Difficult Weaning from Mechanical Ventilation

Sandeep Kumar
Department of Pulmonary Medicine
PGIMER, Chandigarh
Overview

• Types of Weaning

• Causes of Difficult Weaning

• Detection

• Management

• Modes of Weaning
Introduction

• Weaning - Entire process of liberating the patient from mechanical support

• Extubation failure occurs in up to 47% of patients on MV
Stages of Weaning

1) Treatment of ARF
2) Suspicion
3) Assessing readiness to wean
4) SBT
5) Extubation
6) Re-intubation

Admit

Discharge

Eur Respir J 2007; 29: 1033–1056
Simple weaning
Patients who proceed from initiation of weaning to successful extubation on the first attempt without difficulty

Difficult weaning
Patients who fail initial weaning and require up to three SBT or as long as 7 days from the first SBT to achieve successful weaning

Prolonged weaning
Patients who fail at least three weaning attempts or require >7 days of weaning after the first SBT

Eur Respir J 2007; 29: 1033–1056
Eur Respir J 2010; 35:88
Simple weaning group

- Half to two-third of weaning patients
- ICU mortality ~5%

Difficult weaning groups

- 26 to 39% of weaning patients
- ICU mortality ~25%
- Increased patient discomfort
- Increased mortality
- Increased ICU stay
Significance

• Difficult-to-wean patient consumes a third of ICU resources

• ~50 % of patients with difficult weaning end up with prolonged weaning

• Hospital mortality was increased in patients with prolonged weaning (32%)
Limitation of ICC

• Patients who were weaned

• Patients weaned without SBT

• Tracheostomized patients
Weaning according to New Definition (WIND) Classification:

- Group “No weaning”: No separation attempt

- **Group 1** (Short weaning)  
  1st attempt  
  Termination of the weaning process within 1 day

- **Group 2** (Difficult weaning)  
  1st attempt  
  Termination of the weaning process after >1 day till <1 week

- **Group 3** (Prolonged weaning)  
  Weaning not terminated 7 days after the first separation attempt

  **Group 3a**

  **Group 3b**
Predictor of Prolonged Mechanical Ventilation

<table>
<thead>
<tr>
<th>I-TRACH Criteria</th>
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<tbody>
<tr>
<td>Intubation in the ICU</td>
<td>Hospitalized in ICU for &gt;24 hrs</td>
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<tr>
<td>Tachycardia</td>
<td>Heart rate&gt;110</td>
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<tr>
<td>Renal dysfunction</td>
<td>Blood urea nitrogen&gt;25 mg/dL</td>
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<td>Acidemia</td>
<td>pH&lt;7.25</td>
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<tr>
<td>Creatinine</td>
<td>&gt;2.0 or&gt;50% increase from baseline values</td>
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</table>

Criteria ≥4 more likely to require MV>7 days  
Sensitivity-61.8%, Specificity 82%

DIFFICULT WEANING

- Respiratory causes
- Neuropsychologic causes
- Nutrition
- Cardiac causes
- Neuromuscular causes
- Metabolic
- Anaemia
• Sedation, analgesia
• Coma
• Raised intracranial pressure
• Hypercapnia

• Hypophosphataemia
• Disuse atrophy
• Sepsis
• Polyneuropathy/myopathy

• Hyperinflation
• Left ventricular failure
• Bronchospasm
• Lung fibrosis

Thorax 2002;57:986–991
Respiratory causes

- Lung disease
- Cardiovascular dysfunction
- Chest-wall disease
- Muscle weakness
- Diminished respiratory drive
- Impaired neuromuscular function

N Engl J Med
2012;367:2233-9
Respiratory or Ventilatory causes

• Increased ventilator demand
  • Hypoxemia
  • Elevated dead space
  • Excess carbon dioxide production
  • Metabolic acidosis
  • Neuropsychiatric factors
Factors affecting Respiratory mechanics

- Increased resistive load and Reduced compliance

**Increased airway resistance**
- Tube
- Central airways
- Small airways

**Reduced compliance**
- Chest wall
- Lung
Respiratory or Ventilatory causes

- Decreased ventilatory drive
  - Excess sedation
  - Metabolic alkalosis
  - Central nervous system disease
  - Central sleep apnea
  - Obesity hypoventilation syndrome
Ventilatory causes

Ventilator Circuit

• Equipment dead space
• Circuit compliance
• Exhalation valve dysfunction
• Increased resistance

