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LIBERATION FROM MECHANICAL VENTILATION

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LIBERATION FROM MECHANICAL VENTILATION

INTRODUCTION

Weaning is the transition from assisted mechanical ventilation to spontaneous ventilation without an airway. It can take up to 40% of the time spent in an ICU.

Consequences of Delayed Extubation:

- Nosocomial pneumonia
- Barotrauma
- Hemodynamic imbalance
- Tracheal damage
- Oxygen related injury
- ?Diaphragmatic fatigue
- Latrogenic injury

Consequences of Over Aggressive Weaning:

- Loss of airway protection
- Cardiovascular stress
- Sub-optimal gas exchange
- Muscle overload and fatigue
- Risks of Re-intubation:

Risks of Re-intubation:

- Nosocomial pneumonia
- 6 fold increase in mortality.
- Increased in length of ICU and Hospital stay

LOAD/CAPABILITY RELATIONSHIP

Patients will continue to be ventilator dependant until the capability to carry the load placed on the patient by the disease process, is restored.

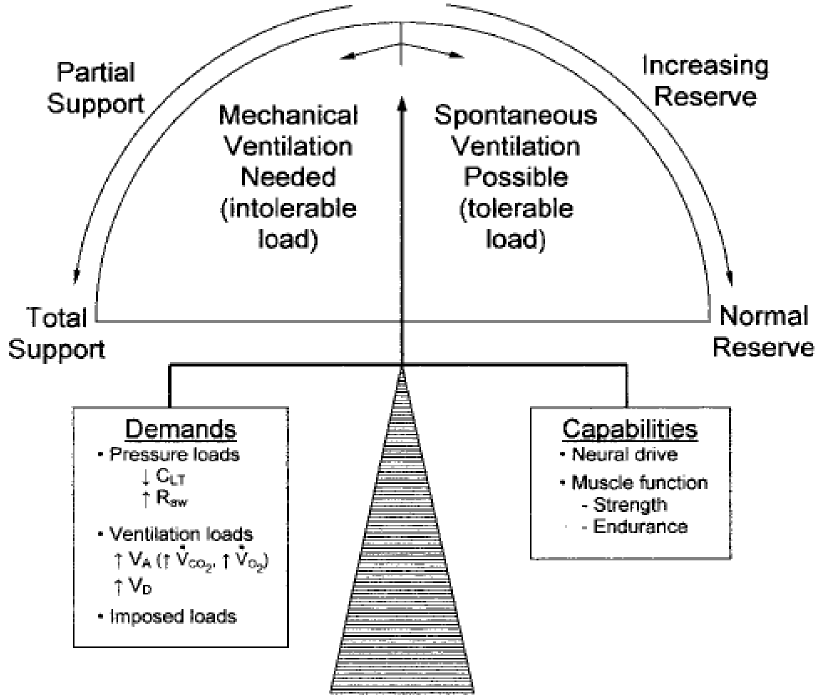

Fig. 1. The balance between respiratory loads and demands determine the need for mechanical ventilatory support. C_{LT} = compliance of the lungs and thorax. R_{aw} = airway resistance. V_A = alveolar ventilation. $\dot{V}_{CO2}$ = carbon dioxide production. $\dot{V}_{O2}$ = oxygen consumption. V_D = dead-space volume.

Increased respiratory work		
Ventilatory demands		
↑ *CO_2*	↑ *Dead space*	↑ *Drive*
Temperature	Pulmonary diseases	Neurogenic
Shivering	Hypovolemia	Psycogenic
Pain/anxiety	Pulmonary embolism	Metabolic
Trauma/burns	Extreme PEEP	Acidosis
Sepsis	Equipment	Hypoxemia
Overfeeding		Sepsis
		Hypoperfusion
Impedance		
↓ *Compliance*	↑ *Resistance*	↑ *$PEEP_i$*
Lung	Airways	Dynamic hyperinflation
Chest wall	Tube and ventilatory circuit	Flow limitation

$PEEP_i$, intrinsic positive end expiratory pressure.

Volta et al, Current Anaesthesia & Critical Care 2006; 17: 321-327

Table 2 Factors decreasing the capacity of the respiratory muscle to accomplish the respiratory work.

