Weaning from Mechanical Ventilation

Scott K. Epstein, MD
Dean for Educational Affairs
Professor of Medicine
Tufts University School of Medicine

Disclosure

• Receive royalties as author for a number of chapters on weaning in UpToDate
**Weaning Classification**

- **Simple Weaning (70%)**
  - 1<sup>st</sup> SBT successful, extubation successful

- **Difficult Weaning**
  - Fails 1<sup>st</sup> SBT (needs up to 3 SBTs)
  - 7 days from 1<sup>st</sup> SBT to successful weaning

- **Prolonged Weaning**
  - Fail at least 3 SBTs or
  - > 7 Days

- **Difficult + Prolonged = 30%**
  - ↑ mortality compared to Simple

*Brochard, ERJ 2004*
Weaning Classification

- **Simple Weaning (30-67%)**
  - 13% (0-11%)

- **Difficult Weaning (20-40%)**
  - 11% (13-21%)

- **Prolonged Weaning (6-30%)**
  - 13-32% (32-39%)

- **Difficult + Prolonged = 30-70%

Mortality: Funk, ERJ 2009, Sellares ICM 2011
Tonneller Resp Care 2011, Penuelas, AJRCCM 2011,
Extub Failure: Jeong PLoS One 2015; Thille CCM 2015

Criteria that suggest readiness for SBT/Weaning

- **Subjective Measurements**
  - Some resolution of acute disease process
    - Clinician believes weaning is possible

- **Objective Measurements**
  - Adequate oxygenation (PaO₂ ≥ 60 on FiO₂ ≤ 0.40,
    P/F ≥ 150; PEEP ≤ 5)
  - Stable cardiovascular system (no or minimal pressors)
  - Adequate mental status (GCS ≥ 11-13)
  - Afebrile (T < 38-38.5)
  - Adequate Hgb (≥ 8-10)
  - Favorable “parameters” (e.g. f < 35, Vₜ > 5ml/kg, NIF < -30)

30 % never satisfying criteria still liberated
Ely Intensive Care Med 1999
How do predictors perform?

- Systematic review of all studies
- Meta-analysis
- ~ 50 weaning predictors
- Only 5 of possible value in predicting
  - LR+ < 4 (small inc in prob of success)
  - LR ~ 0.1-0.3 (small-mod inc of failure)


**RCT of Weaning Predictor: f/VT, RSBI**

To pass the daily screen five criteria to be satisfied:
1. P/F ratio of ≥ 150; or SpO2 > 90% at FiO2 ≤ 0.4
2. PEEP ≤ 5 cm H2O
3. MAP of ≥ 60 mm Hg without vasopressor agents
4. awake or easily arousable
5. adeq cough during suctioning, does not require suctioning more often than every 2hrs

*Tanios et al, Crit Care Med 2006*
What mode for SBT?

484 pts MV >48h

N = 246 T-tube

N = 192 Passed, 78%

Reintubation
36 (18.7%)
38 (18.5%)

N = 238 PSV 7

N = 205 Passed, 86%

Esteban et al, AJRCCM 1997

Imposed WOB: It’s Real

• 10 trached patients
• PTP_{di}, TTI_{di}, f/Vt measured with 8 mm v 6.5 mm internal diameter
• Narrower tube: ↑PTP, TTI, f/Vt
• In vitro study of endotracheal tubes
  – Similarly ↑ resistance with narrower tube

Valentini et al. Respir Care 2012
Imposed WOB: PSV v T-tube

- 31 patients failing 30-min T-tube
- Immediately placed on PSV 7 cmH2O for 30 minutes
- 10 failed
- 21 succeeded – extubated
  - 17 success
  - 4 failed


Automatic Tube Compensation

- Adjusts PSV based on tube characteristics and throughout cycle
- Trend for SBT success, ATC (96%) v CPAP (85%), (Cohen Crit Care Med, 2006)
- No diff ATC v PSV (Cohen, Crit Care 2009)
SBT Duration

- **Zeggwagh** *ICM 1999*, 40% EF with SBT 2 min
- **Esteban** *AJRCCM 1999*
  - 30 v 120 min T-piece, No DIFF in WF or EF
- **Perren**, *Intensive Care Med 2002*
  - 30 v 120 min, PSV 7 cmH20, No Diff in WF or EF
- **BUT**
  - **Vitacca** (*AJRCCM 2001*): 75 COPD pts, MV for > 15 days
    - Median to time to trial failure = 120 minutes
  - **Teixeira** (*CCM 2010*): 73 pts failed > 1 SBT
    - Extubated after successful 30 min SBT: 43% EF