Inappropriate Setting

• Ventilator dysynchrony - e.g., inadequate inspiratory flow rate or flow trigger setting
• Lead time between onset of inspiratory effort and the onset of flow delivery
• Respiratory effort after onset of exhalation
• Ineffective triggering
• Expiratory effort prior to switchover from mechanical inflation to exhalation
• High intrinsic PEEP
Respiratory or Ventilatory causes

Overventilation:

Patients with chronic hypercapnia → Minute ventilation that normalizes PaCO₂ → pH rises → Renal excretion of bicarbonate to normalize pH

Acute respiratory acidosis → Insufficient bicarbonate for buffering → SBT
When to suspect respiratory cause

• COPD, asthma and ARDS patients
• Reduced compliance
• Development of PEEPi:
  • Expiratory flow limitation
  • High breathing frequency
  • Loss of elastic recoil of the lung
  • Patient-ventilator asynchrony (ineffective triggering)
When to suspect respiratory cause

- PEEPi was found to be higher in COPD patients with weaning failure compared with those successfully weaned.

- Duration of mechanical ventilation was significantly longer in patients with ineffective triggering (>10% of all breaths) compared with those having lower incidence of ineffective triggering.

References:
- Respir Crit Care Med 1997, 155:906-915.
Diagnosis of respiratory causes

- PEEPi can be measured adequately is by using an esophageal balloon
Management of respiratory causes

• Changing the cycling-off criterion from 5% to 40% significantly reduce PEEPi and Work of breathing

• Patients with asthma and COPD should be treated optimally to reduce bronchoconstriction

• Optimizing compliance
  • Reducing edema of the lung and chest wall
  • Resolving atelectasis and thoracocentesis
  • Removing ascites
Cardiac causes

- Prevalence of weaning-induced cardiovascular dysfunction occur in up to 59% of patients

- Patients at high risk -
  1. Pre-existing cardiac disease
  2. COPD

Crit Care. 2016;20:369
Weaning may induce myocardial ischemia in susceptible patients
- Pulmonary edema
- Fluid overload

Cardiac causes

Diagram showing the relationship between
- Latent ischaemia
- Manifest ischaemia
- Decreased lung compliance
- Pulmonary edema
- SBT
- LV Compliance
- WOB – Weaning failure
Cardiac causes

• Dres et al. demonstrated that SBT-induced increases in BNP level by >12% suggest diagnosis of weaning-induced pulmonary edema contributing to weaning failure, with a sensitivity of 76% and a specificity of 78%

• PLR did not increase the cardiac index by >10% before the SBT, the occurrence of SBT failure related to cardiac dysfunction was predicted with a sensitivity of 97% and specificity of 81%
Cardiac causes

- Patients with COPD but without cardiac disease

  - Weaning attempt

    - Increased left ventricular afterload

      - Significant reduction in left ventricle ejection fraction

Intensive Care Med
1994, 20:181-186
Diagnostic methods to detect cardiovascular dysfunction

History-predisposing risk factors
   Clinical assessment
   Exclude other causes

Electrocardiogram
   Trans-thoracic Echocardiography
   Lung Ultrasound
   BNP

Confirmed weaning of cardiovascular origin
   Determine etiology and start treatment
Neuromuscular

• Impaired respiratory drive
  • Uncommon cause of weaning failure
  • In most weaning-failure patients, respiratory drive is increased

Am J Respir Crit Care Med
1996, 154:1099-1105
CRITICAL ILLNESS OXIDATIVE STRESS

Mitochondrial swelling, myofibril damage and increased lipid vacuoles. Oxidative modifications noted within 6 h

- Muscle atrophy
- Structural injury
- Fibre remodeling

Loss of diaphragm force-generating capacity that is specifically related to use of controlled mechanical ventilation
USG assessment for VIDD

- Anterior subcostal view- preferred method

- Diaphragmatic ultrasound using either excursion or thickening fraction has been demonstrated to perform at least equally or even better to other established weaning indices like rapid shallow breathing index-RSBI and maximum inspiratory pressure.

