Airway and Ventilation Management

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1 Introduction

More patients with severe neurological deficits are surviving because of improvements in the management of stroke, traumatic brain injury, resuscitation, and sepsis. Advances in neurology and neurosurgery enable survival for many patients with malignant ischemic stroke (when more than two-thirds of the area supplied by a cerebral artery is affected), intracerebral haemorrhage, or other intracranial masses. These patients are often so severely affected that they require mechanical ventilation and cannot be successfully weaned from ventilation during their stay at the acute admitting hospital (Rollnik et al. 2017).

While this book focusses on stroke, we have chosen to write this chapter with a broader perspective as critically ill patients with stroke share similarities and risks with patients having other neurological conditions. In Europe, neurological-neurosurgical early rehabilitation (NNER) centres provide care for such patients by bundling neurological, neurosurgical, intensive care, and neurorehabilitation expertise (Rollnik et al. 2017). These NNER centres have successfully proven themselves as a link between acute medical intensive care and rehabilitation and are also established as weaning centres for these severely neurologically ill patients (Rollnik et al. 2017; Pohl et al. 2016).

Patients relocated to weaning centres have been ventilated on average for more than 3 weeks in their primary care acute hospital (Oehmichen et al. 2012a). Their average age is older and they often have significant and multiple

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morbidities (Oehmichen et al. 2012a). Ventilation for this duration leads to muscular weakness in non-neurological patients through inactivity (disuse atrophy) and through pathologies such as critical illness neuropathy (CIP) or myopathy (CIM) (Oehmichen et al. 2012b; Prange 2004; Ponfick et al. 2014). Neurologic-neurosurgical early rehabilitants often show significant immobility and nursing dependency. They may have a centrally induced paralysis or neuromuscular disease that may considerably complicate the weaning process. In addition, these patients also suffer neurological or neurosurgical complications, e.g. increased intracranial pressure or epileptic seizures, that requires ongoing involvement of neurological-neurosurgical expertise in the early rehabilitation process. These patients thus require a special setting, such as that provided in neurological weaning and rehabilitation centres. Through the possibilities of neurologically oriented multi-professional rehabilitation, the goal of the best possible interaction can be achieved.

With regard to the technical processes of weaning and the pathophysiology of weaning failure, reference is made to guidelines on “prolonged weaning” (Schönhofer et al. 2014). These do not differentiate between weaning of neurological patients compared to non-neurological patients, e.g. those with primary pulmonary disease. Differences between these specialist weaning centres can be seen, however, both in terms of staffing (multi-professional rehabilitation team, neurological, and neurorehabilitation expertise) and the therapies used.

2 Clinical Evidence and Reasoning

There is no strong evidence base as to how a prolonged weaning stroke patient should be best managed. The few studies involving stroke patients have examined heterogeneous groups of patients and a small proportion of neurological or neuromuscular disorders. Neurological patients are often excluded from automated weaning programs by some ventilator manufacturers (Neumann and Schmidt 2018). Basically, three different methods are used (Schönhofer et al. 2014):

- Gradual reduction of pressure support.
- Combination of full and partial relief with phases of full load.
- Increasing phases of full load.

Which of these three methods, or a combination thereof, most benefit stroke patients is unclear (Ladeira et al. 2014). The use of so-called weaning protocols has not been studied in randomized controlled trials. In a recent PubMed search, the combination of terms “*weaning from mechanical ventilation*” AND “*stroke*” identified only 71 matches while the combination of “*prolonged weaning*” AND “*stroke*” identified only 28 matches. None however provided any evidence of optimal approach.

Thus, all the following recommendations are derived from guidelines or the experience of the authors in the context of good clinical practice.

2.1 Weaning of Neurological Patients

Weaning from mechanical ventilation generally takes between 40–50% of total mechanical ventilation time (Schönhofer et al. 2014). The duration of mechanical ventilation is associated with an increase in mortality and complication rates (Boles et al. 2007; Schönhofer et al. 2014). While the underlying condition of the patient obviously plays an important part, there is a significant iatrogenic contribution from ventilator-induced volu barotrauma, cardiovascular sequelae and hemodynamic, and immunosuppressive side effects of sedative agents. Safe and rapid withdrawal from the ventilator is therefore a top priority. According to an international consensus conference of 2005, a distinction is made between simple, difficult, and prolonged weaning (Boles et al. 2007, Schönhofer et al. 2014). Patients who need to be intubated and ventilated due to a neurological condition usually require prolonged weaning according to this definition (Rollnik et al. 2017).

