Weaning from Mechanical Ventilation

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Case Presentation

A 68 year old woman with a history of hypertension, diabetes, asthma, congestive heart failure (CHF) and end stage renal disease was intubated and admitted to the ICU for respiratory failure and hypotension following a one week history of fever, dyspnea, anorexia and cough productive of yellowish-green sputum. At initial presentation to the ICU, she received a bolus of intravenous crystalloid, and was commenced on vasoactive support with norepinephrine, vasopressin and phenylephrine infusions. White blood cell count was 15K and she was commenced on broad-spectrum IV antibiotics. Respiratory and blood cultures subsequently grew *Pseudomonas aeruginosa* and antibiotics were narrowed to IV cefepime. Over the next 72 h she became afebrile, her white blood cell count dropped to 8.5K and her vasoactive support was weaned off. Her most recent CXR, vital signs and mechanical ventilator settings are shown in Fig. 31.1.

Question What approach would best determine her readiness for liberation from the mechanical ventilator?

Answer Spontaneous breathing trial (SBT)

All intubated patients should be assessed with a SBT to determine their readiness for liberation from the mechanical ventilator after the underlying cause for intubation has been addressed and is improving. The patient had been ventilated on small tidal volumes (6 ml/kg ideal body weight) and her plateau airway pressures ranged between 20 and 24 cmH_2O. Her PaO_2/FiO_2 ratio remained >200 with a PEEP of 5cmH_2O and FiO_2 of 40%. Her hemodynamic status remained stable with no requirement for vasopressor support. She received an analgesic infusion of fentanyl, which was interrupted on a daily basis to assess her mental function. Physical and occupational therapy were commenced within 24 h of her ICU admission and she was maintained on a daily negative fluid balance of 1–2 L per day. Her most recent arterial blood gas was 7.32/42/75/98 and she had minimal airway secretions. Continuous sedation was discontinued and while she was awake, a 30-min spontaneous-breathing trial was performed with CPAP of 5 cm of water and her observed vital signs afterwards are depicted in Fig. 31.2.

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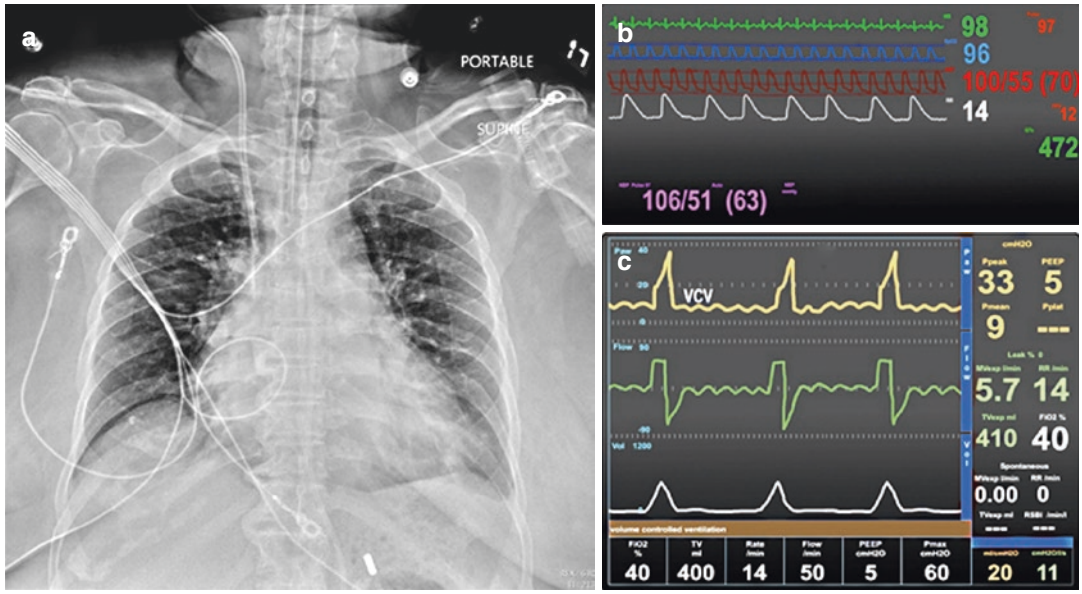