USG assessment for VIDD

- Cut off values for diaphragmatic ultrasound predicting successful weaning were MDT >2 mm, DTF >30% and DE >1.5 cm

- Early switch from controlled MV to assist ventilation (addition of PS and or PEEP) was associated with reversal of VIDD
Management of Neuromuscular causes

• Airway occlusion pressure at 100 ms (P\textsubscript{0.1})
  • The inspiratory limb of the ventilator is occluded and the drop in airway pressure is continuously monitored
  • P\textsubscript{0.1} depends not only on respiratory drive but also on inspiratory muscle capacity (non-specific sign)

• Maximal inspiratory pressure

• Development of hypercapnia during a weaning trial
Management of Neuromuscular causes

• Antioxidants
  • Antioxidants alpha-tocopherol and ascorbic acid was associated with a reduction in ventilator-dependent days from 4.6 to 3.7 (P <0.05)

• Tight glycemic control
  • Intensive glycemic control did not affect the duration of mechanical ventilation

Psychological issues

Oversedation

May limit ventilation

cooperation with a SBT
Psychological

• Depressive disorders: present in ~40% of patients undergoing weaning

• Patients with delirium: twice as likely to be difficult-to-wean

• Midazolam: risk factor for development of delirium
  • Sedation with dexmedetomidine reduces the incidence of delirium and reduces the duration of mechanical ventilation compared with sedation with midazolam

Intensive Care Med 2010; 36:828

Respirology 2016; 21:313

JAMA 2009, 301:489-499
Psychological causes: Diagnosis

<table>
<thead>
<tr>
<th>Items</th>
<th>Grading</th>
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<tbody>
<tr>
<td>1. Acute Onset or Fluctuation of Mental Status</td>
<td>0 absent&lt;br&gt;1 present</td>
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<tr>
<td>Is the patient different than his/her baseline mental status?&lt;br&gt;OR&lt;br&gt;Has the patient had any fluctuation in mental status in the past 24 hours as evidenced by fluctuation on a sedation/level of consciousness scale (i.e., RASS/SAS), GCS, or previous delirium assessment?</td>
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<tr>
<td>2. Inattention</td>
<td>0 absent (correct ≥ 8)&lt;br&gt;1 for inattention (correct 4–7)&lt;br&gt;2 for severe inattention (correct 0–3)</td>
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<tr>
<td>Say to the patient, “I am going to read you a series of 10 letters. Whenever you hear the letter ‘A,’ indicate by squeezing my hand.” Read letters from the following letter list in a normal tone 3 seconds apart. SAVEHAART (Errors are counted when patient fails to squeeze on the letter “A” and when the patient squeezes on any letter other than “A”)</td>
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<tr>
<td>3. Altered Level of Consciousness</td>
<td>0 absent (RASS 0)&lt;br&gt;1 for altered level (RASS 1, -1)&lt;br&gt;2 for severe altered level (RASS &gt;1, &lt; -1)</td>
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<tr>
<td>Present if the Actual RASS score is anything other than alert and calm (zero)</td>
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<tr>
<td>4. Disorganized Thinking</td>
<td>0 absent (correct ≥ 4)&lt;br&gt;1 for disorganized thinking (correct 2, 3)&lt;br&gt;2 for severe disorganized thinking</td>
</tr>
</tbody>
</table>
Nutritional

Protein catabolism

Underfeeding

Respiratory muscle weakness

Overfeeding

Carbon dioxide production

Ventilatory load

- Nutritional status evaluated by:
  BMI, plasma albumin concentration and nitrogen balance

Metabolic

- Metabolic disturbances
- Role of corticosteroids
- Hyperglycaemia
- Hypothyroidism
<table>
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<tr>
<th>Resistance</th>
<th>Airway / Lung Compliance</th>
<th>Gas Exchange</th>
<th>Delirium</th>
<th>Other Cognitive Dysfunction</th>
<th>Cardiac</th>
<th>Diaphragm</th>
<th>Endocrine</th>
<th>Endocrine Metabolic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment</td>
<td>Flow-time loops, inspiratory occlusion</td>
<td>Inspiratory / Expiratory occlusion</td>
<td>CAM-ICU</td>
<td>Screening: depression, anxiety, sleep pattern</td>
<td>12 lead ECG before and after SBT</td>
<td>Pi, max</td>
<td>Serial physical examination (other neuromuscular disorders)</td>
<td>Electrolytes, Blood gas, Indirect calorimetry</td>
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<tr>
<td>Intervention</td>
<td>Albumin, steroids</td>
<td>Repeat loops, inspiratory occlusion</td>
<td>Radiology: Plural fluid</td>
<td>Reorientation, Mobilization, Haloperidol</td>
<td>Anesthesiologist: Behavioral therapy</td>
<td>If ischemia: beta-blocker optimize hemoglobin</td>
<td>Early mobilization</td>
<td>Indirect calorimetry</td>
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<tr>
<td>Advanced Assessment</td>
<td>PEEP/ModVV/ECMO in PSV bronchodilators</td>
<td>Divertics, Physiotherapy</td>
<td>Thoracostentesis</td>
<td>Afterload reduction inotropes</td>
<td>Reduce anesthetic/ hypnotics</td>
<td>Phermic nerve conduction velocity</td>
<td>Transesophageal pressure using gastric and esophageal balloon</td>
<td>Muscle biopsy</td>
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<tr>
<td>Advanced Intervention</td>
<td>Diagnostic bronchoscopy during SBT</td>
<td>Neuropsychologist: depression, anxiety,</td>
<td>Pulmonary artery catheter</td>
<td>Diaphragm fluoroscopy / echocardiography</td>
<td>P_a, l</td>
<td>Examination by neurologist EMG, nerve conduction velocity</td>
<td>Plasma cortisol before / after 250 umol ACTH</td>
<td>Plasma thyroid hormone</td>
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<td>Rescue Assessment</td>
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<td>Cortisol iv</td>
<td>Thyroid hormone</td>
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<td>Rescue Intervention</td>
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Readiness for SBT trials

