Intensive Care Med (2013) 39:1885–1895
DOI 10.1007/s00134-013-3014-9

REVIEW

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Managing the apparent and hidden difficulties of weaning from mechanical ventilation

Received: 12 March 2013
Accepted: 27 June 2013
Published online: 18 July 2013

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Abstract *Background:* In anaesthetized patients scheduled for surgery, tracheal intubation is performed with the expectation of subsequent smooth extubation. In critically ill patients, separation from the ventilator is often gradual and the time chosen for extubation may be either delayed or premature. Thus, weaning is challenging, represents a large part of the ventilation period and concerns all mechanically ventilated patients surviving their stay. *Definitions and management:* Weaning may be stratified in three groups according to its difficulty and duration. In *simple* weaning the main issue is to detect the soonest time to start separation from the ventilator; this is frequently impeded by poor sedation management and excessive ventilator assistance. A two-step diagnostic approach is the most efficacious: screening for ascertained readiness to wean is confirmed by a diagnostic test simulating the post-extubation period, best performed by unassisted breathing (no PEEP). In case of test failure (*difficult* weaning), a structured and thorough diagnostic work-up regarding potentially reversible pathologies is required with a focus on cardiovascular dysfunction or fluid overload at the time of separation from the ventilator, respiratory or global muscle weakness and underlying infection. *Prolonged* weaning is exceptionally time- and resource-consuming, needs to properly appraise psychological problems, sleep and nutrition, and is probably best performed in specialized units. *Conclusions:* Adequately managing simple and difficult weaning requires one to think about ICU policies in terms of sedation, fluid balance and having a systematic screening strategy; it also needs an individualized approach to understand and treat the failing patients. Prolonged weaning requires a holistic approach.

Keywords Mechanical ventilation · Weaning · Weaning groups · Weaning failure

Introduction

Weaning intubated patients from mechanical ventilation (MV) is a continuous process that ideally starts with a patient's intubation and usually ends with successful extubation [1]. Thus, separation from the ventilator is often performed as a gradual transition from total ventilatory support to spontaneous breathing. Unlike the anaesthetized patient, intubated with the expectation of smooth extubation following surgery, the critically ill basically require ventilatory support for failure of the lungs (affection of the lung parenchyma) and/or the respiratory pump (neuromuscular problem), serious cardiac dysfunction or coma from whatever cause [2].

Various complications (such as critical illness polyneuromyopathy [3], catheter-related bloodstream infection [4], acute kidney injury [5], delirium [6] or ventilator-associated pneumonia [7]) may unintentionally increase the duration of ventilation, about 40 % of which is spent on weaning [2, 8–10]. Although rapid and safe discontinuation of MV should be the objective for the majority of patients, both premature and unreasonably delayed extubation still occur, leading to adverse outcomes [11–13].

Figure 1 illustrates reasons which may contribute to weaning/extubation failure. Contributors to failed extubation of the anaesthetized patient may also be present in the critically ill patient, whereas the opposite scenario is usually not the case. The variety of possible reasons explains why this process often necessitates a very individualized care through a complex pathophysiological approach. In this article we concentrate on weaning of the critically ill and provide a narrative review of previously published studies and guidelines. Specific weaning recommendations, useful for daily practice, are summarized in two Tables (1, 4) and reflect our own synthesis of the available evidence.

Stratification of weaning

According to a new classification proposed by the consensus conference (and suggested by Brochard in [1]), weaning should be categorized into three groups with distinct epidemiological characteristics and clinical outcomes. This stratification, though simplistic, distinguishes three types of reasoning and approaches towards patient management. Specific reasons for apparent or hidden weaning difficulties within these groups are discussed below and presented in Table 1.

Simple weaning refers to patients who can be successfully extubated after the first weaning test, often referred to as spontaneous breathing trial (SBT), indicating a short-term trial of spontaneous breathing with no or little ventilator assistance. The term has become misleading because it refers both to unassisted and assisted breathing: we prefer using the term weaning test. Up to 60 % of patients are part of this group for which the main goal has to be avoidance of delayed extubation by identifying weaning readiness as soon as possible (systematic screening strategy) [14–16].

