerebral pathologies (such as acute ischemic stroke, ICH, SAH, TBI). They found EF in 17%, associated with patient baseline factors, duration of MV, presence of COPD, and obstructive sleep apnea. Predictors of extubation success were viscosity of secretions and the ability to follow four simple commands.[44] An almost identical rate of EF (17.5%) was found in a retrospective study by Ko et al in 62 mixed, again cerebrally affected, NICU patients. Classical ICU weaning/extubation criteria did not help predict EF.[43] The subgroup of NICU patients with severe stroke has received particular research interest. In a retrospective review of 112 NICU stroke patients, Lioutas et al found that a National Institutes of Health Stroke Scale Score < 15 (milder strokes) and absence of dysarthria prior to intubation were independently associated with extubation success, but classic ICU extubation criteria were not.[48]

In another retrospective study in NICU patients with middle cerebral artery infarction, 10 of 47 failed extubation, while the rest was extubated successfully. Extubation success only trended more likely in patients with a Glasgow coma scale (GCS) ≥ 8, and other classic extubation criteria were again not helpful.[45] In the only prospective study on extubation prediction in NICU stroke patients to date, 185 very severely affected patients (80% ischemic, 20% hemorrhagic stroke) were first triaged for attempting extubation by certain criteria (GCS >8, no elevated ICP, systolic blood pressure 90–185 mm Hg, heart rate between 60 and 120 bpm, body temperature 36–38.5°C, spontaneous respiratory minute volume [≤ 12 L], positive end-expiratory pressure [≤ 5 mm Hg], PaO_2/FiO_2 [>200], and RSBI <105). If these were not met, patients were primarily tracheostomized (47%). These had more severe strokes, more often of the hemorrhagic type, presented with a lower level of consciousness, needed neurosurgical intervention more often, were more often obese, and had been more frequently intubated because of suspicion of compromised protective reflexes. A subgroup of patients was additionally assessed by a previously established semiquantitative airway score[49] containing the parameters spontaneous cough, gag, sputum quality, and quantity. Of 98 patients primarily extubated, 37% failed extubation, that is, had to be reintubated within 72 hours. EF was independently predicted by prior neurosurgical treatment and a low airway management score. No differences were found for the ability to follow simple commands and classic weaning criteria. The authors concluded that criteria more closely related to extubation success in NICU stroke patients relate to airway safety and secretion handling, and proposed that specific clinical scoring systems should be established.[50]

Regarding peripherally caused respiratory compromise, Wu et al retrospectively evaluated 41 episodes of myasthenic crisis in 199 MG patients, 33 of whom needed MV. EF was as high as 39%, predicted by poor cough and sputum impaction. An independent predictor of extubation success was a maximal expiratory pressure of > 40 cm H_2O.[47] EF rates in similar magnitude and similar predictors (cough or expiration force) were reported in other studies on airway management in myasthenic crisis.[51,52] In a retrospective study on airway management in 44 patients with GBS, 14 were successfully extubated (associated factors were lower negative inspiratory force [< −50 cm H_2O] and higher/improving vital capacity), 20 received tracheostomy, and 10 (23%) failed extubation. Predictors of the latter were pulmonary comorbidities, autonomic dysfunction, and NICU-LOS.[53]

In a recent systematic review and meta-analysis involving nine studies on 928 mixed neurocritical care patients, Wang et al found the following predictors of EF: pneumonia, atelectasis, duration of MV > 24 hours, thick secretions, and the neurological ones low GCS, inability to follow commands (especially to close the eyes), and absent gag reflex. Interestingly, responding to particular commands and coughing were not predictive in that study.[54] In another very recent prospective study, 140 brain-injured patients were analyzed for extubation if they first passed a SBT successfully. EF was 31%, and predictors were upper-airway function (cough, gag reflex, deglutition) and neurological status (Coma Recovery Scale-revised visual subscale). The authors formed a prediction score based on the odds ratios and internally validated it by bootstrap methodology. With a cutoff at sensitivity 92%, specificity 50%, positive predictive value 82%, and negative predictive value of 70%, the interesting observation was made that extubation was successful in 85% with a low consciousness level, if at least two airway functions were operating.[55] It will be very interesting to validate that score externally, preferably in certain NICU subgroups.

