Weaning From Mechanical Ventilation Basic Concepts

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Conflicts of Interest

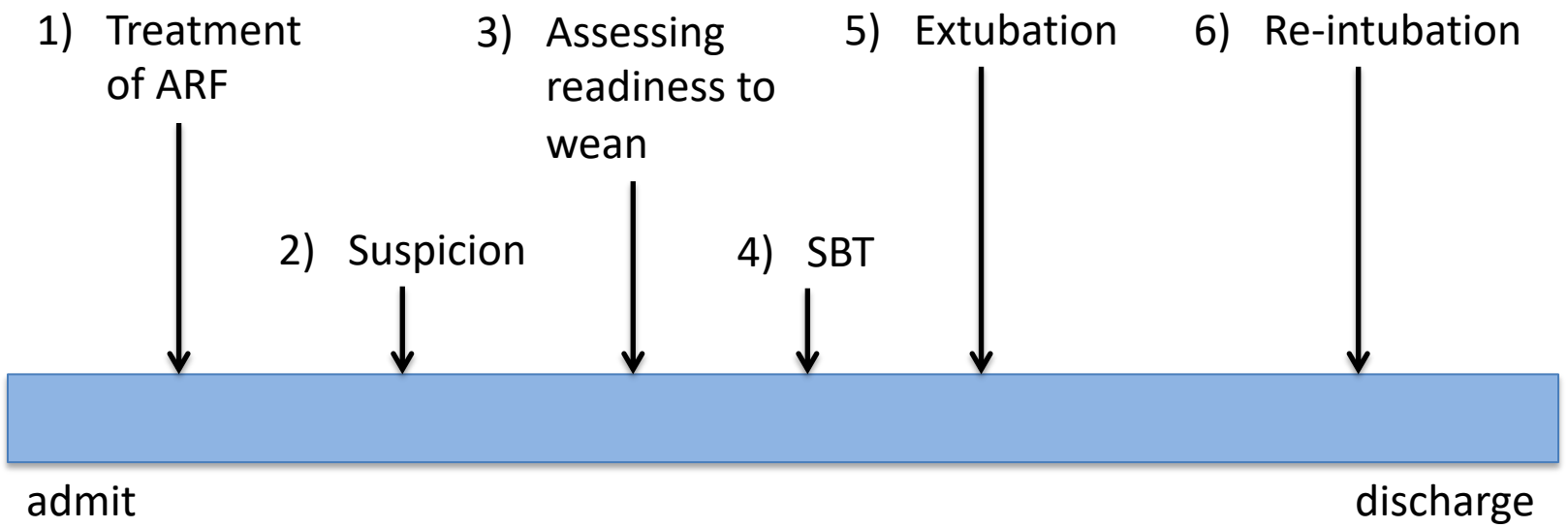
- Tyco
- Draeger
- Maquet
- Taema
- Carefusion
- Hamilton
- GE Healthcare

Why Weaning So Important?

- Weaning tends to be delayed, leading to unnecessary discomfort and increased risk of complications
  - Time spent in the weaning process representing 40 – 50% of the total duration of mechanical ventilation
  - Prolonged mechanical ventilation in 6% of all ventilated patients
  - Almost half of patients with self-extubation during the weaning period do not require reintubation

Boles JM, Bion J, Connors A, et al. Weaning from mechanical ventilation. Eur Respir J 2007; 29: 1033-1056

Weaning Process



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Stages of Mechanical Ventilation: Definition

Stages	Definitions
Treatment of ARF	Period of care and resolution of the disorder that caused respiratory failure and prompted mechanical ventilation
Suspicion	The point at which the clinician suspects the patient may be ready to begin the weaning process
Assessing readiness to wean	Daily testing of physiological measures of readiness for weaning (MIP, f/Vt) to determine probability of weaning success
Spontaneous breathing trial	Assessment of the patient's ability to breathe spontaneously
Extubation	Removal of the endotracheal tube
Re-intubation	Replacement of the endotracheal tube for patients who are unable to sustain spontaneous ventilation

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Weaning Success and Failure: Definition

- Weaning success
  - extubation and the absence of ventilatory support 48 hrs following the extubation
- Weaning failure
  - failed SBT, or
  - reintubation and/or resumption of ventilatory support following successful extubation, or death within 48 hrs following extubation
- Weaning in progress
  - continuation of ventilatory support by NIV after extubation

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Weaning Success and Failure: Definition

- Failure of SBT
  - Objective indices of failure, such as

    tachypnoea, tachycardia, hypertension, hypotension, hypoxaemia or acidosis
  - Subjective indices, such as

    agitation or distress, depressed mental status, diaphoresis, and evidence of increasing effort

Boles JM, Bion J, Connors A, et al. Weaning from mechanical ventilation. Eur Respir J 2007; 29: 1033-1056

Classification of Patients According to the Weaning Process

Group/Category/Definition	Prevalence	ICU mortality	Hospital mortality
Group 1: Simple weaning Patients who proceed from initiation of weaning to successful extubation on the first attempt without difficulty	**~69%**	**~5%**	**~12%**
Group 2: 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	**~16%**	**25%**	
Group 3: Prolonged weaning Patients who fail at least three weaning attempts or require > 7 days of weaning after the first SBT	**~15%**	**25%**	**32%**

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Classification of Patients According to the Weaning Process

TABLE 2 Incidence of weaning success and failure

First author [Ref.]	Yr	Subjects	Failed initial SBT	Passed Initial SBT	Re-intubated	Total failed weaning	Successful weaning
FARIAS [24]	2001	257	56 (22)	201	28 (14)	84 (32.7)	173
ESTEBAN [22]	1999	526	73 (14)	453	61 (13)	134 (25.5)	392
VALLVERDU [17]	1998	217	69 (32)	148	23 (16)	92 (42.4)	125
ESTEBAN [25]	1997	484	87 (18)	397	74 (19)	161 (33.3)	323
ESTEBAN [16]	1995	546	130 (24)	416	58 (14)	188 (34.4)	358
BROCHARD [18]	1994	456	109 (24)	347	8 (3)	117 (25.6)	339
Total		2486	524/2486 (21%)	1962/2486 (79%)	252/1962 (13%)	776 (31.2%)	1710/2486 (68.8%)

Data are presented as n or n (%), unless otherwise stated. SBT: spontaneous breathing trial