1. Cause of respiratory failure has improved
2. $\text{PaO}_2 / \text{FiO}_2 \geq 150$ or $\text{SpO}_2 \geq 90\%$ on $\text{FiO}_2 \leq 40\%$ and $\text{PEEP} \leq 5\text{cmH}_2\text{O}$
3. pH >7.25
4. Hemodynamic stability (no or low dose vasopressor medications)
5. Able to initiate an inspiratory effort

Chest 2001; 120:375S
Readiness for SBT trials

Additional criteria

1. Hemoglobin ≥7 mg/dL
2. Core temperature ≤38 to 38.5°C
3. Mental status awake and alert or easily arousable
Readiness for SBT trials

• Clinical assessment
• Objective measurements:

Clinical stability

Adequate oxygenation
• $\text{SaO}_2 > 90\%$ on $\leq \text{FiO}_2 0.4$ (or $\text{PaO}_2/\text{FiO}_2 \geq 150$ mmHg)
• PEEP $\leq 8$ cmH$_2$O

Adequate pulmonary function
• RR $\leq 35$ breaths/min
• MIP $\leq 20 - 25$ cmH$_2$O
• VT $> 5$ mL/kg
• VC $> 10$ mL/kg
• RR/VT $< 105$ breaths/min/L
• No significant respiratory acidosis

Adequate mentation

Eur Respir J 2007; 29: 1033–1056
Failure criteria of SBT

- Clinical assessment and subjective indices
  - Agitation and anxiety
  - Depressed mental status
  - Diaphoresis
  - Cyanosis
  - Evidence of increasing effort

- Objective measurements
  - $\text{PaO}_2 \leq 50-60 \text{ mmHg on } \text{FiO}_2 \geq 0.5$ or $\text{SaO}_2 < 90\%$
  - $\text{PaCO}_2 > 50 \text{ mmHg or an increase in } \text{PaCO}_2 > 8 \text{ mmHg}$
  - pH $< 7.32$ or a decrease in pH $\geq 0.07$ pH units
  - RR/VT $> 105 \text{ breaths/min/L}$
  - RR $> 35 \text{ breaths/min or increased by } \geq 50\%$
  - HR $> 140 \text{ beats/min or increased by } \geq 20\%$
  - Systolic BP $> 180 \text{ mmHg or increased by } \geq 20\%$
  - Systolic BP $< 90 \text{ mmHg}$
  - Cardiac arrhythmias
Perform daily assessment of patient’s readiness to undergo SBT

Ready

SBT for 30 min

SBT successful

Assess airway, cough, airway secretions, and mentation

Factors adequate

Extubate

Factors inadequate

SBT stopped because of tachypnea, poor gas exchange, or discomfort

Not ready

Resume ventilatory support

2012;367:2233-9
Assessment

• Simple Bedside Tests
  • Rapid shallow breathing
    • Frequency divided by tidal volume, f/v_t
    • Sensitivity of 0.97 with a specificity of 0.64

• Combined tests
  • Rapid shallow breathing combined with the occlusion pressure in the first 100 ms (P_{0.1}), an index of central drive
  • CROP index ((C_{dyn} \times P_{Imax} \times [PaO_2/PAO_2])/rate) which consisted of dynamic compliance (C_{dyn}), maximum mouth pressure (P_{Imax}), oxygenation (PaO_2/PAO_2), and respiratory rate