About 30–40 % of patients present as difficult weaning, who require up to three SBTs (or as long as 7 days) to be successfully extubated [14–16]. The reasons for failed weaning have to be insistently explored and corrected, and the pathophysiology of weaning failure needs to be understood for an optimal management of the patient.

Prolonged weaning (6–15 % of patients) applies to patients who exceed the limits of difficult weaning [14–16]. Weaning is exceptionally time- and resource-consuming, needs a holistic approach of care and is probably best performed in specialized units. This group contains many of the patients elsewhere called the chronically critically ill [17]. Several studies have consistently shown that this latter group has a much worse outcome than the first two groups [14, 16].

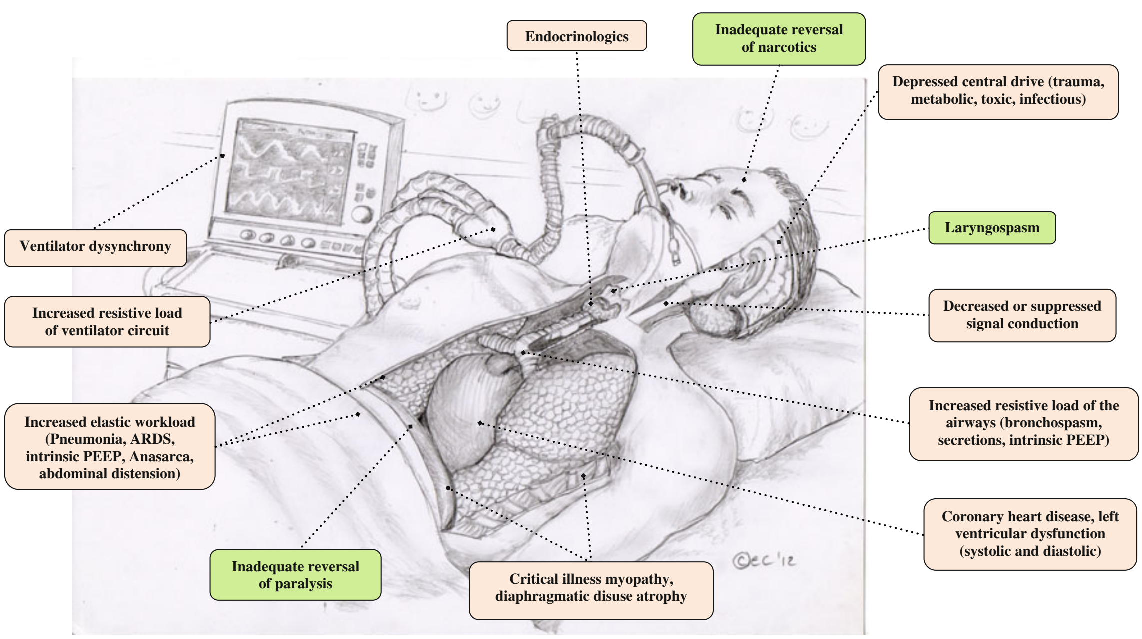

Fig. 1 Synoptic illustration of reasons contributing to weaning/extubation failure in anaesthetized and critically ill patients. ▢ anaesthetized, ▢ critically ill

Table 1 Most frequent reasons for weaning failure according to the three groups of the weaning classification: consequences for daily practice

Simple weaning	Delayed awakening due to accumulation of sedative drugs Lack of screening Excessive level of ventilatory assist making weaning assessment unreliable Lack of systematic discussion during rounds Lack of personnel
Difficult weaning	Accumulation of sedative drugs Fluid overload Left heart failure Respiratory muscle weakness (myopathy) Excessive workload due to infection, secretions, unresolved sepsis, etc.
Prolonged weaning	Severe chronic heart failure Severe chronic respiratory insufficiency Prolonged respiratory muscle weakness (neuro-myopathy) Depression Poor sleep quality, severe constipation, persistent sepsis, etc.