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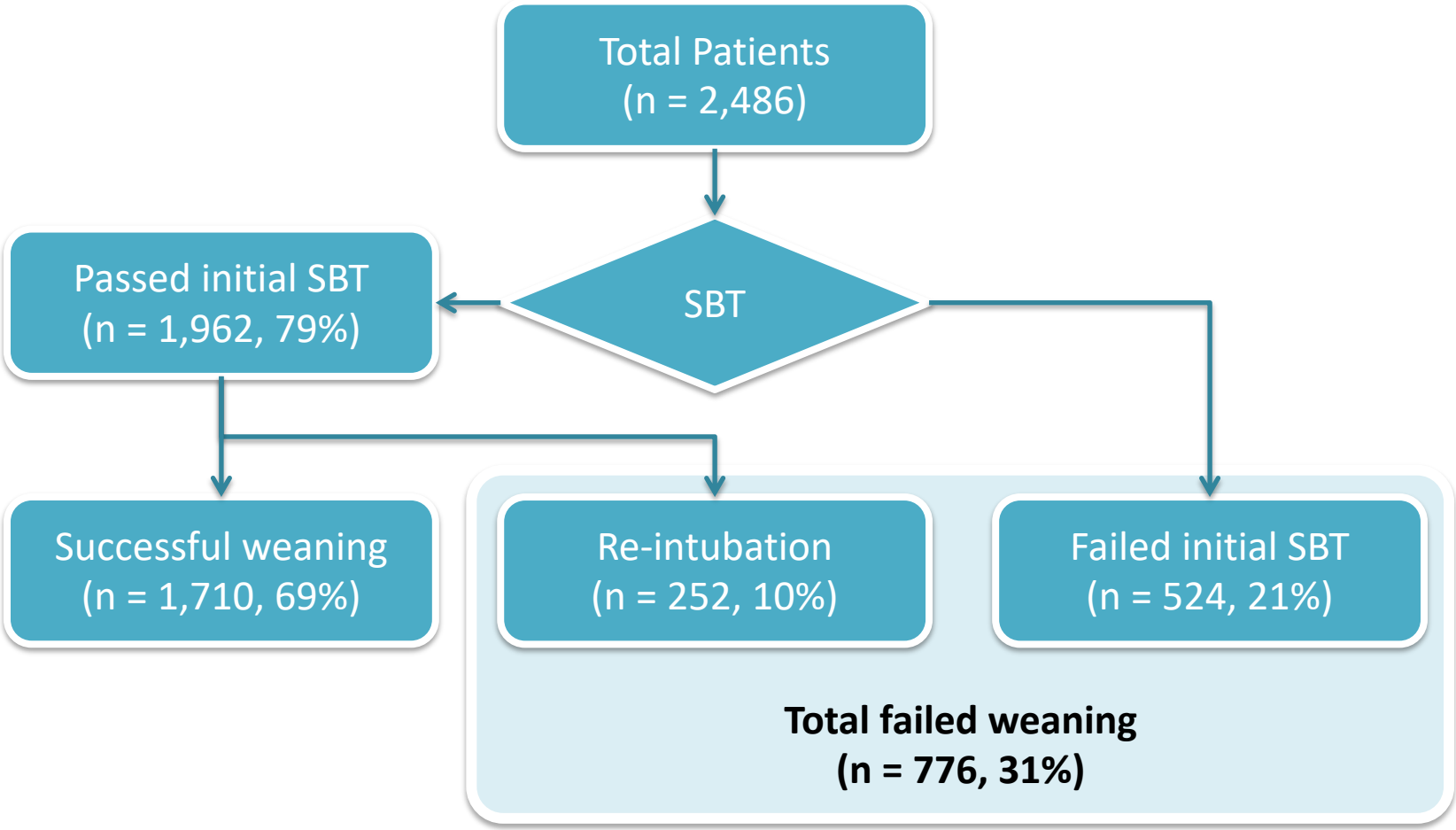
Classification of Patients According to the Weaning Process



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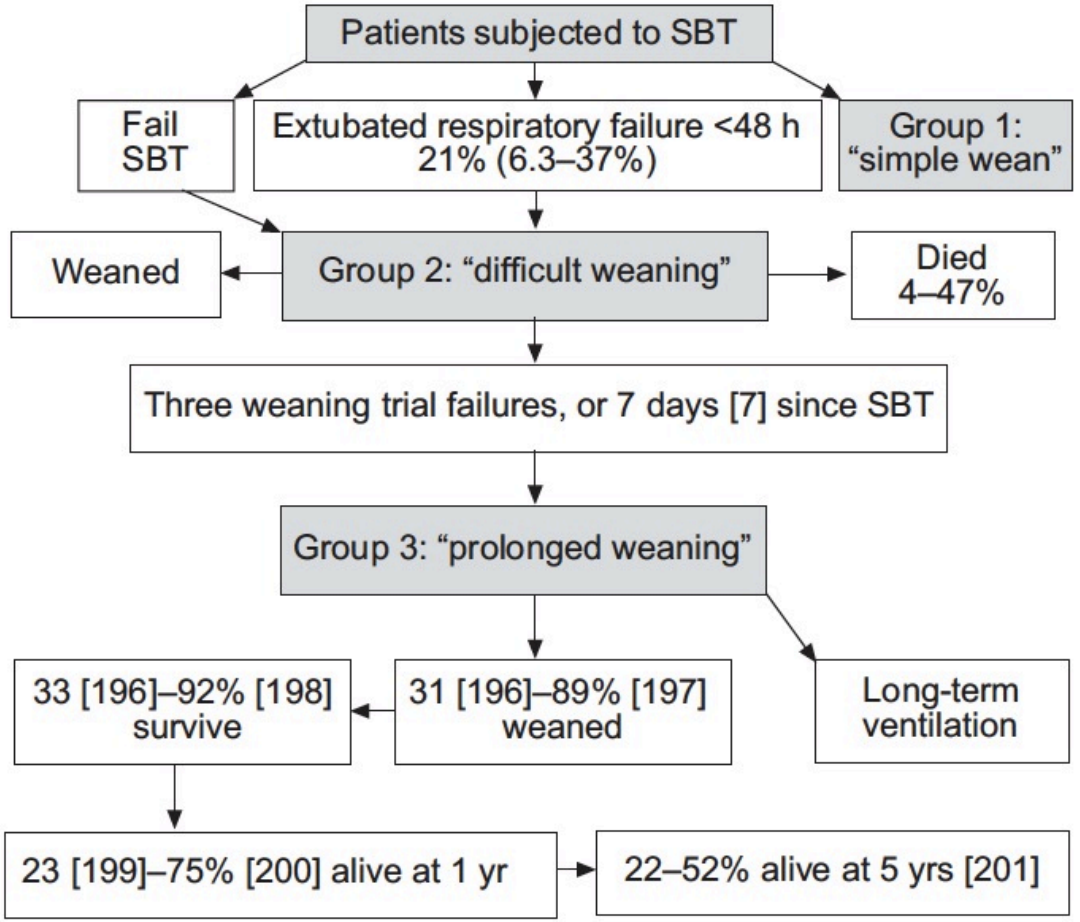
Mortality and Weaning Process in Patients With Prolonged Weaning Failure



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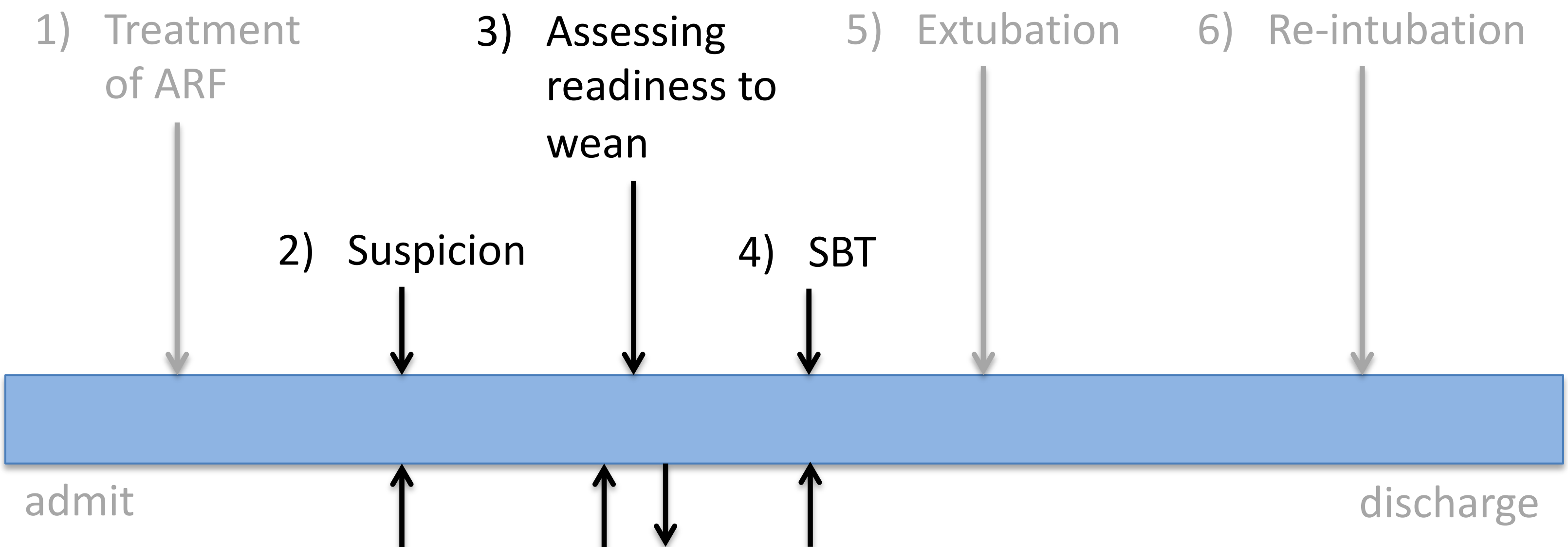
Weaning Process