Am Rev Respir Dis
1993;148:860–6

N Engl J Med
1991;324:1445–50
Difficult Weaning – Mode of Ventilation

• Maintenance of a favorable balance between respiratory system capacity and load

• Attempt to avoid diaphragm muscle atrophy

• Aid in the weaning process
Available modes of weaning

**Conventional Modes**
- Spontaneous breathing trials
- Pressure support ventilation
- SIMV
- SIMV + PSV

**Newer Modes**
- Adaptive support ventilation
- Automatic tube compensation
- Proportional assist ventilation
- NAVA
- Non invasive positive pressure ventilation
Pressure Support

- Weaning by gradual pressure support (PS) reduction without an initial spontaneous breathing trial (SBT) versus PS-supported SBT: A pilot study

- Gradual reduction of PS without an initial SBT was found to be associated with better outcomes compared to once daily PS-supported SBT
T-piece vs SIMV

- After failed SBT, use of progressively increased time on a T-piece or use of PSV as weaning mode are effective means of liberating patients from the ventilator.

- Literature does not support the use of SIMV alone as a weaning mode.
Neurally adjusted ventilatory assist versus pressure support ventilation: a randomized controlled feasibility trial performed in patients at risk of prolonged mechanical ventilation

<table>
<thead>
<tr>
<th>Population</th>
<th>Intervention</th>
<th>Outcome</th>
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<tbody>
<tr>
<td>72 participants</td>
<td>NAVA</td>
<td>No significant differences were observed in duration of MV, ICU or hospital stay, or ICU, D28, and D90 mortality</td>
</tr>
<tr>
<td>open-label, parallel-group, randomized</td>
<td>PSV</td>
<td></td>
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<tr>
<td></td>
<td>NAVA catheters were inserted within 4 h of randomization</td>
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NIV

- Alternative weaning
- Prophylactic high risk for reintubation
- Post-extubation failure
RCT: NIV immediately after extubation improves weaning outcome after acute respiratory failure

• NIV prevented 48 hours reintubation if applied immediately after elective extubation in patients with more than 3 days of ARF when compared with the oxygen mask
Noninvasive Ventilation during Persistent Weaning Failure
A Randomized Controlled Trial

Kaplan–Meier curves for patients successfully weaned from mechanical ventilation, as defined. The first of the three days without ventilatory support, either invasive (dashed lines) or noninvasive (solid lines), was considered the end of the weaning process. The probability of weaning success was significantly higher for patients from the NIV group (solid lines) than in the conventional-weaning group (dashed lines) (log-rank test). Time denotes the period from intubation to final withdrawal of ventilatory support.

Am J Respir Crit Care Med 2003; 168: 70–76
Automated versus non-automated weaning for reducing the duration of mechanical ventilation for critically ill adults and children

- Pooled data from 16 eligible trials reporting weaning duration indicated that automated closed loop systems reduced the geometric mean duration of weaning by 30%.

- There was no strong evidence of an effect on mortality rates, hospital LOS, reintubation rates, self-extubation and use of non-invasive ventilation following extubation

- Prolonged mechanical ventilation > 21 days and tracheostomy were reduced in favor of automated systems
Role of tracheostomy

**Advantages**
- Easier airway management
- Improved patient comfort and communication
- Reduction in sedative use
- Earlier weaning from respiratory support
- Improved respiratory mechanics
- Earlier transition to oral feeding
- Reduced oropharyngeal trauma
- Prevention of VAP

**Adverse effects**
- Misplacement
- Hemorrhage
- Obstruction
- Displacement
- Impairment of swallowing reflexes and late tracheal stenosis.

Crit Care Med 1997; 25: 983–988

Crit Care Med 2004; 32: 2219–2226
Role of tracheostomy

• Timing
  • Early tracheostomy vs Late tracheostomy

• Outcome
  • Longer duration of MV and length of stay in tracheostomized patients
  • A retrospective 3-yr review of 549 patients with tracheostomy reported poor survival and functional outcomes

Chest 1997; 112: 745–751
Chest 2004; 125: 220–227
Summary

Patient Intubated

- Daily screen to assess readiness to wean
  - Thorough and systematic search for potentially reversible pathologies
    - SBT
      - Simple weaning
      - Difficult & Prolonged weaning
Summary

Difficult-to-wean patient

Respiratory / Cardiac / Neuromuscular / Neuropsychologic / Metabolic / Nutrition

Specific risk factors Diagnostics

Determine the cause and start treatment

SBT