Simple weaning

Ideally, close observation of a patient treated with MV should allow one to suspect his/her capacity to sustain spontaneous breathing, often detected by the ability of the patient to trigger all assisted breaths on the ventilator. The evoked suspicion is then confirmed by so-called weaning readiness criteria, which principally focus on reversal of the causative process for ventilatory support, respiratory and ventilatory criteria (adequate gas exchange with reduced ventilatory support), ability to protect the airways (stable mentation, adequate cough, no excessive tracheobronchial secretions) and stability of hemodynamic and metabolic parameters [1, 8, 10]. Although somewhat debated [18, 19], the rapid shallow breathing index [20] is preferably performed at a point when clinicians do not routinely measure weaning predictors and might consequently shorten the delay that frequently occurs in stage two and three of simple weaning. Failure in routinely screening patients for readiness may be due to the absence of a standardized weaning procedure, an underestimation of the patient's ability to breathe spontaneously because of excessive ventilatory assistance [21], of oversedation [22, 23] and possibly scarcity of physicians and nurses [24, 25].

Relying on the amount of ventilatory assistance is often inadequate and a screening test leading to unassisted breathing is crucial: the rapid shallow breathing index, a systematic reduction in pressure support or the use of general criteria constitute possible approaches.

Once a patient has passed this daily screen, a weaning test must take place. This test is presently the major diagnostic tool to determine successful extubation [1], and is used to simulate the work performed after extubation. Weaning guidelines suggest performing the test with no (T-tube strategy) or little ventilator assistance (low levels of inspiratory pressure support or continuous positive airway pressure) [1, 26]. In this regard, the T-tube strategy is the more realistic test [27], although excessive work of breathing is possible in case of an inappropriately small tube diameter or accumulation of dense secretions. Careful observation of the respiratory pattern along with other criteria consent to possibly define a poor tolerance towards durable spontaneous breathing. Failure criteria of the SBT are basically the opposite of weaning readiness criteria, indicating that the previously achieved stability of the pulmonary, hemodynamic and neuromuscular status has vanished [1, 26]. Judgment of the weaning test relies on objective criteria but also depends on the clinician's skills to adequately predict the tolerance of the test, an issue which has received insufficient attention with regards to the consequences of an erroneous decision. Interestingly, the patient's subjective impression at the end of the weaning test has been shown to improve the predictive value of the weaning test [28]. It is noteworthy that all criteria currently used to initiate or assess tolerance to the weaning test derive from several old studies on weaning (e.g. [8, 10]), thus without any clear evidence supporting their use. A test duration of 30 min appears to be adequate [29, 30] but needs to be prolonged for the complex critically ill, for whom a median time to failure of 120 min has been proposed [31]. The general application of PEEP during a weaning test is debated but makes little sense when examining the weaning test as a "test". PEEP is a support that can favourably influence work of breathing or hemodynamics in patients with chronic obstructive pulmonary disease (COPD) or left ventricular heart failure and also prevent atelectasis, but this will not improve the predictive value of the test regarding the tolerance of unassisted breathing [32–34].

The weaning test should not include PEEP. The T-tube strategy is the most realistic approach.

Patients completing the weaning test without developing signs of poor tolerance are evaluated for extubation. When upper airway obstruction due to laryngeal oedema is a potential concern (prolonged period of intubation, traumatic/difficult intubation), a cuff leak test should be performed before proceeding with extubation [35] and, if necessary, a therapy with corticosteroids is initiated [36, 37]. The high frequency of vocal cords and laryngeal injuries observed after prolonged extubation suggest that it may often participate in post-extubation respiratory distress even in the absence of clinical stridor [38]. Helium–oxygen mixtures have been shown to reduce the work of breathing in the immediate post-extubation period, but its clinical usefulness has not been properly tested [39].

A cuff leak test may help the decision to extubate.

The extubation is considered successful when the patient survives 48–72 h following extubation without need for invasive or non-invasive ventilatory support [1, 36]. On average, the extubation failure rate after a sustained weaning test is only 13 % [1], whereas close to 40 % of patients not previously tested with a weaning test eventually require reintubation [40].

Extubation failure is principally a clinical diagnosis [36]. Reintubation in situations other than upper airway obstruction is associated with markedly increased mortality (35–50 %) [12, 29, 30, 41–43], and recent research has suggested a direct and specific effect of reintubation on patient outcome [41]. This emphasizes the importance of making a correct decision.