begins when clinician first thinks there is reasonable probability of weaning success

begins when the clinician actually initiates a process of daily tests of readiness to wean in order to confirm the suspicion

ends when the results of the daily tests [illegible] probability [illegible] high enough level to justify an SBT

[illegible] first SBT, use a T-tube trial, or a low level pressure support (≤8 cmH_2O)

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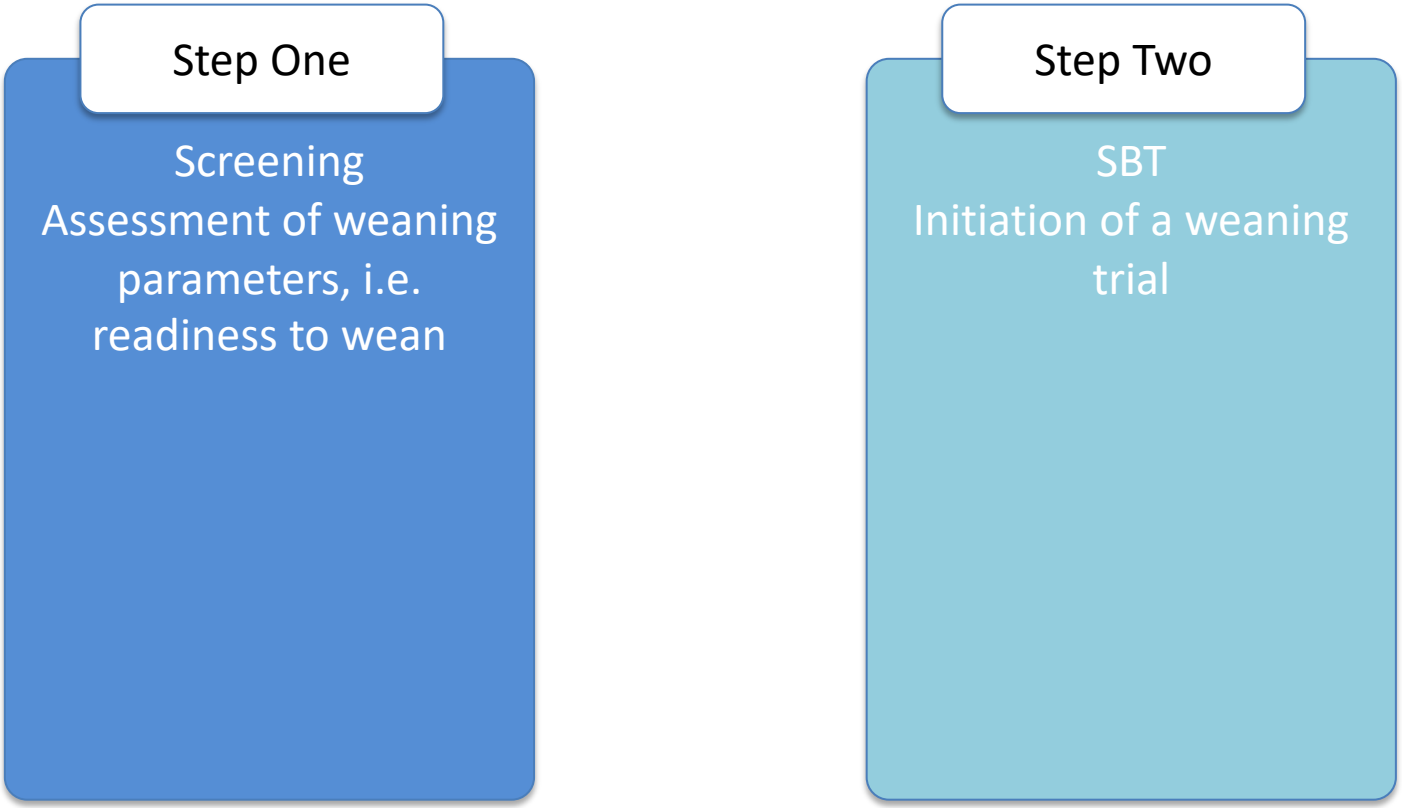
Two-Step Diagnostic Approach for Extubation



Heunks LM, van der Hoeven JG. Clinical review: The ABC of weaning failure – a structured approach. Crit Care 2010; 14: 245

Readiness to Wean

Table. Considerations for Assessing Readiness to Wean*

Clinical assessment	Adequate cough
	Absence of excessive tracheobronchial secretion
	Resolution of disease acute phase for which the patient was intubated
Objective measurements	Clinical stability
	Stable cardiovascular status**
	Stable metabolic status
	Adequate oxygenation
	SaO_2 > 90% on FiO_2 ≤ 0.4 (or PaO2/FiO_2 ≥ 150 mmHg)
	PEEP ≤ 8 cmH_2O
	Adequate pulmonary function
	f ≤ 35 bpm
	MIP ≤ -20 to -25 cmH_2O
	Vt > 5 ml/kg
	VC > 10 ml/kg
	f/Vt < 105 bpm/L
	No significant respiratory acidosis
	Adequate mentation
	Non sedation or adequate mentation on sedation (or stable neurologic patient)

*Since many patients who do not meet all the criteria in table are able to wean successfully from mechanical ventilation, these criteria should be viewed as considerations for probable weaning rather than as strict criteria that must all be met simultaneously.
**HR 140 ≤ bpm, SBP 90 – 160 mmHg, no or minimal vasopressors

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Spontaneous Breathing Trial (SBT)

- T-piece trial
- Low-level pressure support
  - 7 or 8 cmH_2O for adults
  - 10 cmH_2O for paediatric patients
- CPAP
- Automatic tube compensation (ATC)?