Of note, delaying extubation in NICU patients for not meeting classic extubation criteria, especially the one regarding consciousness, leads to complications such as more VAPs and prolonged ICU-LOS, while earlier or later extubated patients do not seem to differ with regard to the reintubation rate.[49] In a small prospective randomized pilot trial in 16 brain-injured NICU patients, there was no difference in complications or functional outcome at discharge between patients extubated immediately after meeting respiratory extubation criteria and those re-evaluated and extubated later because of coma.[56] Although details and benefits of (early) extubation in NICU patients await further prospective research, coma should not be the reason to withhold weaning or extubation from these patients. Rather, particular attention should be paid to presence of dysphagia, which is much more frequent in the NICU population.[57] Endoscopic swallowing tests that not necessarily require cooperation of the patient have been successfully applied in stroke patients, and might help guide the extubation decision in other NICU patients as well.[58]

In summary, nonspecific (i.e., nonneurological) variables such as sputum impaction, secretion load and viscosity, duration of ventilation, or underlying diseases such as COPD seem

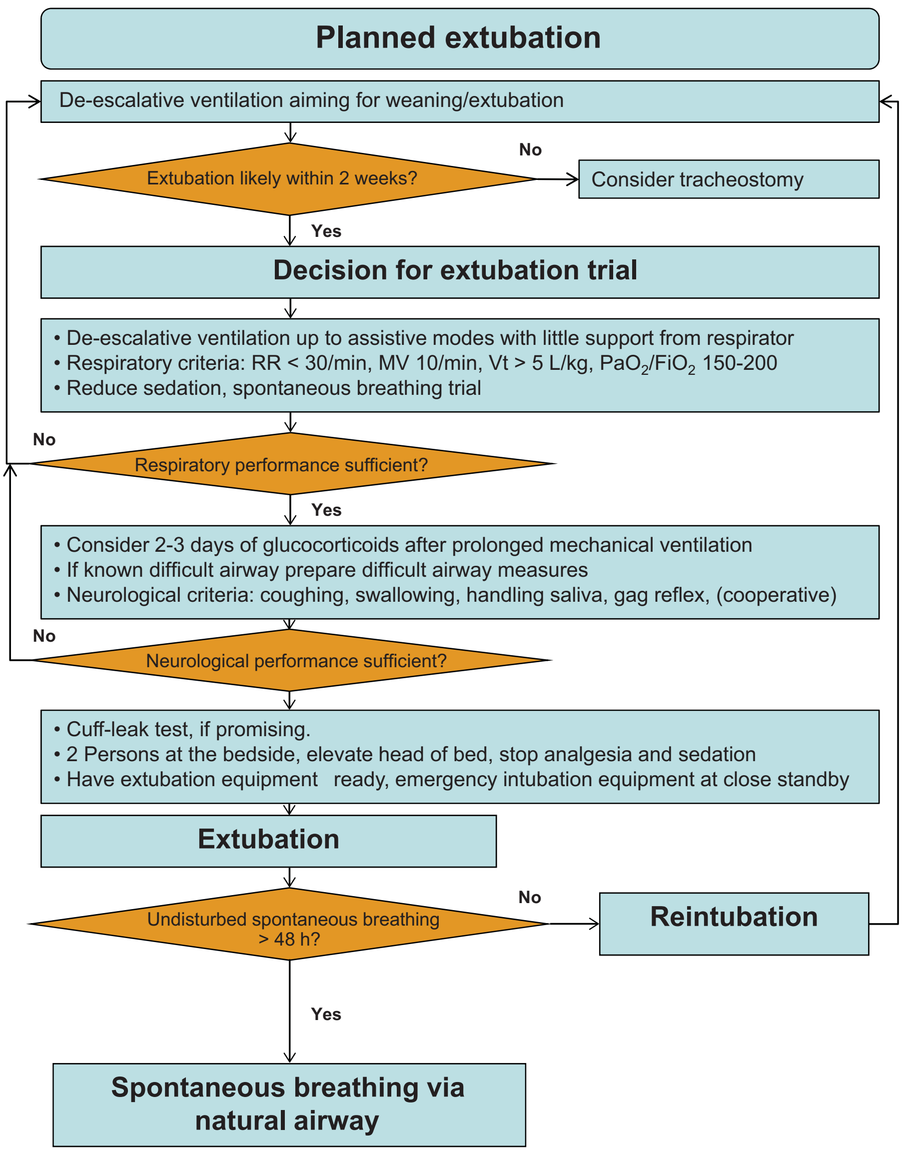

Fig. 1 Suggestion for approaching extubation in the neuroscience intensive care unit.

to play a more predictive role for EF. With some controversy, a few disease-specific positive predictors of extubation success were the ability to follow simple commands or a higher GCS in the brain-lesioned patients, and a strong cough in the neuromuscular patients. More and larger prospective studies are clearly and urgently necessary to clarify safety of extubation in the NICU patient. At present, a stepwise approach involving a protocol should be applied based on current experience and evidence and is outlined in ►**Fig. 1**.

Tracheostomy after Extubation Failure