Non-invasive ventilation (NIV) has been proposed to modify the weaning process and extubation outcome. According to its timing, one basically distinguishes three forms: (1) *facilitative* NIV permits one to anticipate extubation, thus theoretically reducing complications related to prolonged MV. Patients usually do not meet standard extubation criteria and are not supposed to sustain a weaning test. This technique has shown some positive effects (reduced mortality and ventilator-associated pneumonia) in patients with COPD but needs confirmation [44]. (2) In patients at high risk of reintubation (>65 years, underlying respiratory or cardiac dysfunction and hypercapnia during the test are the most frequently used criteria) the early use of *prophylactic* NIV seems to efficiently prevent reintubation [36, 45–47]. (3) Conversely, *curative* NIV—the application of rescue NIV once a patient has developed post-extubation respiratory failure—is mostly inefficient or can even be harmful by delaying reintubation [48, 49].

Extubation failure may worsen patient's outcome.

Only prophylactic NIV in high-risk patients has a proven value.

Especially in under-staffed ICU settings, weaning protocols focussing on appropriate sedation as well as on timely suspecting, assessing and testing for weaning readiness have been proposed with variable efficacy [22, 23, 50]. Different from a human protocol, weaning can be also accelerated by automation. A specific computer program integrated in the ventilator, which continuously monitors physiologic parameters, adapts the ventilator assistance according to various feedback related to the patient's needs [51–53]. Several randomized controlled trials showed the superiority of this automated technique compared to usual care or to a strictly applied weaning protocol [51, 53, 54].

Difficult weaning

A patient failing a weaning test or extubation implies that he/she is automatically allocated to the difficult-to-wean group. This condition usually indicates (1) incomplete resolution of the illness promoting invasive MV; (2) the prior clinical assessment was wrong or, alternatively, an important coexisting factor was missed; or (3) a new problem has arisen in the meantime. The pathophysiologic mechanisms inducing weaning failure include respiratory pump insufficiency (control of breathing, respiratory muscles, lung/chest wall mechanics or, rarely, gas exchange), cardiovascular dysfunction, neuromuscular disorders, psychological factors as well as metabolic/endocrine diseases, alone or combined (Fig. 1).

Respiratory pump insufficiency

Respiratory pump failure is caused by an imbalance between respiratory workload and respiratory capability. Respiratory workload depends on respiratory mechanics (airway resistance and lung and chest wall elastance) imposed upon the ventilator pump and on the ventilatory needs, frequently increased by ventilator-associated pneumonia, sepsis or overfeeding. Relevant reasons generating increased respiratory workload are listed in Table 2 [1].

Apart from pure emphysema, virtually all diseases affecting the lung parenchyma (e.g. pneumonia, pulmonary oedema, atelectasis, ARDS) or the chest wall reduce pulmonary compliance, thus increasing the elastic load. Elastic workload may also be seriously increased in conditions with airway obstruction (COPD, bronchial asthma), when intrinsic PEEP with dynamic hyperinflation induces an inspiratory threshold load and forces the patients to ventilate at the flat upper margin of the pressure–volume curve. Finally, every clinical condition stiffening or deforming the chest wall or increasing the abdominal content/intra-abdominal pressure will augment the elastic workload and may avert successful weaning.

Increased resistive load may be patient- or ventilator-related (see Table 2). Patients with obstructive diseases can present major resistive load due to bonchospasm, mucosal oedema, excessive secretions and air trapping with consecutive intrinsic PEEP. Accurate bedside waveform interpretation of flow, volume and airway pressure is necessary to correct patient–ventilator asynchronies [55]. As there is a clear association between reduced number of asynchronies and shorter duration of MV [56], the use of well-adjusted ventilatory modes to reduce asynchronies [21] or specific modes reducing asynchronies like proportional assist ventilation (PAV) [57] or neurally adjusted ventilatory assist (NAVA) [58] have the potential for reducing the weaning duration, but this has not been formally demonstrated.

Respiratory failure may be precipitated by a worsening in respiratory mechanics, an increase in ventilatory demand or both.