Among patients with prolonged weaning, the initial reason for mechanical ventilation is an acute illness in more than half of the cases (Schönhofer et al. 2014). The cause of ongoing ventilation is however multifactorial, most commonly respiratory tract disorders, oxygenation problems, oxygen distribution disorders, and respiratory pump failure (Schönhofer et al. 2014). Respiratory muscle weakness is often related to critical illness polyneuropathy (CIP) and/or myopathy (CIM). These are diagnosed in one-third of patients with ARDS, one quarter of those who have ventilation duration of more than seven days, and more than two-thirds of patients with sepsis who require prolonged ventilation and hospitalization (Oehmichen et al. 2012b; Ponfick et al. 2014; Oehmichen and Ragaller 2012). In addition to these weakness syndromes acquired in the intensive care unit (ICU), other neurological and psychological consequences of intensive care management (e.g. delirium, post-traumatic stress disorder) also have an unfavourable influence on weaning (Oehmichen and Ragaller 2012; Rollnik et al. 2017).

Primary neurological conditions are also a frequent cause of prolonged weaning (Oehmichen and Ragaller 2012; Oehmichen et al. 2012a; Rollnik et al. 2010; Bertram and Brandt 2013). Twenty-seven percent of ventilated patients with underlying neurological-neurosurgical disorders were reported as experiencing “weaning failure” (Coplin et al. 2000; Oehmichen et al. 2012a).

Such patients may benefit from relocation to specialized facilities (weaning centres) (Rollnik et al. 2017; Schönhofer et al. 2014). In a retrospective study of 1486 patients enrolled in seven neurological weaning centres in 2009, the underlying causes of long-term ventilation were neurological in 69.2% of cases (52.6% central nervous, 45.2% peripheral neurological, 2.2% mixed), pulmonary in 22.8% of cases, and cardiac disorders in 3% (Oehmichen et al. 2012a). Neurological patients who could not be weaned from mechanical ventilation in primary care require a seamless continuation of rehabilitation measures in secondary care, taking into account an ongoing requirement for intensive care. These specialized NNER weaning centres fulfil specific tasks and requirements for the care of these long-term ventilated patients in order to ensure a parallel and early rehabilitation during their ongoing weaning process.

2.2 Existing Studies on Weaning Success

Uncontrolled studies in NNERs reported that prolonged weaning from mechanical ventilation is often successful (Oehmichen et al. 2012a; Rollnik et al. 2010; Hoffmann et al. 2006; Pohl et al. 2016). However, comparative studies examining, for example weaning of neurological patients with and without the intervention of NNER, are hard to achieve. In many countries, this would conflict with the right to rehabilitation guaranteed in social legislation.

The published literature mainly deals with descriptions of the approach to weaning, or provides expert opinions and conceptual representations (Bertram and Brandt 2013; Oehmichen and Ragaller 2012), retrospective data collections (Pohl et al. 2016; Oehmichen et al. 2012a; Rollnik et al. 2010), concepts of weaning (Oehmichen et al. 2013), or presentations of results for weaning in the context of neurological-neurosurgical early rehabilitation (Hoffmann et al. 2006; Bertram and Brandt 2007).

Table 1 shows results in various NNER weaning centres. Comparison of weaning rates to pneumological weaning centres is particularly difficult due to different admission criteria, inconsistent definition of a primary end point, and the therapeutic goal being sought (Oehmichen et al. 2012a; Rollnik et al. 2017). Comparability of results between different weaning centres can only be achieved if a consistent interdisciplinary dataset is developed. Process and result data must therefore be precisely defined. In our opinion, there is a pressing need for clarification, e.g. for a uniform allocation of essential treatment phases for hospital or rehabilitation treatment, a description of inclusion or rejection criteria for admission, criteria to

Table 1 Results from weaning studies in the field of neurological-neurosurgical early rehabilitation

Patient no.	Discharged weaned (%)	Discharged mechanically ventilated (%)	Mortality (%)	Author
193	66.8	20.2	12.9	Hoffmann et al. (2006)
133	78.2	5.3 ^a ? ^b	?	Bertram and Brandt (2007)
82	68.3	6.1 ^a /19.5 ^b	6.1	Rollnik et al. (2010)
1486	64.9	11.3 ^a /7.1 ^b	16.6	Oehmichen et al. (2012a)
644	59.5	9.8 ^a (8.2 ^c /1.6 ^d)/7.8 ^b	23.0	Oehmichen et al. (2013)
192	65.1	8.3 ^a /5.2 ^b	21.4	Pohl et al. (2016)

^aTo extended supply

^bRefer to hospital

^cInvasive mechanical ventilation

^dPatients with non-invasive ventilation

describe disease severity, a precise definition of weaning, and evaluation of results in relation to the therapeutic goal.