It is quite customary to proceed to tracheostomy after the first or at the latest after the second failed extubation in NICU patients. While 10 to 20% of general ICU patients receive a tracheostomy during their stay, this rate is ∼35 to 45% in NICU patients.[8,59] This may again reflect that neurological ICU patients often are not compromised with regard to their pulmonary function but rather to their capacity to protect the airway and handle secretions. Tracheostomy in the NICU, particularly in cerebrovascular patients, is beyond the scope of this article and has been reviewed.[60,61]

Sometimes it becomes apparent within the first week of ventilation that NICU patients will have to receive a tracheostomy in their clinical course, such as in those with severe axonal GBS rapidly proceeding to tetraplegia or others with extensive brain stem damage. If such a situation is not judged overall futile, the patient's and family's will is in accordance, and if the care team is convinced that tracheostomy is necessary, there is no reason why this should be delayed, at times not even by an extubation trial.

Summary

In addition to common reasons for EF known from the general ICU (respiratory performance insufficient, prolonged duration of MV, postextubation laryngeal edema, etc.), the NICU patient may present with particular causes of EF, which are substantially more frequent (20–40%) in these patients. Causes of EF in the NICU include, depending on central or peripheral pathology, decline in level of consciousness, impaired cooperativity, low pharyngeal muscle tone, loss of protective reflexes, dysphagia, impaired handling of secretions, aspiration, weak cough, compromised respiratory muscle performance, etc. As classic extubation criteria do not take these into account but rather relate to pulmonary function, they are only of orientating value. As long as safe extubation in the NICU has not been clarified by sufficiently large prospective studies aiming at identifying particular criteria or prediction scores for NICU subgroup populations, extubation has to remain an extra cautious individual process involving stepwise protocols, back-up plans, and alternatives such as tracheostomy.