Adequate respiratory capability presupposes neuromuscular competence, i.e. integrity in the generation and conduction of neurologic signals down to the

Table 2 Increased respiratory workload

Elastic workload	
Lung parenchyma	Oedema (of whatever origin) Pneumonia, atelectasis, fibrosis, ARDS Extreme hyperinflation (asthma attack) High intrinsic PEEP (COPD)
Chest wall	Abdominal distension, ascites, obesity, anasarca Pleural effusion, pneumothorax Kyphoscoliosis, flail chest
Resistive load	
Airways	Bonchospasm, mucosal oedema, excessive secretions Intrinsic PEEP (asthma, COPD) Glottic oedema
Endotracheal tube resistance	Kinking, deposition of secretions, ventilator circuit Small tube diameter
Ventilator	Malfunctioning ventilator valves Inappropriate ventilator settings (see below) Imbibed heat and moisture exchangers
Ventilatory needs	
Higher minute ventilation	Fever, overfeeding, hyperventilation (agitation, pain) Ventilation/perfusion mismatch Intrapulmonary shunt, increased dead space (emphysema)
Ventilator dyssynchrony	Inappropriate ventilator settings Ineffective triggering (wasted inspiratory effort) Autotriggering (unwanted increase in respiratory rate) Inappropriate cycling off (expiratory effort, hyperinflation)

This is not an exhaustive list
ARDS acute respiratory distress syndrome, *PEEP* positive end-expiratory pressure, *COPD* chronic obstructive pulmonary disease

musculature, intact regulatory feedback mechanisms and adequate muscular strength to sustain the respiratory loads without fatiguing (endurance). Relevant reasons generating decreased respiratory capability are listed in Table 3 [1, 59]. Of particular concern is the weak ICU patient [60, 61]. Critical illness polyneuropathy and myopathy are viewed as an integral part of the multiorgan failure syndrome; their appearance is significantly associated with sepsis, hyperglycaemia and probably corticosteroid use [3]. Also, disuse atrophy of the human diaphragm has been shown to occur very rapidly following diaphragmatic inactivity due to controlled MV, even after 18 h [62]. Preserving diaphragmatic activity with the use of assisted modes has been shown in animals to avert the deleterious effects of controlled MV [63, 64]. This has important clinical implications. It is essential to emphasize that a short period of spontaneous breathing like the weaning test does not induce muscle fatigue provided that the patient is connected back on the ventilator as soon as signs of respiratory distress develop [65].

Testing limb and respiratory muscle force may help to understand weaning difficulties.

Cardiovascular dysfunction

Cardiovascular dysfunction is increasingly recognized as an important cause of weaning failure both in patients with known or previously unrecognized left heart disease [66]. Switching a patient from positive pressure ventilation to spontaneous breathing re-establishes negative inspiratory intra-thoracic pressures thus increasing venous return (left ventricular preload), central blood volume and left ventricular afterload [67]. This normal condition, often an effort test for the patient, can decompensate the cardiorespiratory function in case of volume overload and left ventricular systolic or diastolic dysfunction.

Volume overload should ideally be treated before a weaning test is carried out, as it has been associated with worse weaning outcome [68, 69]. A weaning strategy based on daily measurements of brain natriuretic peptide was able to reduce the duration of weaning from MV for this reason [70].

Patients failing a weaning test are frequently not capable of adequately increasing cardiac index and oxygen transport [71] and some may develop lung oedema [72]. Supplementary cardiac stress may be anticipated in patients with severe obstructive and restrictive pulmonary diseases (larger negative pleural swings during inspiration). Figure 2 elucidates the different cardiocirculatory mechanisms presumably leading to failure of the weaning test. The diagnosis of cardiac pulmonary oedema explaining weaning failure is usually made with non-invasive approaches, including transthoracic echocardiography [66, 73], biological signs of haemodilution [74] and cardiac biomarkers, especially natriuretic peptides [75, 76]. Bedside transthoracic echocardiography, if properly executed during the weaning test, may provide important information regarding the global/regional left