Decreased neuromuscular competence			
Muscle weakness			
Metabolic troubles	*Pathological neuromuscular transmission*	*Drugs*	*Deficiency of movement*
Starvation/malnutrition	Neuromuscular disease	Neuromuscular blockers	
Electrolyte derangement	Spinal cord lesion	Corticosteroids	
Acidosis	Phrenic nerve injury		
Hypoxemia	Critical illness polyneuropathy		
Sepsis			
Cancer			
Muscle inefficiency			
Chest wall disease			
Hyperinflation			
Fatigue			

Volta et al, Current Anaesthesia & Critical Care 2006; 17: 321-327

WHEN SHOULD YOU CONSIDER WEANING A PATIENT?

TABLE 5 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 (*i.e.* $f_C \leqslant 140$ beats·min^{1}, systolic BP 90–160 mmHg, no or minimal vasopressors)
	Stable metabolic status
	Adequate oxygenation
	S_{a,O_2} >90% on $\leqslant F_{I,O_2}$ 0.4 (or $P_{a,O_2}/F_{I,O_2} \geqslant 150$ mmHg)
	PEEP $\leqslant 8$ cmH_2O
	Adequate pulmonary function
	$f_R \leqslant 35$ breaths·min^{1}
	MIP $\leqslant$-20– -25 cmH_2O
	V_T >5 mL·kg^{1}
	VC >10 mL·kg^{1}
	f_R/V_T <105 breaths·min^{1}·L^{1}
	No significant respiratory acidosis
	Adequate mentation
	No sedation or adequate mentation on sedation (or stable neurologic patient)

Data taken from [5, 6, 13, 16–18, 22]. f_C: cardiac frequency; BP: blood pressure; S_{a,O_2}: arterial oxygen saturation; F_{I,O_2}: inspiratory oxygen fraction; P_{a,O_2}: arterial oxygen tension; PEEP: positive end-expiratory pressure; f_R: respiratory frequency; MIP: maximal inspiratory pressure; V_T: tidal volume; VC: vital capacity. 1 mmHg−0.133 kPa.

PREDICTORS OF WEANING

The search continues for an accurate, reproducible, sensitive and specific predictor of weaning success.

Meade et al looked at the possible role of 66 specific measurements as predictors. They were able to identify 8 measurements that had consistently significant likelihood ratios to predict successful outcome.

Parameter	Studies (n)	Threshold Values	Positive LRs Range
Measured on Ventilator			
$\dot{V}_E$	20	10–15 L/min	0.81–2.37
NIF	10	−20 to −30 cm H_2O	0.23–2.45*
$P_{I_{max}}$	16	−15 to −30 cm H_2O	0.98–3.01
$P_{0.1}/P_{I_{max}}$	4	0.30	2.14–25.3
CROP score	2	13	1.05–19.74
Measured During a Brief Period of Spontaneous Breathing			
RR	24	30–38 breaths/min	1.00–3.89
V_T	18	325–408 mL (4–6 mL/kg)	0.71–3.83
f/V_T ratio	20	60–105/L	0.84–4.67

LR = likelihood ratio
V_E = minute ventilation
*1 study reported a likelihood ratio (LR) of 35.79.
NIF = negative inspiratory force (maximum inspiratory pressure)
$P_{I_{max}}$ = maximum inspiratory pressure
$P_{0.1}$ = mouth occlusion pressure 0.1 s after the onset of inspiratory effort
CROP = index including compliance, respiratory rate, oxygenation, and pressure
RR = respiratory rate
V_T = tidal volume
f/V_T = respiratory rate/tidal volume ratio

Ventilation, Respiratory rate and Tidal volume Minute are self explanatory.

Negative Inspiratory Force

Ventilatory muscle strength is commonly measured during the peak inspiratory pressure manoeuvre (PImax, which is measured during the patient's maximum inspiratory effort against a closed shutter). Recommendations are that the closed shutter should be in place for at least 20 seconds and perhaps 30 seconds to achieve a maximum result. Values more negative than –20 to –30 cm H_2O are thought to be necessary for ventilator withdrawal.