2.3 Difficulties in the Weaning Process

In prolonged weaning of neurological patients, the weakened “respiratory muscle pump” (resulting from peripheral and/or central paresis) and/or a respiratory drive disorder (from brain stem dysfunction) are of primary relevance (Rollnik et al. 2017). In addition to these primary neurological conditions, there may also be development of an ICU-acquired weakness syndrome (Ponfick et al. 2014; Pohl and Mehrholz 2013). Both may lead to pronounced weakness thereby complicating the weaning process (Rollnik et al. 2017). A third of patients transferred to an NNER facility had a main diagnosis of CIP or CIM (Oehmichen et al. 2012a; Pohl et al. 2016). The average age of patients in these centres was 63.7 years (Oehmichen et al. 2012a), thus relevant comorbidities are likely. As mentioned earlier, this particular study classified 22.8% of cases as having an underlying pulmonary cause for mechanical ventilation and 3% a cardiac cause (Oehmichen et al. 2012a).

2.4 Weaning Strategies

Weaning strategies are used with a combination of synchronized intermittent mandatory ventilation (SIMV) and/or pressure support ventilation (PSV) and/or progressively extended spontaneous breathing phases (Rollnik et al. 2017). However, it is known that respiratory muscle recovery does not occur through pressure-assisted ventilation or SIMV and that assisted spontaneous breathing modes may be more of a burden on the breathing pump due to ineffective triggering (Rollnik et al. 2017). Therefore, especially in cases of respiratory muscle pump weakness, weaning strategies with intermittent spontaneous breathing alternating with controlled mechanical ventilation should be used (Rollnik et al. 2017).

The question as to whether one ventilation mode is superior to another in weaning neurological/neurosurgical patients is currently uncertain due to a lack of studies. This question is also controversial in non-neurological patients or in unselected patient groups. Sample sizes are generally small and the use of now outdated technical equipment means that ventilation modes were not used in a way that would have allowed an exact separation between assisted spontaneous breathing and controlled ventilation. In more recent investigations, combinations of assisted spontaneous breathing (ASB) and controlled ventilation (assist-control ventilation and BIPAP) were used during the phases of controlled ventilation (Rollnik et al. 2017).

The aim of weaning in neurological patients is independent breathing, without equipment support. Non-invasive ventilation is used as a de-escalation therapy in patients with good swallowing function and persisting respiratory

pump insufficiency (Rollnik et al. 2017). To summarize, during prolonged weaning of neurological patients, weaning strategies can be used that incorporate progressively expanded spontaneous breathing phases, taking into account the underlying pathology and a constant re-evaluation of patient response. With disturbances in neuromuscular transmission, additional pressure support may be useful during the spontaneous breathing phases. Weaning in patients with central respiratory dysregulation disorders should be individualized, taking into account their underlying injury and regular adjustment according to patient response.

2.5 Weaning Protocols and Special Ventilation Techniques

Protocols are generally recommended when weaning long-term mechanically ventilated patients (Rollnik et al. 2017; Schönhofer et al. 2014). These should include a gradual extension of spontaneous breathing attempts. During spontaneous breathing, the patient is disconnected from the ventilator for temporary periods; this is intended to achieve recovery of respiratory muscles with replenishment of energy stores. Such weaning protocols are therefore used in all patients in neurological weaning centres, regardless of whether the patients are suffering from a central nervous disorder, a neuromuscular weakness, a primary hypoxic disorder due to pulmonary insufficiency, or a combination thereof.

Oehmichen et al. described in detail standardized extensions of spontaneous respiration phases (Oehmichen et al. 2013). The documentation of compliance with the protocol (i.e. individual steps in the development of spontaneous breathing phases) is made by the nursing staff. The medical team monitors protocol compliance (per daily documentation) and sets different individualised plans. They reported that this protocol was followed in 86% of ventilator-weaned patients. The authors thus concluded that the use of this spontaneous breathing protocol is well suited to successful weaning of neurological intensive care patients requiring prolonged weaning.