Criteria: Not Tolerating SBT

- **Objective**
  - PaO2/FiO2 < 150
  - ↑ PaCO2 > 10 or ↓ pH > 0.10
  - Resp rate > 35
  - HR > 140 or ↑ >20%
  - Syst BP < 90 or > 160 or Δ >20%

- **Subjective**
  - Signs of ↑ WOB (TA paradox or acc muscle use)
  - Other signs of distress (diaphoresis, agitation)

MDs & nurses underestimate breathlessness during **SBT** (*Haugdahl, AJRCCM 2015*)
Heart Rate Variability (HRV)

- Organ function variability – “natural mechanism reflecting adaptability of system” “response to stress”
- ↓ HRV may reflect ↑ catechols (sympathetic stimulation)
- 101 pts, 24 failed SBT, 13 reintubated
- Reduced HRV assoc with SBT failure
- ↑ HRV post extubation identifies ES

Huang et al Crit Care 2014

HRV & Resp Rate Variability (RRV)

- Multicenter prospective observational study of 721 pts, heterogeneous causes for MV
- Altered HRV & RRV, during SBT, associated with extubation failure
- Improved accuracy when combined with RBSI
- Of concern: 40% excluded because of protocol or technical violations or poor data quality

Seely et al Crit Care 2014
Patient Ventilator Asynchrony

• ↑ asynchrony (AI>10%) → ↑ duration of MV

• Patient-ventilator asynchrony during SBT
  – 6/15 (40%) during SBTs had trigger asynchrony
    (more likely to fail) (Tanios, AJRCCM 2002)

• Newer modes ↓ asynchrony (PAV or NAVA)

• Strategies to ↓ asynchrony have not clearly ↑
  weaning success

What questions should we ask when a patient fails?

✓ Can we identify the cause?
✓ Are the responsible factors reversible?
Transition to spontaneous breathing can be associated with an increased PAOP.

Lemaire et al, Anesthesiology 1988
May occur in 20-40% 

Teboul, Intensive Care Med 2014;40:1069
Detecting Weaning Induced Cardiac Dysfunction

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Cardiac Dysfunction Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA catheter</td>
<td>Did PAOP increase ≥10 mmHg?</td>
</tr>
<tr>
<td>Echocardiography</td>
<td>Did E/A and E/Ea ratios increase?</td>
</tr>
<tr>
<td>Blood sample</td>
<td>Did BNP increase ≥48 ng/l or ≥12%?</td>
</tr>
<tr>
<td>Blood sample</td>
<td>Did plasma protein and Hb concentrations increase ≥5-6%?</td>
</tr>
<tr>
<td>TP thermodilution</td>
<td>Did extravascular lung water increase ≥14%?</td>
</tr>
</tbody>
</table>


**Hemoconcentration/EVLW:** Dres CCM 2014

*From, Dres, Curr Op Crit Care 2014*

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Non-invasive Detection of Weaning Induced Cardiac Dysfunction

- Non-invasive CO at SBT start/end
- 85 pts, 34% failed SBT

*Tanios et al, Am J Crit Care, 2016;25:257*
Passive Leg Raising during SBT

Dres et al, Intensive Care Med 2015; 41:487

What SBT mode if cardiac dysfunction?

- 14 pts failed T-piece, PA catheter
- Pt effort (WOB and PEEPi) during SBT
  - T-piece > PSV+ZEEP > PSV+PEEP

Thille AJRCCM 2013, Cabello et al. Intensive Care Med 2010
Treating cardiac dysfunction

- **Nitrates** *(Routsi Crit Care 2010)*
  - 12 COPD, failed >3 SBT: ↑SBP, RPP, PA, PAOP
  - NTG: no physiol Δ, 11/12 extubated

- **BNP driven fluid management protocol** *(Mekontso-Dessap AJRCCM 2012;186:1256)*
  - Intervention grp more fluid restriction and diuretics
  - More neg fluid balance during weaning
  - Shorter time to successful weaning and extubation

- **ACE inhibitor for HFrEF**
- **Ca channel blocker for HFpEF**

What Mode for Weaning?