Vital capacity

Another assessment of patient capacity is a simple vital capacity maneuver, in which the patient is asked to voluntarily take a maximal inspiration and subsequent expiration. Vital capacity <1 L is associated with prolonged mechanical ventilatory support.

Inspiratory pressure generation

An interesting measurement of patient capabilities is the inspiratory pressure generation after 100 milliseconds of effort against a closed circuit ($P_{0.1}$). This measurement actually reflects 2 properties. First, it is a reflection of inspiratory drive. The more vigorous the patient's inspiratory drive, the greater the $P_{0.1}$. However, $P_{0.1}$ also reflects ventilatory muscle strength. Because of these multiple determinants, interpreting $P_{0.1}$ can be challenging.

For example, a low $P_{0.1}$ may reflect either muscle weakness (bad) or a low respiratory drive, which may be good if it indicates that the patient is comfortable, or bad if it indicates a depressed respiratory drive. In contrast, a high $P_{0.1}$ may reflect strong muscles (good) or a vigorous respiratory drive, which may be good if it indicates an intact patient drive, or bad if it indicates that the patient is uncomfortable.

CROP

Conceptually, assessing loads with respect to capacity would make more sense than measuring either alone. There are several approaches to this. An interesting integrated assessment is the CROP index, which incorporates **compliance**, **respiratory rate**, **oxygenation**, and **inspiratory pressure** in a straightforward formula:

CROP = (Cdyn x PImax x (PaO2/PAO2))/f

in which Cdyn is dynamic compliance, PImax is maximum inspiratory pressure, PaO_2 is arterial partial pressure of oxygen, PAO_2 is alveolar partial pressure of oxygen, and f is respiratory rate. CROP values >13 are thought to indicate high likelihood of ventilator withdrawal success.

Rapid Shallow Breathing Index (RSBI)

The most commonly used test is calculation of the RSBI (respiratory frequency (fR)/VT). A value, 100–105 breaths/min/L predicts a successful SBT with a reported sensitivity of 0.97 and specificity of 0.65.

In 2001 an American Task Force decided that there was insufficient use for predictors in weaning a patient from mechanical ventilation, including RSBI. In 2007, the European Task Force on weaning from mechanical ventilation mentions the use of RSBI during initial stages of a spontaneous breathing test (SBT). Still unanswered is *"What is the place for RSBI now with the heavy reliance on SBT?"*

SPONTANEOUS BREATHING TRIAL

The direct assessment of spontaneous breathing capabilities for up to 2h has been shown in several randomized trials to be the most effective way to shorten the ventilator discontinuation process.

The SBT involves an integrated patient assessment during spontaneous breathing with little or no ventilator assistance (*eg*, T-piece trial or using 1 to 5 cm H_2O continuous positive airway pressure [CPAP], 5 to 7 cmH_2O of pressure support from the ventilator, or automatic tube/airway compensation).

No single parameter can be used to judge SBT success or failure.
Indeed, a recent study has shown that reliance on only a single parameter such as the f/Vt ratio during the SBT can potentially delay ventilator discontinuation.

Rather, an integrated assessment of the **respiratory** pattern (especially the development of tachypnea), **hemodynamic** status (especially tachycardias, bradycardias, or BP swings), **gas exchange** (especially decreases in pulse oximetric saturation), and **patient comfort** (especially the development of anxiety or diaphoresis).

The trial must last at least 30 min but no longer than 120 min. If it is not clear that the patient is an SBT success at the 120-min mark, then the patient should be considered an SBT failure.

Six large studies demonstrated that only 13% of patients who successfully passed the SBT and were extubated required reintubation. In patients who do not receive an SBT and are extubated, the failure rate is 40%.