References

1 Berrouschot J, Rössler A, Köster J, Schneider D. Mechanical ventilation in patients with hemispheric ischemic stroke. Crit Care Med 2000;28(08):2956–2961

2 Steiner T, Mendoza G, De Georgia M, Schellinger P, Holle R, Hacke W. Prognosis of stroke patients requiring mechanical ventilation in a neurological critical care unit. Stroke 1997;28(04):711–715

3 Wijdicks EF, Scott JP. Causes and outcome of mechanical ventilation in patients with hemispheric ischemic stroke. Mayo Clin Proc 1997;72(03):210–213

4 Mayer SA, Copeland D, Bernardini GL, et al. Cost and outcome of mechanical ventilation for life-threatening stroke. Stroke 2000;31(10):2346–2353

5 Roch A, Michelet P, Jullien AC, et al. Long-term outcome in intensive care unit survivors after mechanical ventilation for intracerebral hemorrhage. Crit Care Med 2003;31(11):2651–2656

6 Rabinstein AA, Wijdicks EF. Outcome of survivors of acute stroke who require prolonged ventilatory assistance and tracheostomy. Cerebrovasc Dis 2004;18(04):325–331

7 Holland MC, Mackersie RC, Morabito D, et al. The development of acute lung injury is associated with worse neurologic outcome in patients with severe traumatic brain injury. J Trauma 2003;55(01):106–111

8 Pelosi P, Ferguson ND, Frutos-Vivar F, et al; Ventila Study Group. Management and outcome of mechanically ventilated neurologic patients. Crit Care Med 2011;39(06):1482–1492

9 MacIntyre N. Discontinuing mechanical ventilatory support. Chest 2007;132(03):1049–1056

10 Walz JM, Zayaruzny M, Heard SO. Airway management in critical illness. Chest 2007;131(02):608–620

11 Nolan JP, Kelly FE. Airway challenges in critical care. Anaesthesia 2011;66(Suppl 2):81–92

12 Lavery GG, McCloskey BV. The difficult airway in adult critical care. Crit Care Med 2008;36(07):2163–2173

13 Practice guidelines for management of the difficult airway. A report by the American Society of Anesthesiologists Task Force on Management of the Difficult Airway. Anesthesiology 1993;78(03):597–602

14 Henderson JJ, Popat MT, Latto IP, Pearce AC; Difficult Airway Society. Difficult Airway Society guidelines for management of the unanticipated difficult intubation. Anaesthesia 2004;59(07):675–694

15 Popat M, Mitchell V, Dravid R, Patel A, Swampillai C, Higgs A; Difficult Airway Society Extubation Guidelines Group. Difficult Airway Society guidelines for the management of tracheal extubation. Anaesthesia 2012;67(03):318–340

16 Thomas AN, McGrath BA. Patient safety incidents associated with airway devices in critical care: a review of reports to the UK National Patient Safety Agency. Anaesthesia 2009;64(04):358–365

17 Mort TC. The incidence and risk factors for cardiac arrest during emergency tracheal intubation: a justification for incorporating the ASA guidelines in the remote location. J Clin Anesth 2004;16(07):508–516

18 Jaber S, Jung B, Corne P, et al. An intervention to decrease complications related to endotracheal intubation in the intensive care unit: a prospective, multiple-center study. Intensive Care Med 2010;36(02):248–255

19 MacIntyre NR, Cook DJ, Ely EW Jr, et al; American College of Chest Physicians; American Association for Respiratory Care; American College of Critical Care Medicine. Evidence-based guidelines for weaning and discontinuing ventilatory support: a collective task force facilitated by the American College of Chest Physicians; the American Association for Respiratory Care; and the American College of Critical Care Medicine. Chest 2001;120(6, Suppl):375S–395S

20 Esteban A, Alía I, Gordo F, et al; The Spanish Lung Failure Collaborative Group. Extubation outcome after spontaneous breathing trials with T-tube or pressure support ventilation. Am J Respir Crit Care Med 1997;156(2 Pt 1):459–465

21 Ochoa ME, Marín MdelC, Frutos-Vivar F, et al. Cuff-leak test for the diagnosis of upper airway obstruction in adults: a systematic review and meta-analysis. Intensive Care Med 2009;35(07):1171–1179

22 Jaber S, Chanques G, Matecki S, et al. Post-extubation stridor in intensive care unit patients. Risk factors evaluation and importance of the cuff-leak test. Intensive Care Med 2003;29(01):69–74