- **Ladeira et al, Cochrane Database Syst Rev 2014**
- Nine RCTs, 1208 patients
- No clear evidence of difference when comparing PSV to T-tube
- Get rid of SIMV
- But heterogeneity of patients may hide benefits in certain groups
A multicenter randomized trial of computer-driven protocolized weaning from mechanical ventilation

- Closed-loop system, interprets clinical data in real-time (N=144 patients)
- Continuously adjusts level of vent assistance
  - Adapts level of PS to keep pt in “comfort zone”
  - Resp rate, Tidal volume, PetCO2 below maximal threshold
  - When minimal PSV achieved: SBT
- CDW associated with:
  - ↓ Duration of weaning, duration of MV, ICU LOS
  - NO diff in complications

Automated Weaning

- **Australian study**, N=102, (Rose, ICM 2008)
  - Automated: No diff in dur weaning or MV
  - Why?: younger pts, Less ill, No COPD, 1:1 nurse:patient 24-h in house intensivist
- **Surgery pts**, N=300 (Schadler AJRCCM 2012)
  - Automated v written protocol, No difference
  - Cardiac surg pts, ↓ MV duration, earlier SBT
- **Automated v protocol**, N=92, (Burns AJRCCM 2013)
  - ↓ time to successful SBT, extubation (3 v 4d)
- **Meta-analysis, Automated**: ↓ duration of weaning, MV, LOS in mixed/medical ICU (Rose, Crit Care 2015)
NIV in Weaning, Meta-analysis

**Pooled Data**
16 RCTs, N=994, ~80% COPD
Mortality, RR 0.53
Weaning Failure, RR 0.63
VAP, RR 0.25
Duration of intubation, -5.6 d
Hosp LOS, -5.6 d
ICU LOS, -6.0 d
Reintubation, RR 0.65
Tracheostomy, RR 0.19
No effect on duration of weaning

Burns et al, Can Med Assoc J, 2014

VENISE Trial

- RCT, 208 patients, 13 French ICUs
- Inclusion: MV > 48 hrs, acute/chronic resp failure* (hypercapnia), failed SBT 5-120 minutes
- Three arms: Invasive weaning, NIV, Oxygen
- No diff: reintub, LOS, survival, complications
- Rescue NIV: 50% (successful in 50%)
- ~1/3 of pts randomized to O₂ did well w/o NIV

Girault et al, AJRCCM 2011:184:672
**NIV Weaning - Conclusions**

- Some Patients with Acute on Chronic RF (COPD) - *only in very select patients*
- SBT Readiness Criteria Satisfied
- Satisfies extubation criteria
  - CNS, cough, secretions (suction freq)
- Caveats (Good candidate for NIV)
  - Adequate interface; not a difficult reintubation
  - Able to breathe spontaneously for ~5-10 min

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**Daily Screen**

- P/F ≥ 200 & PEEP ≤ 5;
- Cough; No IV sedation;
- Hemodynamically Stable
- f/V̅T ≤ 105

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**300 patients**

- **Fail**
  - Intervention
  - **Pass**
  - 2 hr SBT
    - T piece CPAP-FB
    - Prompt MD

**Ely et al, NEJM 1996**
Protocols: Meta-analysis

- N=17 studies
- N= 2434 patients
- Weaning protocols:
  - Duration of Mech Vent ↓ by 26%
  - Duration of Weaning ↓ by 70%
  - ICU LOS ↓ by 11%
- Reductions were most likely to occur in medical, surgical and mixed ICUs, but not in neurosurgical ICUs *(exception Navalesi CCM 2008)*

Blackwood et al, Cochrane 2014

Strategies: ↓ duration MV

- Nursing/Resp Therapy
  - Thorens et al, CCM 1995 *(Better nursing ratio)*
  - Henneman et al, CCM 2001 *(Bedside communication sheet, flow sheet)*
- Sedation protocols (RCTs)
  - Brook et al, Crit Care Med 1999 *(algorithm)*
  - Kress et al, N Engl J Med 2000 *(daily cessation or DIS)*
  - Girard et al, Lancet (ABC) 2008 *(SAT + SBT)*
    - ↑ vent-free days, ↓ time in coma, ↓ ICU, hosp LOS, ↑ One year survival
  - de Wit et al Crit Care 2008 *(protocol vs DIS)*
  - Mehta et al, JAMA 2013 *(protocol vs protocol+DIS)*
- Early Physical Therapy
  - Schweikert, Lancet 2009 *(1-2d post MV)*
What are the consequences of delaying extubation?