Table 3 Decreased respiratory capability

Signal generation	
Depressed central drive	Sedatives, narcotics Metabolic-toxic (urea↑, metabolic alkalosis) Infectious (encephalitis, meningitis) Stroke, trauma, oedema, central hypoventilation)
Signal conduction	
Decreased conduction	Spine lesion (para-/tetraplegia) Motoneuron (GBS, ALS, AIP) Phrenic nerve (traumatic/iatrogenic, poliomyelitis) Critical illness polyneuropathy (sepsis, MOF, hyperglycaemia, corticosteroids, aminoglycosides, prolonged use of neuromuscular blocking agents) Neuromuscular transmission (MG, neuromuscular blocking agents)
Muscular strength	
Reduced strength and/or endurance	Critical illness myopathy MV (disuse atrophy), muscular dystrophies Metabolic (decreased levels of PO_4, Mg, K, Ca), under nutrition Endocrinologic (thyroid disturbances, adrenal insufficiency)

This is not an exhaustive list
GBS Guillain–Barré syndrome, *AML* amyotrophic lateral sclerosis, *AIP* acute intermittent porphyria, *MOF* multiple organ failure, *MG* myasthenia gravis, *PO_4* phosphate, *Mg* magnesium, *K* potassium, *Ca* calcium

ventricular systolic function, ischaemia-induced left ventricular systolic dysfunction, left ventricular diastolic dysfunction or biventricular interdependence (related to weaning-induced right ventricular dilation, especially in COPD) [66, 77]. A precise diagnosis of the reason explaining pulmonary oedema is important because it will influence therapy. A difficult situation is the treatment of cardiac dysfunction associated with normal preload conditions. Vasodilators like nitrates might represent an interesting pharmacological option for preventing cardiac-induced weaning failure by restoring the increases in venous return and left ventricular filling during the weaning test [78]. In some situations, a specific interventional treatment of ischaemia may be indicated [79].

Fluid overload should be suspected using biomarkers and treated before weaning.

A precise diagnosis of the mechanism of cardiac dysfunction is necessary to guide therapy.

Psychological factors

Psychological factors may be critical for successful weaning in some patients. Jubran found a significant association between depressive disorders and failing weaning attempts as well as with mortality [80]. Delirium, a disorder with cognitive brain dysfunction, might also negatively impact weaning outcome [80, 81]. Daily screening for delirium with a well-validated tool (e.g. the confusion assessment method) is therefore mandatory, particularly for not missing its hypoactive form [82]. Nonetheless, delirium may still be present even at ICU discharge.

Both delirium and depression may impede weaning.

Management of difficult weaning

After a failed weaning test or extubation failure, a ventilation mode allowing a supposedly normal level of work of breathing is resumed. Pressure support ventilation (PSV) might represent a propitious ventilation mode as it maintains an adequate balance between respiratory work load and capability, probably averts disuse atrophy of the diaphragm [63] and aids in the weaning process [8]. Attention has to be paid to the level of pressure support in order to avoid excessive assistance and asynchronies, which could result in poor sleep [83]. A thorough diagnostic work-up is then carried out, namely a careful clinical evaluation and various ancillary investigations [84]. Subsequently, all reversible pathologies met are corrected, weaning readiness regularly ascertained and the weaning test repeated. In the absence of clinically apparent respiratory muscle fatigue, more than one daily weaning test may be performed [65], otherwise respiratory support is provided for at least 24 h [85]. Tracheostomy may be considered as a useful adjunct for an easier care of the patient, especially for mobilization [86, 87].

Tracheostomy may improve comfort.

Prolonged weaning

Prolonged weaning concerns about 10 % of critically ill intubated patients and is associated with a high mortality