The central notion of all protocol-based weaning strategies is to check respiratory status daily and to continually adjust the plan for the next weaning steps. Whether such a procedure is the subject of a formal treatment protocol led by caregivers, or whether the process is ensured by a structured medical visit, seems to be of minor importance for the outcome but more dependent on the particular circumstances of an intensive care unit.

There is no evidence of superiority to the discontinuous cessation approach described above for continuous weaning in modes such as SIMV or BiLevel ventilation with a gradual reduction of pressure support (Bertram and Brandt 2013; Jubran et al. 2013).

Pressure-assisted spontaneous breathing—inspiratory pressure support of spontaneous breathing (IPS), assisted spontaneous breathing (ASB), pressure support ventilation (PSV)—is another spontaneous breathing mode suitable for weaning of neurological patients with an intact respiratory drive, for example those with severe

damage to the peripheral nervous system such as Guillain-Barré syndrome. Without disconnection periods, the muscular respiration pump can be trained by gradually reducing inspiratory pressure, i.e. a gradual “transfer” of ventilation to the patient takes place (Jubran et al. 2013). It is an alternative process to the discontinuous weaning protocols.

Adaptive support ventilation (ASV) is a modern advancement of mandatory minute ventilation (MMV) with a complex adaptive control taking into account the anatomical dead space. In experienced hands, this procedure allows compliance with pulmonary protection rules, targets minute ventilation, an optimal target breathing pattern (Otis formula), and a safe, patient-based weaning. However, no advantage has yet been shown over other modes for ventilated, tracheotomized patients (Bertram and Brandt 2013).

The intermittent use of CPAP in the late weaning phase may possibly assist with better alveolar recruitment in preventing atelectasis and reducing the work of breathing (Bertram and Brandt 2013). In the case of unsupported spontaneous breathing using a T-piece, automatic tube compensation (ATC) can compensate for an increased work of breathing due to tube resistance (Bertram and Brandt 2013). However, whether the use of these procedures in ventilated patients with neuromuscular weakness and/or respiratory drive disorders shortens the time of weaning or increases the weaning rate has not been adequately studied (Bertram and Brandt 2013). In general, unsupported spontaneous respiratory phases should be performed using a T-piece under close nursing control.

Neurally adjusted ventilatory assist (NAVA) is a “neuronal” controlled ventilation (Moerer et al. 2008; Navalesi and Longhini 2015). The support is synchronous and proportional to the activity of the diaphragm. The diaphragmatic activity is measured by a special electrode applied on a nasogastric tube. This is intended to achieve improved synchronization between the respiration trigger and the patient’s breathing demand in order to reduce false triggering and thus an increased work of breathing. In the case of this procedure, it is also unclear as to whether a shortening of the time to successful weaning or an improved outcome can be achieved (Moerer et al. 2008, Navalesi and Longhini 2015).

In principle, the frequency and duration of spontaneous respiration at the T-piece should be successively increased in a fixed step pattern. If successful, the patient can be moved to the next level, and in case of failure they can be moved back to the previous level or the same level re-applied (Bertram and Brandt 2013; Oehmichen et al. 2013). If this step scheme (or weaning protocol) cannot be met, it requires an individual, medically guided weaning plan with close patient surveillance (Bertram and Brandt 2013, Oehmichen et al. 2013).

Classic weaning protocols are aimed at rapid extubation of patients in intensive care units who are ventilated for longer than 24 hours. An important premise of these protocols is the presence of adequate alertness and the ability to assess the patient’s neurological status. Weaning and sedation protocols are thus often coupled (Girard et al. 2008). However, for neurological/neurosurgical patients, these conventional weaning parameters can only be used to a very limited extent, if at all

(Ko et al. 2009). This may be due to a lack of consideration of certain aspects of neurological/neurosurgical patients:

- As most prolonged weaning ventilated patients are already tracheotomised—between 91 and 96% (Pohl et al. 2016), there should not be a dichotomous yes/no decision to extubate but rather a plan involving gradual weaning from the ventilator. This is often achieved by daily extension of time without ventilator support.
- There are often problems with the respiratory pump/respiratory muscles, for example due to CIP/CIM. In contrast, pulmonary insufficiency (as in the case of the classic COPD patient) often plays only a subordinate role or, at most, represents comorbidity.
- The problems of reduced vigilance and neurogenic dysphagia are mostly completely disregarded.