Fig. 31.1 (**a**) Chest x-ray of index patient on admission day 3. (**b**) Telemetry monitor showing the patient's vital signs on admission day 3. (**c**) Mechanical ventilator parameters of the index patient on admission day 3

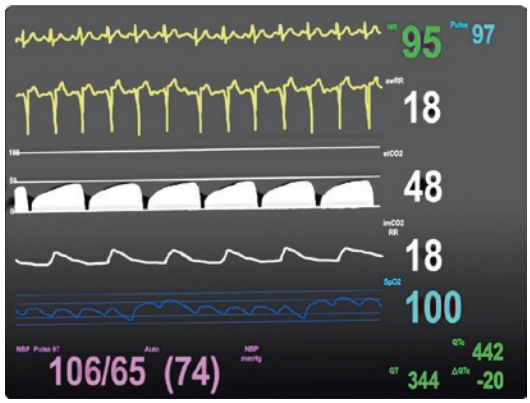

Fig. 31.2 Telemetry monitor showing the patient's vital signs after a 30-min spontaneous breathing trial

Principles of Management

Strategies to Minimize the Requirement for Mechanical Ventilation

Various disease states predispose patients to respiratory failure ultimately requiring mechanical ventilation for respiratory support. In patients with sepsis, the need for mechanical ventilation may be prevented by instituting early aggressive resuscitative measures [1]; however, this protocol-based care may not result in improved outcomes [2, 3]. Similarly, instituting non-invasive ventilation in patients with acute cardiogenic pulmonary edema or acute exacerbation of chronic obstructive pulmonary disease could reduce the need for intubation and mechanical ventilation in these patients [4–7].

Strategies to Reduce the Duration of Mechanical Ventilation

Once a patient has been intubated, several strategies which could speed up readiness for liberation from mechanical ventilation include the use of lung protective ventilation in ARDS [8], interruption of sedatives on a daily basis [9], implementing physical and occupational therapy early [10], conservative fluid management in ARDS [11] and the prevention of ventilator-associated pneumonia [12].

Evaluation of Patient's Readiness for Spontaneous Breathing

Patients determined to be ready for a trial of spontaneous breathing should exhibit improvement in the underlying factors that led to respiratory failure and be hemodynamically stable with a ratio of partial pressure of arterial oxygen to the fraction of inspired oxygen (PaO_2/FiO_2) that exceeds 200 on a positive end-expiratory pressure (PEEP) of 5 cmH_2O or less [13].

Perform a Spontaneous Breathing Trial in Patients Deemed Ready

An SBT is performed to demonstrate the patient's ability to breathe on minimal or no ventilator support for at least 30 min. Usually, this is performed on continuous positive airway pressure, low-level pressure support or utilizing a T-piece. The occurrence of oxygen saturation ≤90 %, heart rate >140/min, respiratory rate >35/min for more than 5 min, a sustained variation of 20 % or more in the heart rate, systolic blood pressure below 90 mmHg or exceeding 180 mmHg, increase in anxiety or diaphoresis all portend failure [13].

Assess Patient's Ability to Protect the Airway

A successful trial of spontaneous breathing will lead to an evaluation of the patient's ability to effect airway protection upon removal of the endotracheal tube. This assesses the patient's mentation, strength of cough and quantity of airway secretions. Demonstration of adequate unassisted breathing and airway protection should prompt immediate removal of the endotracheal tube. Otherwise, if SBT is unsuccessful, re-initiation of mechanical ventilation at the prior support level should be ensured while a careful investigation is performed to determine and treat the underlying reason for failure before repeating an evaluation for a trial of spontaneous breathing again [13].

Evidence Contour

Assessing the Need for an Artificial Airway

Demonstration of some capability to interact with the health care team is required prior to removal of the patient's endotracheal tube. However, the exact significance and the degree to which it plays a role in successful extubation remain controversial [14]. It has been suggested that in patients capable of protecting their airway, a Glasgow coma scale score of ≥8 predicts successful extubation [15]. Prolonged mechanical ventilation, female sex and traumatic or repeated intubation have all been associated with post-extubation upper airway obstruction [16] leading to suggestions for the use of the cuff leak test (air leak detection during mechanical ventilation with a deflated endotracheal tube balloon) in these patients to assess the patency of the upper airway prior to extubation [17]. Patients at high risk of post-extubation stridor were identified in a single study of intubated medical patients using a cuff leak of <110 ml within 24 h of extubation [18]. Steroids and/or epinephrine may be used during this period to reduce the risk or for treatment in those patients who develop stridor afterwards [19]. The use of NIPPV and/or heliox has also been advocated [19].