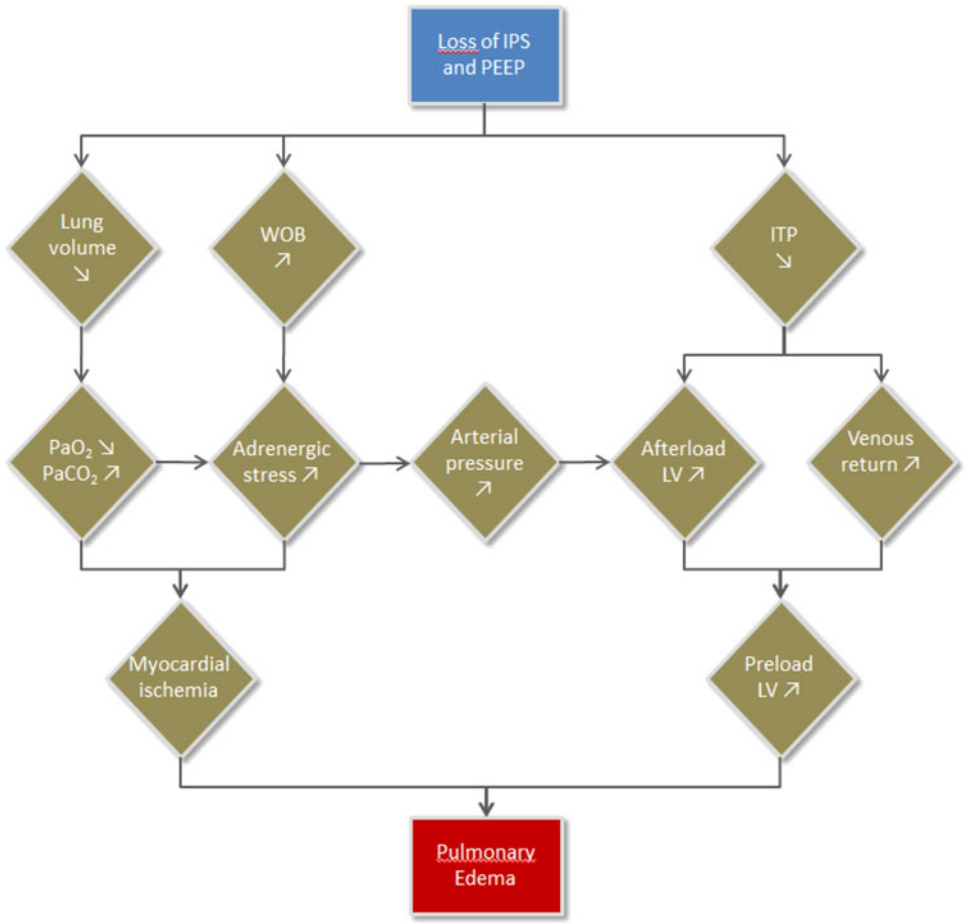

Fig. 2 Cardiocirculatory mechanisms seemingly leading to failure of the T-tube test. *IPS* inspiratory pressure support, *PEEP* positive end-expiratory pressure, *WOB* work of breathing, *ITP* intrathoracic pressure, ↓ decrease, ↑ increase, PaO_2 arterial oxygen tension, $PaCO_2$, arterial carbon dioxide tension

[14–16]. In several countries specialized facilities have been created to accommodate patients requiring just prolonged mechanical ventilatory support and being otherwise clinically stable.

Outcomes of weaning attempts at discharge from these centres are worrisome: 60 % of patients are weaned (median time 15 days), about 20 % remain ventilator-dependent, and 20 % die. Few (20 %) may be discharged home, and the remainder are transferred to rehabilitation and extended-care facilities [88, 89]. Merely one third of patients are known to be alive 12 months after admission to these units, and half of all patients eventually liberated from MV still require supplemental oxygen at time of discharge [89]. Full-time home ventilation by tracheostomy is more frequently applied than non-invasive ventilation, the latter habitually as partial (nocturnal) support [88, 89].

Management of prolonged weaning

Given the lack of specific research, recommendations are based on the experiences collected in specialized weaning units, which provide a multidisciplinary rehabilitative approach and also serve as a bridge to home or long-term care facilities [88–92]. Weaning is started as soon as possible, as about 20 % of transferred patients will tolerate their initial weaning test and be successively liberated from the ventilator. The best time window for successful weaning appears to be within the first 3 weeks [31, 89, 92]. Particular attention is paid to an aggressive physiotherapy, to the patients' environment (privacy, longer visiting hours and undisturbed sleep), supervised daytime activity, and counselling, to name only a few [93]. The physiotherapy is tailored to patient tolerance and stability and includes the progressive transition from motion exercises in the supine position to other bed mobility activities, upright sitting, balance activities, functional tasks of daily living, transfer training, and finally pre-gait exercises and walking [94]. The application of a tracheostomy (if not already in situ) corresponds to good clinical practice [16, 31, 89]. Swallowing dysfunction may be present, complicate the extubation process and delay the return to normal eating habits [95]. Similarly, the nasogastric tube should be removed soon. The tracheostomy cannula has to be progressively downsized and the tube kept uncuffed to increase the airway diameter [95]. A recent randomized controlled