- Prosp study 136 brain injured patients
- Criteria used to determine readiness for extubation (q day)
- Extubation delay: # of days between readiness day and extubation (less 48h)
- 27% experienced extubation delay

Coplin et al. AJRCCM 2000

Extubation Failure

N~35,000 (60 studies)
Outcome of Extubation Failure

Outcome of Extubation Failure (EF) - Frutos-Vivar et al, J Crit Care 2011

- 1152 extubated pts, 29% met EF criteria (16% reintubated)
- EF: older, higher severity of illness, pneumonia
- EF & reintubation independently assoc with mortality
- ↑ ICU mortality: complications after reintubation
  - Organ failure: CV (27%), renal (12%), hepatic (8%), hematologic (7%)
  - Complications (most in 1st 72 h): VAP (31%), sepsis (21%), acute resp distress (12%)

Thille et al, Curr Opin Crit Care 2013
Direct and Specific Effect of Extubation Failure

**Procedural Complications of Reintubation**

- Registry of >1000 pts, looked at 151 with repeated intubation
- Last intubations associated with more complications (13%)
  - New sustained hypotension (41%)
  - Hypoxia (35%)
- ↑ risk with ↑ time (>72h) between extub & reintub
- Given no ↑measurable marker of technical difficulty – patient physiologic factors rather than airway anatomic factors

*Thille A et al, Crit Care Med 2011

*Elmer et, Crit Care 2015*
Who’s at risk for EF?

- Increased age (>65 yrs)
- Pneumonia
- Chronic Resp/Cardiac disease
- Diaphragm dysfunction
- + fluid balance within 24 hrs
- Severity of illness at time of extubation
- Weak cough
- Increased secretions
- ↑ PaCO2 during SBT or immediately after extubation
- Post-extubation dysphagia

Can we accurately predict extubation outcome?

- Traditional predictors
- Modification of traditional predictors
- What does the patient think (Perren ICM 2010)
- Ability to protect the airway
  - Strength of cough (qualitative, quantitative)
  - Volume of secretions (qualitative, quantitative)
- Patency of upper airway (cuff leak test)
- Mental status (sedation, GCS, delirium)
- Integrated
Upper Airway Obstruction

- Majority MV for >24h → laryngeal lesions (Tadie, ICM 2010:36:991)
  - Laryngeal edema occurs in 5-15%
  - Post-extubation stridor 6-37%
  - UAO is cause of EF in 7-20%
- At risk: women, ETT too large for trachea, difficult intubation, prolonged intubation, UA trauma
- Pre-extub syst steroids ↓ stridor & ↓ reintubation*
- Cuff leak test (CLV <110-130 ml OR <10-24%)

CLV = 600 - 550 = 50

Positive Cuff Leak Test

Two meta-analyses*: Reintubation
LR+ (4-6), LR- (0.5)

*Ochoa ICM 2009, Zhou JEBM 2011

CLV = 600 - 600 = 0

False Positive Cuff Leak Test

Secretions
Upper Airway Obstruction

- Measure cuff leak test but only in high risk patients
- If positive (suggesting UAO)
  - Delay extubation 12-24 hrs
  - Methylprednisolone 20-40mg every 4-6 hrs for 12-24 hours
- Alternatives: extubate over an airway exchange catheter or have difficult airway cart at bedside

Prinianakis, Crit Care 2005
Assessment of cough

0 = no cough on command
1 = audible movement of air thru ETT but no audible cough
2 = weak (barely) audible cough
3 = clearly audible cough
4 = stronger cough
5 = multiple sequential strong coughs

Duan et al, AJCC 2015;24:e86

Putting it all together to predict extubation outcome

Can’t complete 4 simple commands
PCF ≤ 60 L/min
Secretions > 2.5 ml/h

Secretions: Suction > q2h

Salam et al, Intensive Care Med 2004
Mokhlesi Respir Care 2007
• N=225, MV >24hrs, 14% reintubation

1/3 reintubated considered at high risk by care givers
• *indep risk factors in multivariate analysis (if all absent 5% risk for reintubation)

Thille et al, CCM 2015:43:613

NIV: Non-invasive ventilation

Demoule et al, Intensive Care Med (2016) 42:82
NIV in Extubation Failure

- **Case control**: COPD patients *(Hilbert ERJ 1998)* - Yes,
- **RCTS**
  - Overt ext. failure *(Keenan, JAMA 2002)* - No
  - Early signs of ext. failure *(Esteban, NEJM 2004)* – No
  - Preventive: unselected *(Su, Resp Care 2012)* - No
  - **Preventive: high risk for ext. failure** – Yes
    - Fail > 1 SBT, CHF, PaCO2 > 45, comorbidity, airway at risk *(Nava, CCM 2005)*
    - Age > 65, CHF, APACHE II > 12 *(Ferrer AJRCCM 2005)*
    - Hypercapnia at end of SBT *(Ferrer Lancet 2009)*
- **Meta-analysis**: 9 studies, NIV ↓ reintubation rate, ICU LOS, mortality *(Bajaj, Heart & Lung 2015)*