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

TABLE 6 Failure criteria of spontaneous breathing trials

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
	Dyspnoea
Objective measurements	$P_{a,O_2} \leqslant 50$–60 mmHg on $F_{I,O_2} \geqslant 0.5$ or $S_{a,O_2} < 90\%$
	$P_{a,CO_2} > 50$ mmHg or an increase in $P_{a,CO_2} > 8$ mmHg
	pH < 7.32 or a decrease in pH $\geqslant 0.07$ pH units
	$f_R/V_T > 105$ breaths·min^{1}·L^{1}
	$f_R > 35$ breaths·min^{1} or increased by $\geqslant 50\%$
	$f_C > 140$ beats·min^{1} or increased by $\geqslant 20\%$
	Systolic BP > 180 mmHg or increased by $\geqslant 20\%$
	Systolic BP < 90 mmHg
	Cardiac arrhythmias

Task Force:Weaning from Mechanical Ventilation
Eur Respir J; 29: 1033-1056

Both American and European Task Force both recommend performing a SBT when the patient is considered eligible to be weaned. It is a safe test, in one cohort of more then a thousand patients only one adverse outcome occurred. Compare that to the risk of prolonging potentially dangerous therapy when not needed any longer.

WHY DO PATIENTS FAIL TO WEAN?

TABLE 4 Common pathophysiologies and their incidence, which may impact on the ability to wean a patient from mechanical ventilation

Pathophysiology	Consider
Respiratory load	Increased work of breathing: inappropriate ventilator settings
	Reduced compliance: pneumonia (ventilator-acquired); cardiogenic or noncardiogenic oedema; pulmonary fibrosis; pulmonary haemorrhage; diffuse pulmonary infiltrates
	Airway bronchoconstriction
	Increased resistive load
	During SBT: endotracheal tube
	Post-extubation: glottic oedema; increased airway secretions; sputum retention
Cardiac load	Cardiac dysfunction prior to critical illness
	Increased cardiac workload leading to myocardial dysfunction: dynamic hyperinflation; increased metabolic demand; unresolved sepsis
Neuromuscular	Depressed central drive: metabolic alkalosis; mechanical ventilation; sedative/hynotic medications
	Central ventilatory command: failure of the neuromuscular respiratory system
	Peripheral dysfunction: primary causes of neuromuscular weakness; CINMA
Neuropsychological	Delirium
	Anxiety, depression
Metabolic	Metabolic disturbances
	Role of corticosteroids
	Hyperglycaemia
Nutrition	Overweight
	Malnutrition
	Ventilator-induced diaphragm dysfunction
Anaemia	

SBT: spontaneous breathing trial; CINMA: critical illness neuromuscular abnormalities.

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Neurological

The ventilatory pump is controlled by the brainstem which is a rhythm pattern generator. The brainstem itself can be affected by cerebrovascular disease. The brainstem receives its inputs from cortical centres, chemo- and mechano-receptors which may be depressed in trauma, severe sepsis, hypoxia, acidosis, narcotic-use, and electrolyte disturbances.

Peripheral nerves and ventilatory muscle are susceptible to Critical Illness Neuropathy(CIN) and Critical Illness Myopathy(CIM). Electromyography in patients undergoing mechanical ventilation for 5-7 days revealed showed non-specific neuromuscular alteration in 50-100% of cases. Patients with CIN and CIM require longer periods of mechanical ventilation.

Cardiovascular

Weaning is a cardiovascular stress test.
Spontaneous breathing increases left ventricular afterload.

Lemaire et al showed that pulmonary capillary wedge pressure (PCWP) increases from between 39 and 65% in patients with COPD and cardiac disease.
Jubran et al showed that patients who succeed weaning increase cardiac index and oxygen transport, but patients who failed did not increase cardiac index, but increased oxygen extraction instead leading to a decrease in mixed venous saturation, decreasing arterial oxygen content. In both patients, oxygen consumption during weaning were identical.

Spontaneous respiration normally requires less then 5% of total oxygen delivery, but in diseased lung states, the work of breathing may consume up to 25% of delivered oxygen.

The transition from positive pressure ventilation to spontaneous ventilation can be associated with pulmonary oedema, myocardial ischaemia evidenced by ECG and thallium blood flow scan, tachycardia, and gut ischaemia. Patients with limited cardiac reserve (coronary artery disease and cardiac failure) are at particular risk.