23 McCaffrey J, Farrell C, Whiting P, Dan A, Bagshaw SM, Delaney AP. Corticosteroids to prevent extubation failure: a systematic review and meta-analysis. Intensive Care Med 2009;35(06):977–986

24 Khemani RG, Randolph A, Markovitz B. Corticosteroids for the prevention and treatment of post-extubation stridor in neonates, children and adults. Cochrane Database Syst Rev 2009;(03):CD001000

25 Latronico N, Bolton CF. Critical illness polyneuropathy and myopathy: a major cause of muscle weakness and paralysis. Lancet Neurol 2011;10(10):931–941

26 Keenan SP, Sinuff T, Burns KE, et al; Canadian Critical Care Trials Group/Canadian Critical Care Society Noninvasive Ventilation Guidelines Group. Clinical practice guidelines for the use of noninvasive positive-pressure ventilation and noninvasive continuous positive airway pressure in the acute care setting. CMAJ 2011;183(03):E195–E214

27 Rabinstein AA. Noninvasive ventilation for neuromuscular respiratory failure: when to use and when to avoid. Curr Opin Crit Care 2016;22(02):94–99

28 Nevins ML, Epstein SK. Weaning from prolonged mechanical ventilation. Clin Chest Med 2001;22(01):13–33

29 Scheinhorn DJ, Chao DC, Stearn-Hassenpflug M. Liberation from prolonged mechanical ventilation. Crit Care Clin 2002;18(03): 569–595

30 MacIntyre NR. The ventilator discontinuation process: an expanding evidence base. Respir Care 2013;58(06):1074–1086

31 Boles JM, Bion J, Connors A, et al. Weaning from mechanical ventilation. Eur Respir J 2007;29(05):1033–1056

32 Brochard L, Rauss A, Benito S, et al. Comparison of three methods of gradual withdrawal from ventilatory support during weaning from mechanical ventilation. Am J Respir Crit Care Med 1994;150 (04):896–903

33 Esteban A, Frutos F, Tobin MJ, et al; Spanish Lung Failure Collaborative Group. A comparison of four methods of weaning patients from mechanical ventilation. N Engl J Med 1995;332 (06):345–350

34 Vitacca M, Vianello A, Colombo D, et al. Comparison of two methods for weaning patients with chronic obstructive pulmonary disease requiring mechanical ventilation for more than 15 days. Am J Respir Crit Care Med 2001;164(02):225–230

35 Skoglund K, Enblad P, Hillered L, Marklund N. The neurological wake-up test increases stress hormone levels in patients with severe traumatic brain injury. Crit Care Med 2012;40(01):216–222

36 Skoglund K, Enblad P, Marklund N. Effects of the neurological wake-up test on intracranial pressure and cerebral perfusion pressure in brain-injured patients. Neurocrit Care 2009;11(02): 135–142

37 Helbok R, Kurtz P, Schmidt MJ, et al. Effects of the neurological wake-up test on clinical examination, intracranial pressure, brain metabolism and brain tissue oxygenation in severely brain-injured patients. Crit Care 2012;16(06):R226

38 Jaskulka R, Weinstabl C, Schedl R. [The course of intracranial pressure during respirator weaning after severe craniocerebral trauma]. Unfallchirurg 1993;96(03):138–141

39 Teismann IK, Oelschläger C, Werstler N, et al. Discontinuous versus continuous weaning in stroke patients. Cerebrovasc Dis 2015;39(5-6):269–277

40 Yang KL, Tobin MJ. A prospective study of indexes predicting the outcome of trials of weaning from mechanical ventilation. N Engl J Med 1991;324(21):1445–1450

41 Rabinstein AA, Wijdicks EF. Warning signs of imminent respiratory failure in neurological patients. Semin Neurol 2003;23(01): 97–104

42 Reich DL, Hossain S, Krol M, et al. Predictors of hypotension after induction of general anesthesia. Anesth Analg 2005;101(03): 622–628