Weaning Protocols

The use of weaning protocols enforces daily evaluation of readiness for extubation by using pre-specified criteria and implementing trial of spontaneous breathing in a structured form. The WEAN study, a multicenter, randomized controlled trial which compared automated weaning with the use of a standardized protocol demonstrated significantly faster liberation from mechanical ventilation and fewer cases of protracted ventilation or tracheostomies [20]. Similarly, a large Cochrane meta-analysis of ten trials compared automated weaning protocols and non-automated weaning strategies and

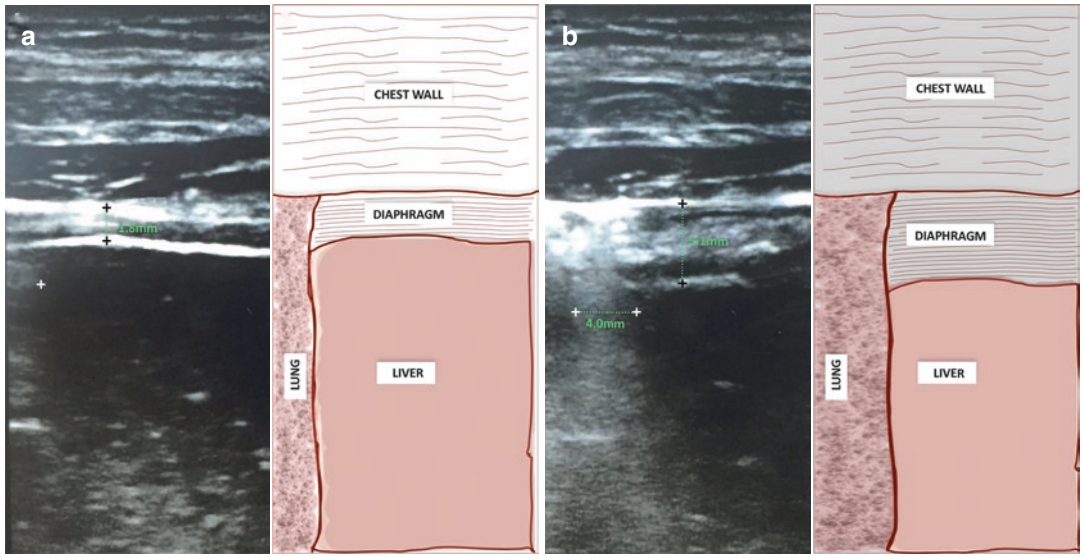

Fig. 31.3 A high resolution 13–6 MHz ultrasound linear probe (SonoSite Edge, SonoSite, Inc., Washington USA) held perpendicular to the chest was used to evaluate real-time movement of the diaphragm in the zone of apposition. Measurements obtained were recorded in B mode (two dimensional) ultrasonography by placing the transducer along the line of an intercostal space between the right anteroaxillary and midaxillary lines to ensure the zone of apposition is visualized ~0.5–2 cm below the right costophrenic sinus. Air in the lungs facilitates easy detection of the inferior border of the sinus and the two bright parallel lines of its peritoneal and pleural membranes identify the diaphragm with an intervening muscular layer during maximal expiratory effort (**a**) and maximal inspiratory effort (**b**). Ultrasonographic measurements of diaphragmatic thickening (*black crosses*) and hepatic displacement (*white crosses*) during spontaneous breathing trials have been demonstrated to be useful in predicting extubation outcomes [22–24]

demonstrated a decrease in the duration of mechanical ventilation, time to successful extubation, ICU length of stay and proportion of patients on mechanical ventilation for more than 7 days in patients on a protocolized weaning strategy [21]. Though yet to be widely adopted, this automated strategy possibly ensures all mechanically ventilated patients are given a fair chance to demonstrate their ability for spontaneous breathing at the earliest time (Figs. 31.3 and 31.4).