A weaning protocol in neurological patients therefore has fundamentally different requirements compared to a conventional protocol. Examples of a weaning protocol used in the NNER can be found in the literature (Oehmichen et al. 2013).

2.6 Special Features of Prolonged Weaning in Neurological Patients

2.6.1 Definition of Successful Weaning from Mechanical Ventilation

In the respiratory literature, a weaning end point is inconsistently defined. Although non-invasive ventilation is recognized as full-fledged ventilation in the Diagnosis-Related Group (DRG) coding system (Institut für das Entgeltsystem im Krankenhaus (InEK GmbH) 2015), the respiratory literature often suggests that successful weaning is achieved after switching from invasive to non-invasive mechanical ventilation (Schönhofer et al. 2014). Thus, successful withdrawal from ventilation is equated to the removal of invasive ventilation access (endotracheal/tracheostomy tube). In contrast to these patients, the indication for an endotracheal/tracheostomy tube in neurological patients is not only for (invasive) ventilation but also often because of dysphagia and the risk of aspiration (see below). Thus, in principle, there are two indications for an endotracheal/tracheostomy tube.

Patients undergoing early neurological-neurosurgical rehabilitation are considered to have been successfully weaned from respiration if patients manage for at least 48 hours without any mechanical ventilation (Rollnik et al. 2017). Removal of the tracheal cannula occurs when there is no longer a risk of aspiration. This is one of the main differences between respiratory patients who rarely have such dysphagia, and neurological-neurosurgical early rehabilitants (Rollnik et al. 2017). The use of non-invasive ventilation, which plays a fundamental role in early extubation and successful weaning, plays a subordinate role in neurological-neurosurgical early rehabilitation as, in the majority of cases, there are

contraindications to this form of ventilation. Examples include lack of cooperation, retention of secretions with impaired/absent coughing, missing protective reflexes, central respiratory drive disorders, and complex dysphagia with risk of aspiration and/or disorders of gastric motility with frequent vomiting (Rollnik et al. 2017). Non-invasive ventilation (NIV) in these patients requires special expertise and close monitoring. It was used as an integral part of the weaning process in only 4.4% of patients according to the NNER study on ventilatory cessation in neurological weaning centres (Oehmichen et al. 2012a). Studies on the use of NIV with pressure support in neurological-neurosurgical patients are lacking. This application remains reserved for experts who are familiar with this type of ventilation and can afford the specific treatment risks and the considerable mechanical and, above all, human resources necessary.

2.6.2 Invasive and Non-Invasive Ventilation

Most patients are invasively ventilated when transferred to a neurological weaning centre—96.7% in one multicentre observational study (Oehmichen et al. 2012a), in whom 99.9% were ventilated via a tracheostomy (Oehmichen et al. 2012a). Comparable data were found in two other multicentre studies (Pohl et al. 2016; Hoffmann et al. 2006). It thus follows that neurological weaning centres need a structured approach to the handling and weaning of the tracheostomy tube.

Non-invasive ventilation (NIV) can be used for hypercapnic respiratory failure or global respiratory insufficiency. This has the advantage that a tracheostomy is avoided, thereby preserving the body's own filtering, moistening and warming of inhaled air. However, NIV with mask ventilation is only possible in cooperative persons without disturbances of consciousness, significant dysphagia and secretion clearance, and with intact swallowing reflexes. Accordingly, their use in neurological weaning centres is severely limited. Non-invasive ventilation should not be used in patients with neurogenic dysphagia or prolonged reduced vigilance and high aspiration risk (Rollnik et al. 2017). In these patients, a blocked-off tracheostomy tube should remain in situ until there is no danger of macro-aspiration (Rollnik et al. 2017). Swallowing status in patients with dysphagia should be determined by a controlled clinical examination (Rollnik et al. 2017).

2.6.3 Accompanying Neurological-Neurosurgical (Early) Rehabilitation

Weaning of neurological patients should always include (early) rehabilitation of various concomitant aspects to achieve the best possible patient participation (Rollnik et al. 2017). Examples include:

- Management of the tracheostomy tube.
- Dysphagia and secretion management.
- Treatment of patients with organic brain syndromes and neurocognitive dysfunction.
- Treatment of patients with spinal cord injury.

- Increasing independence in the activities of daily living.
- Accompanying therapies in neurological-neurosurgical early rehabilitation.
- Nursing techniques and activities.
- Psychological interventions.