Table 4 Weaning recommendations useful for daily practice

Process of healing (MV)	Minimize or avoid sedation Use ventilation modes allowing some spontaneous breathing activity Daily wake-up trial Mobilize early and frequently
Weaning readiness	Standardize your screening and weaning procedure Detect as early as possible Even if underlying cause prompting MV is not resolved Avoid excessive ventilator assistance Check whether all assisted breaths are triggered Disconnect from ventilator → RSBI < 105 breaths min^{-1} L^{-1}?
Weaning Test	≥Once a day TTT ~ 30 min for patients with a high pre-test probability of success, TTT ≥ 120 min for COPD and patients with a low pre-test probability
Extubation	In case of sustained test Ask the patient about his/her own prediction of extubation success Risk of upper airway obstruction? → consider corticosteroids several hours before extubation Consider facilitative NIV for COPD Consider prophylactic NIV for high-risk patients Do not delay reintubation in case of failure
Difficult weaning	Do a thorough diagnostic work-up Respiratory pump failure versus cardiac dysfunction versus muscle weakness Correct all reversible pathologies Consider BNP measurements Repeat tests after correction of abnormalities
Prolonged weaning	Consider tracheostomy for increased patient comfort Holistic approach, including nutrition, sleep and psychological factors Specialized unit may be useful Reversibility of the disease prompting prolonged weaning? Discuss about realistic versus futile goals of care Consider home ventilation

MV mechanical ventilation, *RSBI* rapid shallow breathing index (respiratory frequency divided by tidal volume), *SBT* spontaneous breathing trial, *TTT* T-tube trial, *NIV* non-invasive ventilation, *COPD* chronic obstructive pulmonary disease

trial suggested that tracheostomized patients were more rapidly separated from the ventilator by repetitive T-tube trials than with a gradual reduction of PSV without influencing survival at 12 months [96]. Short daily cuff-down trials with a speaking valve are performed to induce vocal cords to exert their original function during expiration. When definitive weaning eventually becomes unlikely (>1 month of structured, multidisciplinary weaning approach), home ventilation has to be considered [88, 89]. Frequent and unambiguous communication with the patient and his/her family includes explicit discussion about realistic versus futile goals of care [91].

Uncertainties

Further research might concentrate on the following queries: (1) Which precise patient populations potentially benefit from prophylactic post-extubation NIV? (2) What are the incidence and impact of ventilator-induced diaphragmatic atrophy according to different modes of MV? (3) What are the minimal criteria required to properly assess readiness to wean? (4) Could the patient's subjective impression of extubation success be used on a large scale to improve the predictive value of a sustained weaning test? (5) What is the long-term impact of different weaning strategies?

Conclusion

During the last three decades important advances have been made in weaning critically ill patients from MV. A two-step diagnostic approach is an efficacious method for simple and difficult weaning. Ascertained readiness to wean is confirmed by a diagnostic test (a short-term period of spontaneous breathing). A patient's tolerance to this test usually leads to definite removal of the endotracheal tube, whereas weaning failure needs a structured and thorough diagnostic work-up regarding potentially reversible pathologies. Prolonged weaning is exceptionally time- and resource-consuming, needs a holistic approach of care and is probably best performed in specialized units. Specific weaning recommendations are summarized in Table 4 and reflect our own synthesis of the available evidence.

Acknowledgments We are thankful to Francesco Bordoni and Marzio Della Santa for their precious help in designing Figs. 1 and 2, respectively.

Conflicts of interest LB's research laboratory has received research grants from the following companies over the last 5 years: Drager (SmartCare), Covidien (PAV+), Vygon (CPAP), Philips Respironics (NIV), Fisher Paykel (Optiflow). There is no other conflict of interest.

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