Spontaneous Breathing Trial

Table. Failure Criteria of Spontaneous Breathing Trial

Clinical assessment and subjective indices	Agitation and anxiety
	Depressed mental status
	Diaphoresis
	Cyanosis
	Evidence of increasing effort
	Increased accessory muscle activity
	Facial signs of distress
	Dyspnea
Objective measurements	PaO_2 50 – 60 mmHg on $FiO_2 \geq 0.5$ or $SaO_2 < 90\%$
	$PaCO_2 > 50$ mmHg or an increase in $PaCO_2 > 8$ mmHg
	pH < 7.32 or a decrease in pH 0.07 ≥ pH units
	f/Vt > 105 bpm/L
	f > 35 bpm or increased by ≥ 50%
	HR > 140 bpm or increased by ≥ 20%
	SBP > 180 mmHg or increased by ≥ 20%
	SBP < 90 mmHg
	Cardiac arrhythmias

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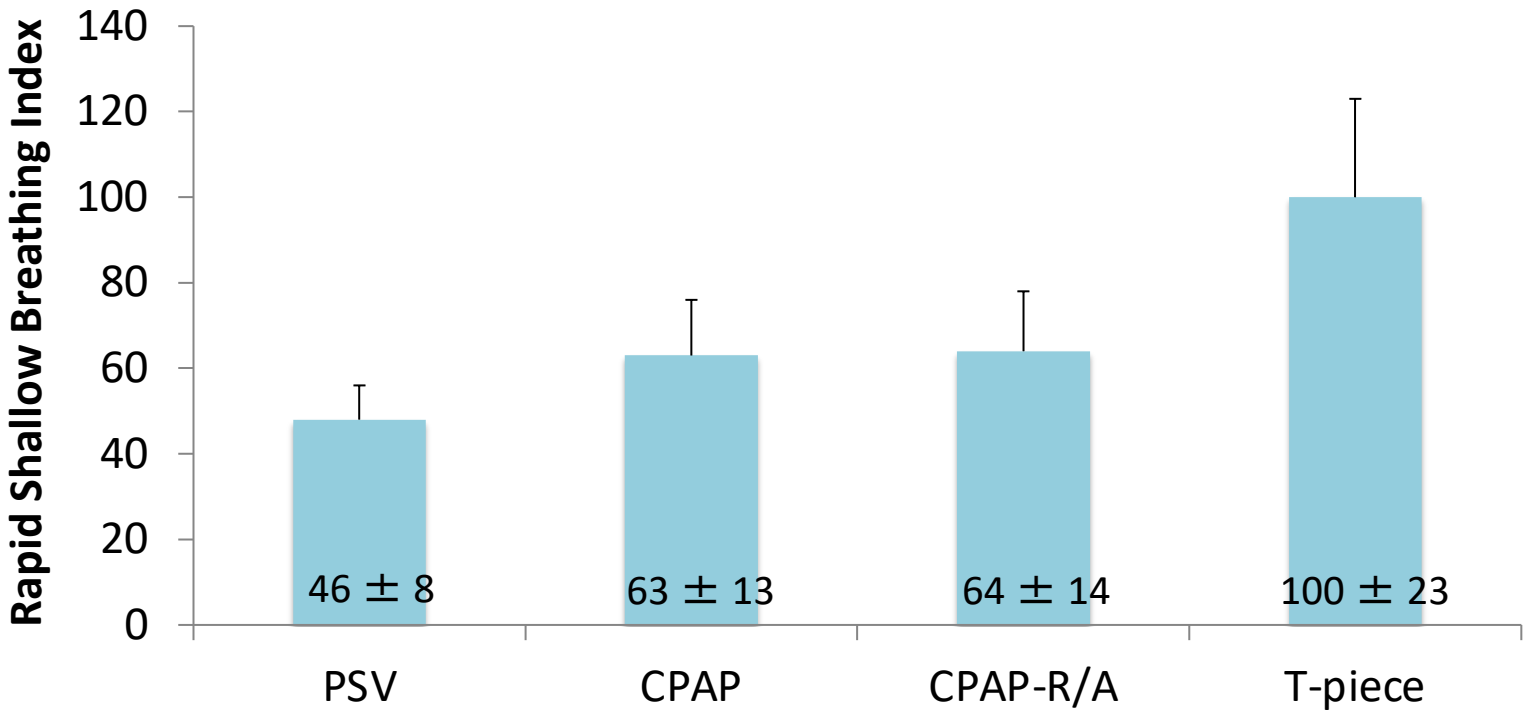
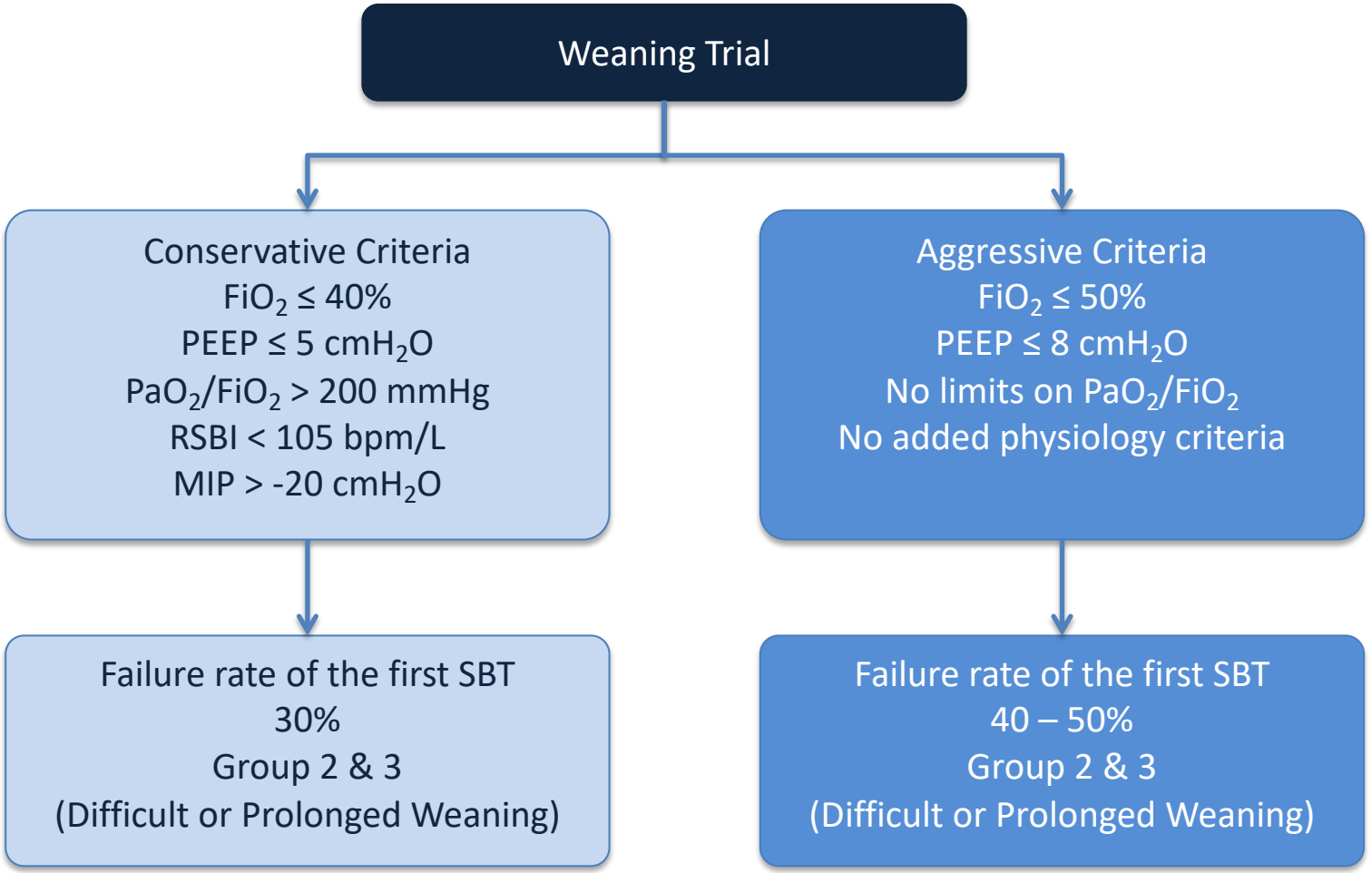
Pressure Support and RSBI