Sample Ventilator Liberation Pathway

Procedure to be implemented by physician or appropriately certified healthcare professional after eligibility has been determined following collaborative daily assessment by nursing and respiratory therapist. Necessary equipment and personnel confirmed to be available and responsible physician notified.

1. Initiate FiO_2 Wean Protocol:
   - Monitor pulse oximetry (SpO_2) during FiO_2 weaning (once determined to correlate with arterial blood gas)
   - Post-intubation, decrease FiO_2 by 10–20 % every 30 min till $FiO_2 < 0.5$ while $SpO_2 > 95$ % and/or $PaO_2 > 75$ mmHg
   - At target SpO_2, obtain ABG to confirm adequate oxygen saturation
   - PEEP may be increased (after discussion with the physician) to ensure $FiO_2 \leq 0.7$
2. Daily Assessment for Eligibility for Liberation:
   - Respiratory therapist screens all ventilated patients daily by asking these questions between 5:00–7:00 am. Assessment per-

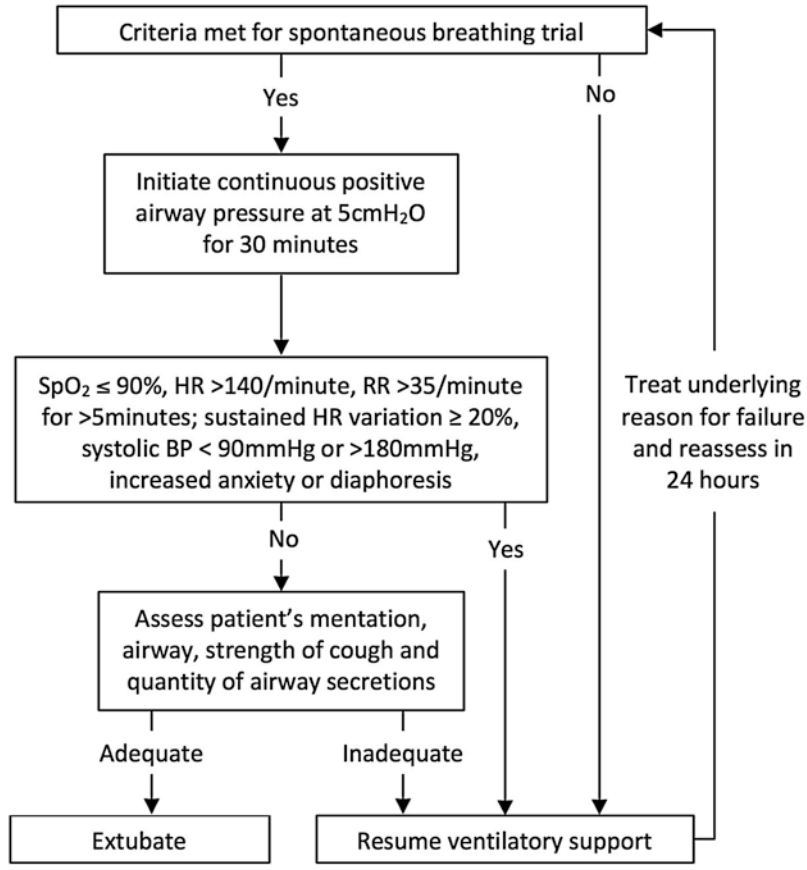

Fig. 31.4 Sample weaning protocol. Readiness for spontaneous breathing evaluated and patient meets the following criteria: (1) Demonstrates hemodynamic stability. (2) Sedative infusion discontinued. (3) Tube feedings stopped. (4) $PaO_2/FiO_2 > 200$; PEEP $\leq 5cmH_2O$

formed on all post-operative/post-procedure patients as needed upon awakening from sedation.

- Response must be "yes" for 'a – c'; or "yes" for 'a – d' in the presence of neuromuscular disease.