High Flow Nasal Cannula (HFNC)

- Improved oxygenation
- Clearing of anatomic dead space
- Improved mucociliary/secretion clearance
- ↑ EELV, ↓resp rate, ↓ Asynchrony
- ↓ WOB
- Improved comfort, ↓ complications

HFNC after Extubation

• RCT v Venturi (Maggiore Am J Resp Crit Care Med 2014)
  – v. air entrainment mask (N=105), P/F≥300
  – ↓ postextubation resp failure (7.5 v 34.6%)
  – ↓ need for NIV (3.8 v. 15.4%)
  – ↓ reintubation (3.8% v. 21.2%)

• RCT v NIV (Stephan JAMA 2015), noninferiority
  – Post extubation in 830 high risk cardiac surg pts
  – Failed SBT, or high risk for EF: No diff in reintubation

• RCT v SOT for 24h (Hernandez JAMA 2016)
  – ↓ reintubation (5% vs 12%) in 527 low risk patients

HFNC – Cautionary Note

– 175 patients intubated after HFNC
– 130 before 48h, 45 after 48h (late)
– Late group
  • Higher ICU mortality (67 v 39%)
  • Lower extubation success
  • ↓ Vent free days
  • More frequent complications
– HFNC may delay intubation

Kang et al, Intensive Care Med 2015;41:623
Mechanical Insufflation-Exsufflation (MIE)

- 75 patients ventilated for >48h (~10d)
- RCT: MIE v standard care (NIV allowed in both groups)
- MIE: One RX pre-extubation → 3 daily sessions
  - ↓ reintubation (17 v 48%)
  - ↓ retub (NIV failure) (6 v 33%)
  - ↓ LOS post-extubation (3 v 10d)

*Goncalves, Crit Care 2012:16:R48*

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**B-mode**

![B-mode image](image1)

**M-mode**

![M-mode image](image2)

*Goligher et al, Intensive Care Med 2015*
Ultrasound - Diaphragm

- Study of 88 pts, M-mode (*Kim CCM 2011*)
  - Diaphragm dysfunction (vertical excursion <10 mm or paradox), present in 29% of patients (uni 20/ bi 4)
  - longer weaning time (17 v 4d)
- Study of 63 pts, 14 EF (*DiNino Thorax 2014*)
  - B-mode: measure diaphragm thickening (tdi) in zone of apposition during SBT (PS,T piece)
  - predict ES (Δtdi ≥ 30%): Sens 88%, Spec 71%, PPV 91%, NPV 63% (more accurate than RSBI)

Ultrasound – Lung Parenchyma

- Prospective study of 100 patients
  - 14 WF, 86 extubated (29 or 34% EF)
  - Among those passing SBT, lung derecruitment greater in those with EF
  - Derecruitment: UAO, pneumonia, CHF, secretion aspiration, ineffective cough, muscle weakness
  - LUS < 13, low risk for EF (LR_{neg} = 0.2)
  - LUS > 17, high risk for EF (LR_{pos} = 12)

Soumer et al, Crit Care Med 2012:40:2064
Prolonged MV > 14-21 d

- ~50% weaned, ~70% hosp surv, ~40% 1-yr surv, ~20 d/c home\textsuperscript{1,3}
- 10-32% don’t need “weaning”\textsuperscript{2,6,7}
- RCT: ↓ median weaning time, trach v. PSV\textsuperscript{7}
- RCT: deflating cuff ↓ wean time v. inflated\textsuperscript{8}
- WS: ↑ Pimax, ↑ Pdimax, ↓ Pdi/Pdimax, ↓ TTI\textsuperscript{4}
- Inspray train: ↓ wean time\textsuperscript{9,10}
- WF: Anxiety, Depression, PTSD\textsuperscript{5}

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1. Scheinborn, Chest 2007
2. Vitacca, AJRCCM 2001
4. Carlucci, J Crit Care 2009
5. Jubran, ICM 2010
7. Jubran, JAMA 2013
8. Hernandez, ICM 2013
9. Martin, Crit Care 2011

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Assess Readiness

RT-RN Driven Protocol

30-120 min SBT

Airway Cough Secretions Mental status

Extubate, NIV/HFNC

Progressive Withdrawal / NIV

Rest

Identify and Treat Reversible Causes of Failure

Full Ventilatory Support

Not Ready

Assess

Fail

Weaning Predictors Unnecessary

Not Ready

Assess

Fail