43 Ko R, Ramos L, Chalela JA. Conventional weaning parameters do not predict extubation failure in neurocritical care patients. Neurocrit Care 2009;10(03):269–273

44 Anderson CD, Bartscher JF, Scripko PD, et al. Neurologic examination and extubation outcome in the neurocritical care unit. Neurocrit Care 2011;15(03):490–497

45 Wendell LC, Raser J, Kasner S, Park S. Predictors of extubation success in patients with middle cerebral artery acute ischemic stroke. Stroke Res Treat 2011;2011:248789

46 Vallverdú I, Calaf N, Subirana M, Net A, Benito S, Mancebo J. Clinical characteristics, respiratory functional parameters, and outcome of a two-hour T-piece trial in patients weaning from mechanical ventilation. Am J Respir Crit Care Med 1998;158(06):1855–1862

47 Wu JY, Kuo PH, Fan PC, Wu HD, Shih FY, Yang PC. The role of noninvasive ventilation and factors predicting extubation outcome in myasthenic crisis. Neurocrit Care 2009;10(01):35–42

48 Lioutas VA, Hanafy KA, Kumar S. Predictors of extubation success in acute ischemic stroke patients. J Neurol Sci 2016;368:191–194

49 Coplin WM, Pierson DJ, Cooley KD, Newell DW, Rubenfeld GD. Implications of extubation delay in brain-injured patients meeting standard weaning criteria. Am J Respir Crit Care Med 2000;161 (05):1530–1536

50 Steidl C, Boesel J, Suntrup-Krueger S, et al. Tracheostomy, extubation, reintubation: airway management decisions in intubated stroke patients. Cerebrovasc Dis 2017;44(1-2):1–9

51 Rabinstein AA, Mueller-Kronast N. Risk of extubation failure in patients with myasthenic crisis. Neurocrit Care 2005;3(03):213–215

52 Seneviratne J, Mandrekar J, Wijdicks EF, Rabinstein AA. Predictors of extubation failure in myasthenic crisis. Arch Neurol 2008;65 (07):929–933

53 Nguyen TN, Badjatia N, Malhotra A, Gibbons FK, Qureshi MM, Greenberg SA. Factors predicting extubation success in patients with Guillain-Barré syndrome. Neurocrit Care 2006;5(03):230–234

54 Wang S, Zhang L, Huang K, Lin Z, Qiao W, Pan S. Predictors of extubation failure in neurocritical patients identified by a systematic review and meta-analysis. PLoS One 2014;9(12):e112198

55 Godet T, Chabanne R, Marin J, et al. Extubation failure in brain-injured patients: risk factors and development of a prediction score in a preliminary prospective cohort study. Anesthesiology 2017;126(01):104–114

56 Manno EM, Rabinstein AA, Wijdicks EF, et al. A prospective trial of elective extubation in brain injured patients meeting extubation criteria for ventilatory support: a feasibility study. Crit Care 2008; 12(06):R138

57 Langmore SE. Dysphagia in neurologic patients in the intensive care unit. Semin Neurol 1996;16(04):329–340

58 Dziewas R, Warnecke T, Olenberg S, et al. Towards a basic endoscopic assessment of swallowing in acute stroke - development and evaluation of a simple dysphagia score. Cerebrovasc Dis 2008;26(01):41–47

59 Kurtz P, Fitts V, Sumer Z, et al. How does care differ for neurological patients admitted to a neurocritical care unit versus a general ICU? Neurocrit Care 2011;15(03):477–480

60 Lazaridis C, DeSantis SM, McLawhorn M, Krishna V. Liberation of neurosurgical patients from mechanical ventilation and tracheostomy in neurocritical care. J Crit Care 2012;27(04):417. e1–417.e8

61 Bösel J. Tracheostomy in stroke patients. Curr Treat Options Neurol 2014;16(01):274