	PSV	CPAP	CPAP-R/A	T-piece
PS	5	0	0	0
PEEP/CPAP	5	5	5	0
FiO_2	40	40	21	21

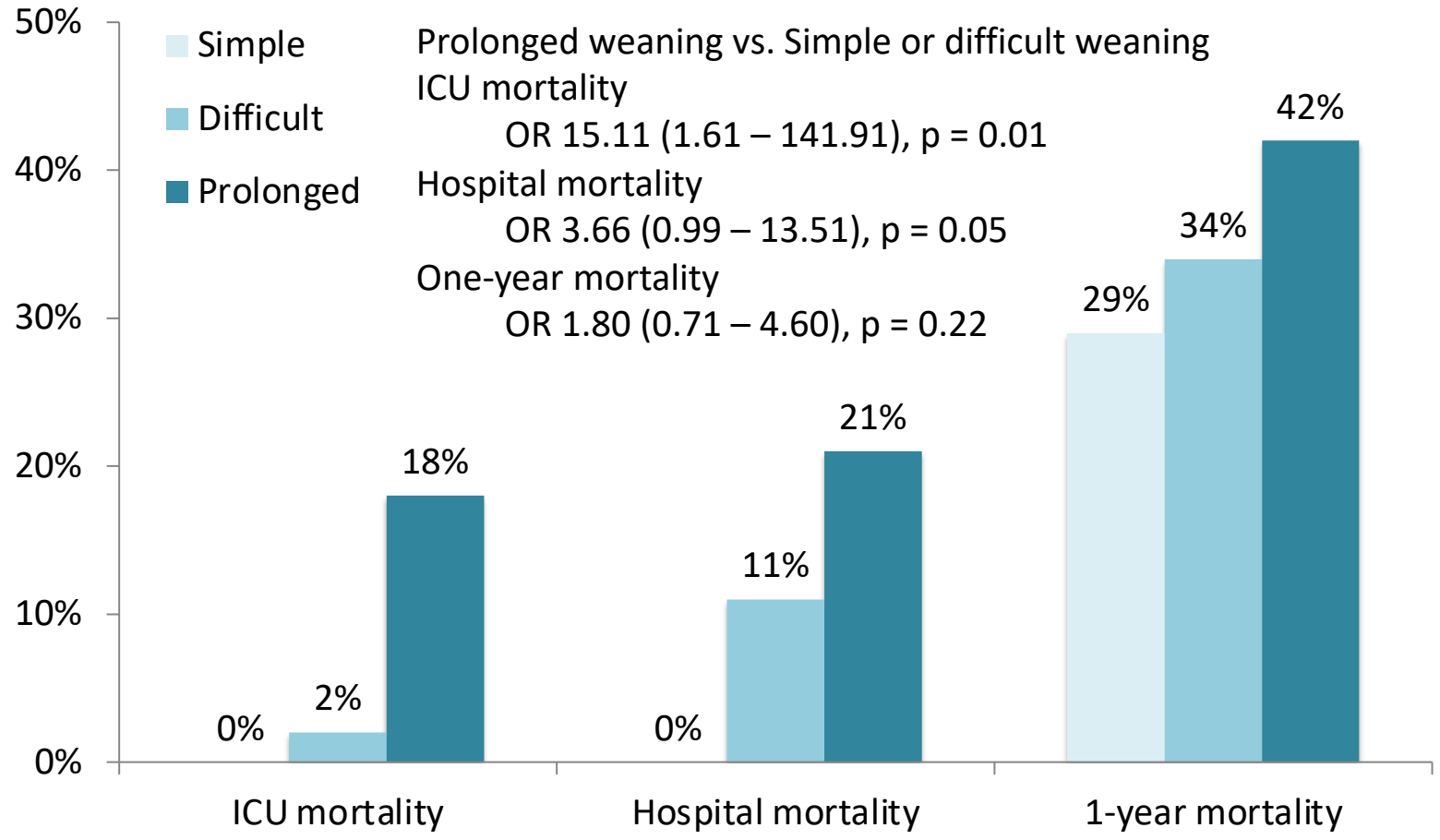
El-Khatib MF, Zeineldine SM, Jamaleddine GW. Effect of pressure support ventilation and positive end expiratory pressure on the rapid shallow breathing index in intensive care unit patients. Intensive Care Med 2008; 34: 505-510

Weaning Strategy: Different Protocols



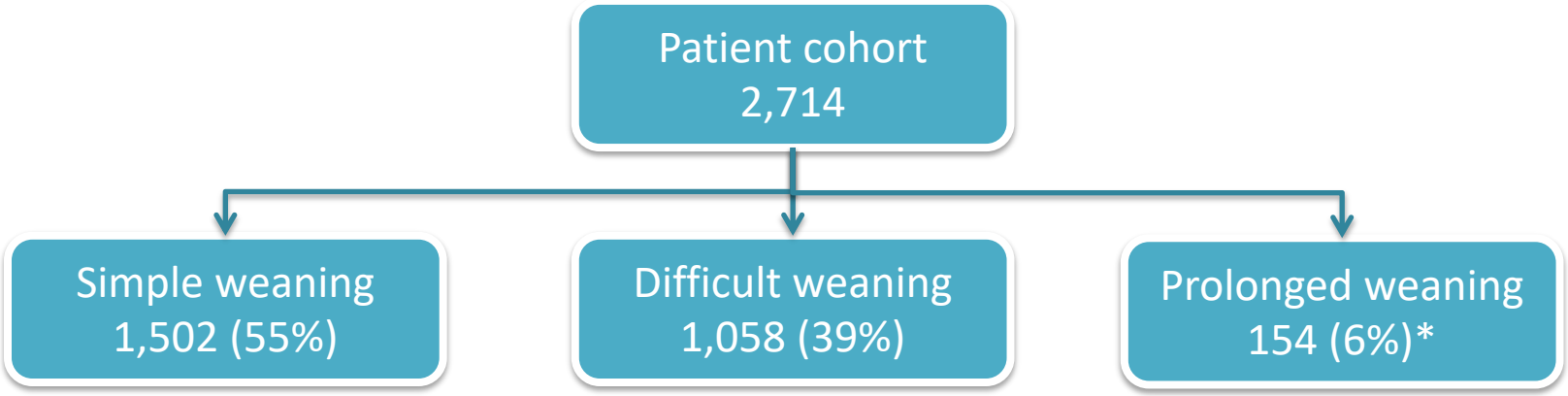
Thille AW. Simple, difficult, or prolonged weaning: the most important factor is the success or failure of the first weaning trial. Respir Care 2011; 56: 716-717

Weaning Strategy: Different Protocols



Tonnelier A, Tonnelier JM, Nowak E, et al. Clinical relevance of classification according to weaning difficulty. Respir Care 2011; 56: 583-590