(a) $PaO_2 \geq 60$ mmHg on $FIO_2 \leq 0.5$, PEEP ≤ 7.5, $SpO_2 \geq 88\,\%$
(b) Hemodynamically stable, absence of vasoactive support except for Dopamine/Dobutamine ≤5 mcg/kg/min or norepinephrine ≤2 mcg/kg/min
(c) Patient triggers ventilator spontaneously
(d) Vital capacity >15 ml/kg; maximum expiratory pressure >40 & negative inspiratory force >25

3. Spontaneous Breathing Trial (Fig. 31.4):
   - Patient to be placed in semi-fowlers position.
   - Switch ventilator to spontaneous mode with pressure support of 8–10 or CPAP of 5 for 30 min on the same FiO_2.
   - If patient does not tolerate SBT, resume full ventilator support immediately and reassess daily or every 4 h for post-op/post-procedure patients; if patient tolerates SBT, screen for extubation readiness.
4. Screen for Extubation Readiness:
   - Awake & responsive to verbal commands?
   - Can Patient protect his/her airway? (Intact & adequate cough reflex)
   - Cough strength: (Weak/Satisfactory/Strong)

- No concerns about frequency of suctioning
- No concerns about upper airway patency?
- For patients with neuromuscular disease – can sustain head lift against moderate resistance?

  (If patient passes, extubation can be performed and new supplemental oxygen modality instituted; else go to Step 2. If repeated failure and intubated for >10–14 days – consider tracheostomy).

5. Extubation Procedure:
   - Request anesthesiologist or senior critical care physician for 'difficult to intubate patients' or 'prior airway trauma' prior to extubation
   - Ensure gastric feeds have been held for ≥2 h
   - Place mask for non-invasive ventilation at bedside
   - Perform oropharyngeal and ETT suctioning
   - Encourage patient to breathe in maximally
   - Extubate to nasal cannula at 4–6 l/min with close observation for at least 30 min
   - Ensure $SpO_2 \geq 92\%$ by titrating FIO_2 accordingly
   - For impending respiratory failure, expedite management of stridor with racemic epinephrine (0.5 q20 min up to 3× prn); humidified O_2±dexamethasone. Consider non-Invasive ventilation prior to reintubation
   - Deep breathing and cough maneuvers every 1–2 h
   - Maintain NPO for 4 h; evaluate for aspiration risk – if high: consult speech therapy; if minimal: resume tube feeds
   - Assessment by patients nurse every 4 h for signs of respiratory distress during ICU stay

Diaphragmatic Ultrasound as an Index for Discontinuation of Mechanical Ventilation

Ventilator induced diaphragm atrophy has been shown to occur even with short periods of mechanical ventilation and may delay liberation from the ventilator. Diaphragm dome motion as visualized by ultrasonography has limited utility and success in predicting extubation outcomes [25]. A recent prospective study of 63 subjects demonstrated that ultrasonographic measurement of diaphragm muscle thickening (Δtdi%) ≥30 % in the zone of apposition using a 7–10 Mhz ultrasound transducer is an effective predictor of extubation success or failure with a sensitivity and specificity of 88 % and 71 % respectively; a positive predictive value (PPV) of 91 % and a negative predictive value (NPV) of 63 % (area under the receiver operating characteristic curve for Δtdi% was 0.79) [26]. A similar prospective study of 43 subjects and Δtdi% >36 % had a PPV of 93 % and a NPV of 88 % [27]. The increasing use of ultrasonography in intensive care and the non-invasive approach with no special effort required of the patient makes it appealing in the evaluation of extubation outcomes.

Pressure Support Versus T-Tube for Weaning from Mechanical Ventilation

Low-level pressure support and spontaneous breathing through a T-Tube are optional modes of ventilator support used in liberation from mechanical ventilation. It was recently shown in a small prospective study of 28 patients undergoing cardiac surgery that either method did not confer a significant difference in the lung function or post-operative hospital course [28]. However, a large Cochrane review of >1200 patients suggests that pressure support ventilation may be more effective than a T-tube in facilitating successful spontaneous breathing trial. The evidence was insufficient to demonstrate superiority to T-tube in successful weaning, rapid shallow breathing index, reintubation risk, ICU mortality and length of stay [29].

Tracheostomy for Prolonged Transition

Patients who require prolonged weaning are increasingly being subjected to tracheostomy

[30]. The optimal time for performing tracheostomies in these patients remains controversial. Multiple studies have reported conflicting results on the effect of early tracheostomy on short-term mortality, incidence of pneumonia and ICU length of stay [31–34]. A meta-analysis of the available studies concluded that the evidence remains insufficient to recommend the early performance of tracheostomy in mechanically ventilated patients [35].

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