3 Clinical Practice Recommendations for Weaning in Stroke Patients (and Other Patients with Neurological Conditions)

3.1 Methodological Explanations

In general, the recommendations given in this book, authorized by the World Federation for NeuroRehabilitation (WFNR), are accompanied by an indication of the level of evidence, e.g. from expert opinion (level 5) to systematic reviews (with homogeneity) of RCTs (level 1a). The overall quality of evidence supporting the recommendations ranges from “very low” when no systematic evidence is available to “high” when there is substantial high-quality evidence and when further evidence is unlikely to change the estimates of therapy effects (and harm). The grading of the recommendations will vary from “*can*” (option), e.g. when based on expert opinion only to “*ought to*” (strong recommendation) when based on high-quality evidence or clinically mandated for ethical reasons.

Levels of evidence for recommendations are indicated below using the “Oxford Centre for Evidence-Based Medicine (CEBM) Levels of Evidence” (version dating from March 2009, <http://www.cebm.net/Oxford-centre-evidence-based-medicine>). Here, the quality of evidence was rated into four categories according to the “GRADE” (“Grades of Recommendation, Assessment, Development, and Evaluation”) system (Owens et al. 2010):

- High quality: further research is unlikely to affect confidence in the estimation of the (therapeutic) effect.
- Medium quality: further research is likely to affect confidence in the estimation of the (therapeutic) effect and may alter the estimate.
- Low quality: further research will most likely influence confidence in the estimation of the (therapeutic) effect and will probably change the estimate.
- Very low quality: any estimation of the (therapy) effect or prognosis is very uncertain.

The GRADE rating of recommendations corresponds to the categories of “*ought to*” (A—strong recommendation) or “*should*” (B—weak recommendation) (Schünemann et al. 2013). As third category “*can*” (0—option) had been introduced (Platz 2017). Recommendation category A is granted for clinically effective interventions with high-quality evidence support; category B for medium-quality evidence, and category 0 for low- or very low-quality evidence. Deviations from this rule could be indicated based on clinical judgement, with individual reasons

denoted in [brackets]. A+ and B+ denote a strong or weak recommendation in favour on an intervention, while A– and B– recommend against its use.

3.2 Recommendations

3.2.1 Organizational Setting

Prolonged weaning in stroke patients requires a special setting which can best be provided in neurological weaning and rehabilitation centres. Through the integrated possibilities of an adequate weaning process and a neurologically oriented multi-professional rehabilitation both successful weaning and the goal of the best possible interaction may simultaneously be achieved (CEBM classification: level 2c, GRADE quality: low, recommendation: B+ [clinical reasoning]).

3.2.2 Weaning Strategy

For prolonged weaning of stroke patients, strategies with progressively expanded spontaneous breathing phases can be used, taking into account the underlying pathology and a constant re-evaluation of patient response. In cases of disturbances of neuromuscular transmission, additional pressure support during the spontaneous breathing phases can be useful. Weaning in patients with central respiratory dysregulation disorders should be individualized, taking into account the underlying injury and also regular adjustments according to patient response (CEBM classification: level 5, GRADE quality: very low, recommendation: 0).

Non-invasive ventilation ought not to be used in patients with neurogenic dysphagia or prolonged reduced vigilance and a high risk of aspiration; in these patients, a blocked-off tracheostomy tube should remain as a portal for ventilator access until there is no danger of macro-aspiration (CEBM classification: level 5, GRADE quality: very low, recommendation: A– [clinical reasoning]).

Weaning in stroke patients ought to include (early) rehabilitation of various concomitant aspects of care to achieve best possible patient participation (CEBM classification: level 5, GRADE quality: very low, recommendation: A+ [clinical reasoning]).

3.2.3 Weaning Process Characteristics

Weaning protocols can be used during the weaning process of long-term mechanically ventilated stroke patients (CEBM classification: level 5, GRADE quality: very low, recommendation: 0).

The frequency and duration of spontaneous respiration using a T-piece can be increased in a fixed step pattern; if successful, the patient can move to the next level, in case of failure the patient returns to the previous level or the same level is re-applied (CEBM classification: level 2c, GRADE quality: low, recommendation: 0).

Patients undergoing early neurological-neurosurgical rehabilitation are considered to have been successfully weaned if they manage at least 48 h without any mechanical ventilation (CEBM classification: level 5, GRADE quality: very low, recommendation: B+ [clinical reasoning]).

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