Classification of Patients According to the Weaning Process

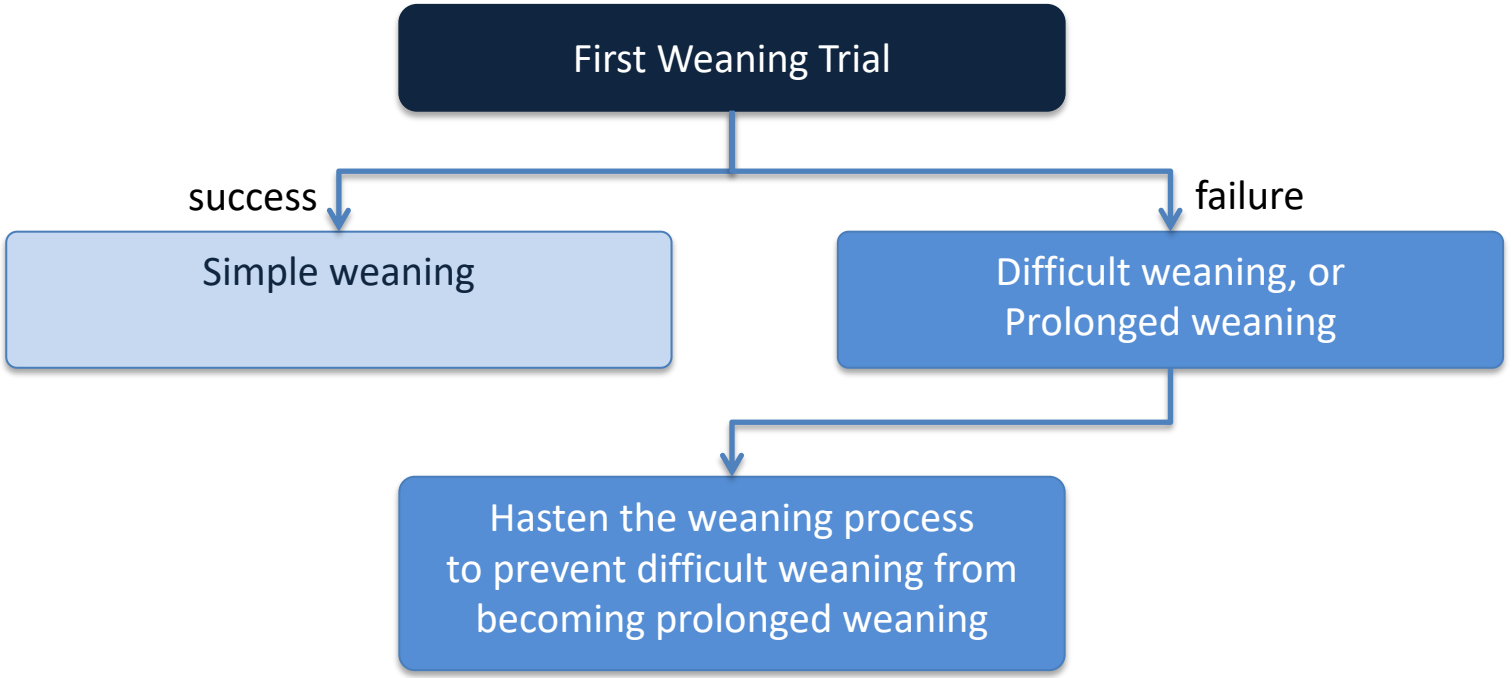


Variable associated with prolonged weaning	OR	95%CI
SAPS II	1.01	1.001 – 1.02
Duration of mechanical ventilation	1.10	1.06 – 1.13
Chronic pulmonary disease other than COPD	13.23	3.44 – 51.05
Pneumonia as the reason to start mechanical ventilation	1.82	1.07 – 3.08
Level of PEEP before weaning	1.09	1.04 – 1.14

*OR for ICU mortality 1.97, 95%CI 1.17 – 3.31

Penuelas R, Fruto-Vivar F, Cristina Fernandez C, et al. Characteristics and outcomes of ventilated patients according to time to liberation from mechanical ventilation. Am J Respir Crit Care Med 2011; 184: 430-437

Weaning Strategy



Thille AW. Simple, difficult, or prolonged weaning: the most important factor is the success or failure of the first weaning trial. Respir Care 2011; 56: 716-717

Evaluation of Difficult Weaning

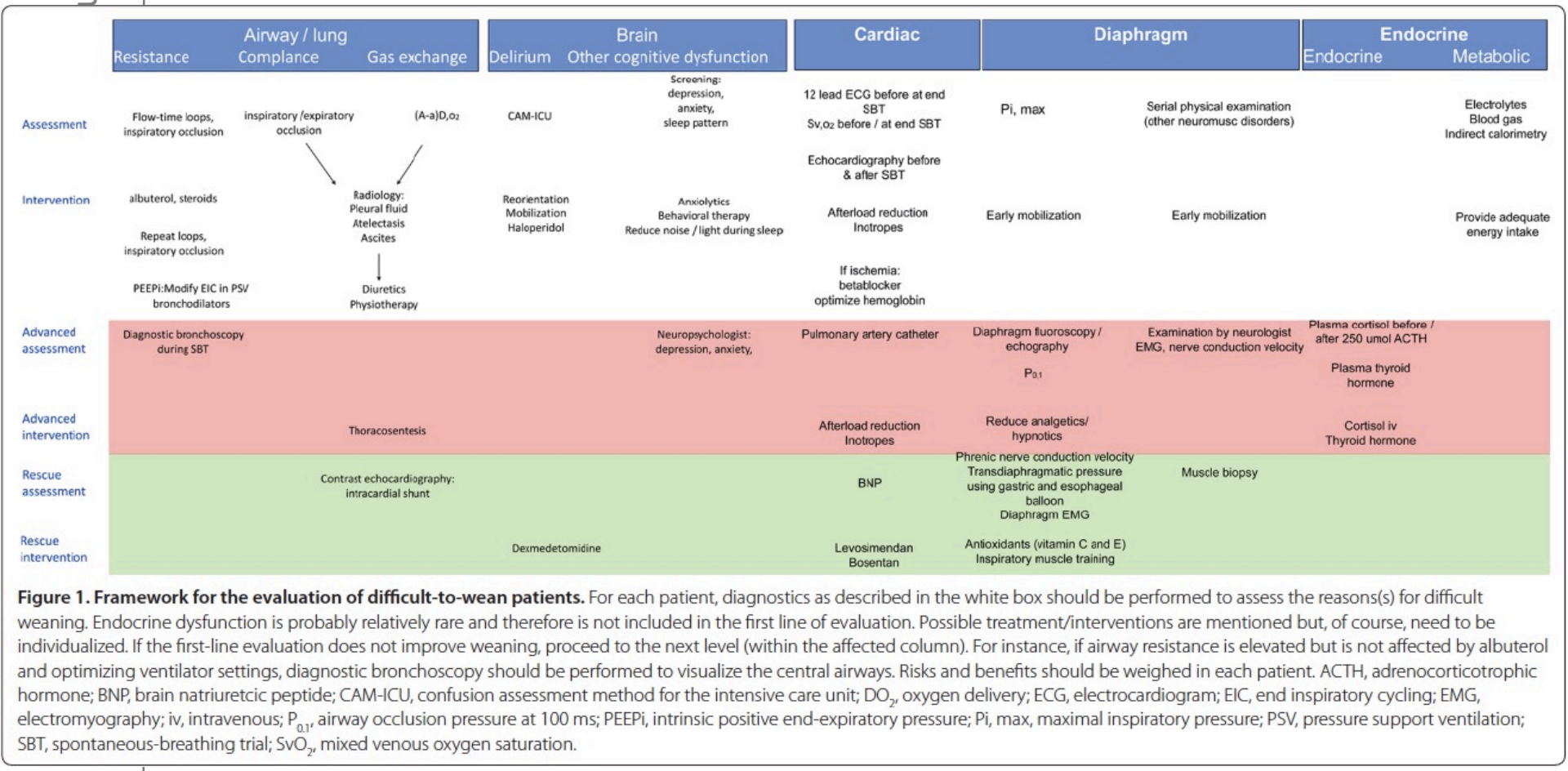


Figure 1. Framework for the evaluation of difficult-to-wean patients. For each patient, diagnostics as described in the white box should be performed to assess the reasons(s) for difficult weaning. Endocrine dysfunction is probably relatively rare and therefore is not included in the first line of evaluation. Possible treatment/interventions are mentioned but, of course, need to be individualized. If the first-line evaluation does not improve weaning, proceed to the next level (within the affected column). For instance, if airway resistance is elevated but is not affected by albuterol and optimizing ventilator settings, diagnostic bronchoscopy should be performed to visualize the central airways. Risks and benefits should be weighed in each patient. ACTH, adrenocorticotrophic hormone; BNP, brain natriuretcic peptide; CAM-ICU, confusion assessment method for the intensive care unit; DO_2, oxygen delivery; ECG, electrocardiogram; EIC, end inspiratory cycling; EMG, electromyography; iv, intravenous; $P_{0.1}$, airway occlusion pressure at 100 ms; PEEPi, intrinsic positive end-expiratory pressure; Pi, max, maximal inspiratory pressure; PSV, pressure support ventilation; SBT, spontaneous-breathing trial; SvO_2, mixed venous oxygen saturation.

Heunks LM, van der Hoeven JG. Clinical review: The ABC of weaning failure – a structured approach. Crit Care 2010; 14: 245

Evaluation of Difficult Weaning: A & B

	Airway/lung			Brain	
	resistance	compliance	gas exchange	Delirium	Other cognitive dysfunction
assessment	Flow-time loops, inspiratory occlusion	Inspiratory/expiratory occlusion	(A-a)DO_2	CAM-ICU	Screening: depression, anxiety, sleep pattern
intervention	albuterol, steroids Repeat loops, inspiratory occlusion	Radiology: pleural fluid Atelectasis Ascites		reorientation mobilization haloperidol	Anxiolytics Behavioral therapy Reduce noise/light during sleep
	PEEPi: modify EIC in PSV bronchodilators	diuretics physiotherapy			
advanced assessment	diagnostic bronchoscopy during SBT				Neutropsychologist: Depression, anxiety
advanced intervention		thoracocentesis			
rescue assessment		contrast echocardiography: intracardiac shunt			
rescue intervention				dexmedetomidine	

Heunks LM, van der Hoeven JG. Clinical review: The ABC of weaning failure – a structured approach. Crit Care 2010; 14: 245

Evaluation of Difficult Weaning: C

	Cardiac
assessment	12 lead ECG before/at end SBT $ScvO_2$ before/at end SBT Echocardiography before & after SBT
intervention	afterload reduction inotropes if ischemia: beta-blocker optimize hemoglobin
advanced assessment	pulmonary artery catheter
advanced intervention	afterload reduction inotropes
rescue assessment	BNP
rescue intervention	Levosimendan bosentan

Heunks LM, van der Hoeven JG. Clinical review: The ABC of weaning failure – a structured approach. Crit Care 2010; 14: 245

Weaning Failure of Cardiac Origin

Diagnosis of weaning-induced pulmonary edema

- Clinical context
  - Suspected when intolerance to SBT occurs and other causes of weaning failure have been ruled out
  - Suggestive by early onset of respiratory distress after starting SBT
    - Combined increase in arterial pressure and heart rate
  - High-risk population = h/o left heart disease + COPD
- PAC
  - Higher than normal PAOP during an unsuccessful SBT
- TTE
  - E/A > 0.95 and E/Ea > 8.5 at the end of SBT
- Cardiac biomarker
  - BNP > 275 pg/ml

Teboul JL, Monnet X, Richard C. Weaning failure of cardiac origin: recent advances. Crit Care 2010; 14: 211

Evaluation of Difficult Weaning: D & E

	Diaphragm		Endocrine	
			Endocrine	metabolic
assessment	Pi, max	Serial physical examination (other neuromus disorders)		Electrolytes Blood gas Indirect calorimetry
intervention	early mobilization	early mobilization		Provide adequate energy intake
advanced assessment	Diaphragm fluorscopy / echography $P_{0.1}$	Examination by neurologist EMG, nerve conduction velocity	Plasma cortisol before/after 250 µmol ACTH Plasma thyroid hormone	
advanced intervention	Reduce analgesics/hypnotics		Cortisol iv Thyroid hormone	
rescue assessment	Phrenic nerve conduction velocity Transdiaphragmatic pressure using gastric and esophageal balloon Diaphragm EMG	Muscle biopsy		
rescue intervention	Antioxidants (vit C and E) Inspiratory muscle training			

Heunks LM, van der Hoeven JG. Clinical review: The ABC of weaning failure – a structured approach. Crit Care 2010; 14: 245

Criteria for Extubation Failure

Table. Criteria for Extubation Failure

f > 25 bpm for 2 hrs

HR > 140 bpm for sustained increase or decrease of > 20%

Clinical signs of respiratory muscle fatigue or increased work of breathing

SaO_2 < 90%; PaO_2 < 80 mmHg on FiO_2 ≥ 0.50

Hypercapnia ($PaCO_2$ > 45 mmHg or ≥ 20% from pre-extubation), pH < 7.33

HR, cardiac frequency; SaO_2, arterial oxygen saturation; PaO_2, arterial oxygen tension; FiO_2, inspiratory oxygen fraction; $PaCO_2$, arterial carbon dioxide tension.

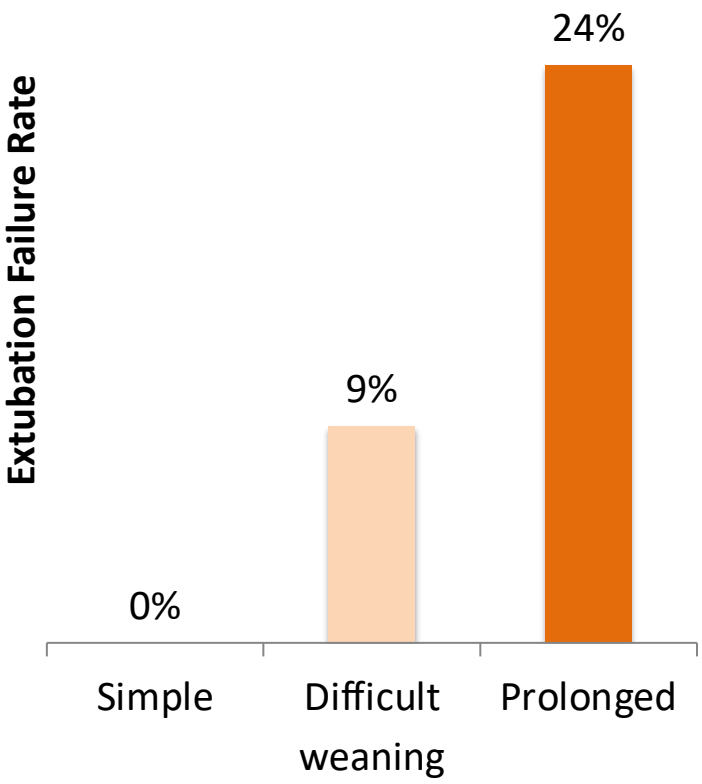
Boles JM, Bion J, Connors A, et al. Weaning from mechanical ventilation. Eur Respir J 2007; 29: 1033-1056

Reasons of Extubation Failure

- Upper airway obstruction or respiratory secretions that could not be managed by the patient
  - No manifestation until removal of the translaryngeal tube
- Loss of positive pressure in the thorax after extubation
  - Increased left ventricular afterload leading to left heart failure

Eskandar N, Apostolakos MJ. Weaning from mechanical ventilation. Crit Care Clin 2007; 23: 263-274

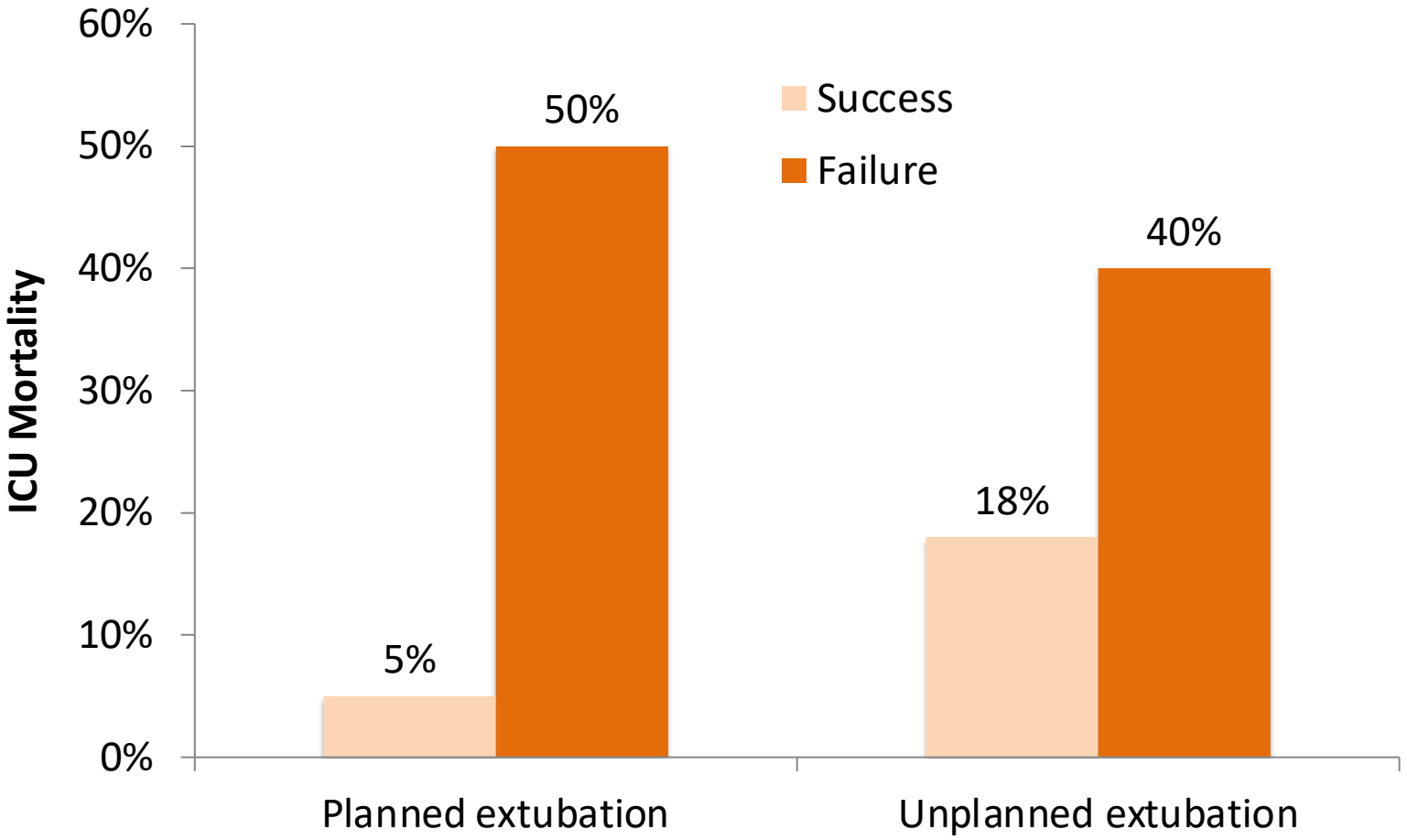
Extubation Failure – Risk Factor for Mortality



- High mortality rate in patients who fail extubation
  - 40 – 50%
- More prolonged T-piece trial might help to identify at-risk patient
  - Reduce the re-intubation rate

Tonnelier A, Tonnelier JM, Nowak E, et al. Clinical relevance of classification according to weaning difficulty. Respir Care 2011; 56: 583-590

Outcomes of Extubation Failure



Thille AW, Harrois A, Schortgen F, et al. Outcomes of extubation failure in medical intensive care unit patients. Crit Care Med 2011

Post-Extubation Airway Obstruction

- Definition
  - The presence of an audible high-pitched inspiratory wheeze requiring medical intervention, and usually associated with respiratory distress
- Characteristics
  - Prevalence 12% (13/112)
  - Delay for the occurrence 3.2 ± 3.3 hr
- Cuff-leak test
  - Threshold 130 ml and 12%
  - Sensitivity 85% (65 – 99%), specificity 95% (91 – 99%), positive predictive value 69%, negative predictive value 98%

Jaber S, Chanques G, Matecki S, et al. Post-extubation stridor in intensive care unit patients: risk factors evaluation and importance of the cuff-leak test. Intensive Care Med 2003; 29: 69-74

Cough Strength and Endotracheal Secretions in Predicting Extubation Outcome

- Weak cough
  - RR 4.0; 95%CI 1.8 – 8.9
- White card test
  - Absence of wetness of a white card placed 1 to 2 cm from the end of the ETT after 3 to 4 coughs
  - RR 3.0; 95%CI 1.3 – 6.7
- Moderate-to-abundant secretions
  - RR 5.1; 95%CI 1.7 – 15.4; p = 0.003
- Synergy between poor cough strength and endotracheal secretions
  - Rothman synergy index 3.7; RR 31.9; 95%CI 4.5 – 225.3

Khamiees M, Raju P, DeGirolamo A, et al. Predictors of extubation outcome in patients who have passed a trial of spontaneous breathing. Chest 2001; 120: 1262-1270

Cough Strength in Predicting Extubation Outcome

Scale of cough strength

0. No cough on command
1. Audible movement of air through the ETT but no audible cough
2. Weakly (barely) audible cough
3. Clearly audible cough
4. Stronger cough
5. Multiple sequential strong coughs

Amount of secretions*

- No
- Mild
- Moderate
- Abundant

*based on personal observations and collective information from the nursing and respiratory therapists from their assessments within 4 to 6 h preceding endotracheal extubation

Khamiees M, Raju P, DeGirolamo A, et al. Predictors of extubation outcome in patients who have passed a trial of spontaneous breathing. Chest 2001; 120: 1262-1270

Cough Strength in Predicting Extubation Outcome

- Peak expiratory flow (PEF) ≤ 60 lpm
  - Extubation failure
    - RR 5.1; 95%CI 1.7 – 15.4; p = 0.003
    - Sensitivity 69%, specificity 74%
  - Hospital mortality
    - RR 19.1; 95%CI 2.5 – 145.9; p = 0.0002

Smina M, Salam A, Khamiees M, et al. Cough peak flows and extubation outcomes. Chest 2003; 124: 262-268

Summary

- Delay in weaning process common in clinical practice
- First weaning trial very crucial to differentiate simple weaning and difficult/prolonged weaning
- ABCDE approach in difficult-to-wean patients
- Understanding extubation failure also important