Respiratory

During weaning, patients that fail tend to increase their frequency of breathing, tidal volumes decrease, respiratory effort increases by more then four times, respiratory resistance increases by seven times, and lung stiffness increases five times. Patients that increase their respiratory rate and decrease their tidal volume will increase the ventilation of their dead space leading to inefficient removal of carbon dioxide.
Of patients that increase their $PaCO_2$ by more then 10mmHg during a weaning trial, 50% will fail weaning. Furthermore a $PaCO_2$ of more then 45mmHg is an independent predictor associated with a lower survival rate.

Ventilatory muscles and failure-to-wean

Muscle weakness may be as a result of several issues:

- Critical Illness Myopathy
- Electrolyte disturbances
- Malnutrition
- Corticosteroid therapy
- Continuous sedation and CMV is associated with prolong ventilation and development of selective diaphragmatic atrophy(over-ventilating)
- Insufficient/dyssynchronous mechanical support resulting in overuse and fatigue

Chang et al. found that respiratory muscle endurance was negatively correlated with the length of stay. The implications? It confirms a problem either the muscle, however, is it the dysfunctional muscle that makes the patient dependant on the ventilator or is it the ventilator that is the cause of the dysfunctional muscle?

Recent data has emerged pointing to the ventilator as a possible cause of diaphragm-dysfunction resulting in a decrease in the diaphragm capacity to meet the needs of the patient. Rats ventilated for two days on Continuous Mechanical Ventilation (CMV) have decreased pressure generating capacity by 42% compared to rats breathing spontaneously.

Proposed mechanisms for Diaphragmatic Dysfunction:

- **Atrophy**
  Atrophy is caused by either decrease in protein synthesis or increased degradation, or both. In 12 neonates ventilated for more then 12 days showed atrophic changes in the muscle fibres of the diaphragm, but in patients ventilated for less then 7days showed no changes in ventilatory and non-ventialtory muscles.
- **Fibre Re-modelling**
  The diaphragm has mainly two types of muscle. Slow-twitch type-I fibres take long to fatigue but cannot generate as much force as type-II. Fast-twitch type-II fibres are stronger then type-I but are easily fatigued. Initially, there is a decrease in type-II fibres with consequent decrease in force of respiratory effort. Then there is an increase in hybrid fibres and a decrease in type-I fibres resulting in easily fatigueable muscle.
- **Oxidative stress**
  In animal studies, there is increase in protein oxidation and lipid peroxidation suggesting free radical injury. Oxidant stress can contribute to muscle atrophy and contractile dysfunction. Critically ill patients treated with anti-oxidants have shorter time spent on mechanical ventilators.
- **Structural injury**
  Animal histological studies looking at ventilatory muscles showed disrupted myofibrils, mitochondrial swelling and lipid droplets which was not present in the hind legs of the animal.
- **Fluid balance**
  Patients with a positive fluid balance in previous 24hours is associated with failed weaning.

A FAILED SBT

Task Force recommendations are that for patients that have failed an SBT, the cause for failing needs to be looked for and reversed.

Ventilation

In surveys in North America, Portugal and Spain showed wide variability in clinicians' choice as to which mode they prefer to wean patients with. Both American and European task Forces both recommend that after the cause for failing an SBT has been found and reversed, daily trials of SBT should be conducted using non-fatiguing forms of ventilation.

- **SIMV**
  This was shown to be the worst performing mode of ventilation. This mode was shown to increase the work of breathing by breath-by-breath dyssynchrony and increased effort required to overcome resistance created by valve-demand systems, circuit and filters. It is also totally unresponsive to patient effort.

- **PSV**
  PSV presents a better option to weaning a patient.
  The patient is the only determinant of
  - Respiratory rate
  - Cycling times
  - Inspiratory work
  - Tidal volume (by limiting inspiration)

  This results in:
  - Good synchrony with mechanical ventilation
  - Reduces respiratory work
  - Reduces oxygen consumption by respiratory muscles.
  - Improves efficiency of breathing

  PSV is also non-fatiguing and PSV also eliminates resistance of external circuit.
  iPEEP still is a potential problem.

- **CPAP**
  It is the application of positive pressure at the end of expiratory phase. Reduces respiratory work and there is complete synchrony with the ventilator.
  Most of the work with CPAP is in COPD and cardiac patients. There is still not data available.

- **Spontaneous T-piece**
  Esteban et al showed that in patients that failed a SBT, once daily, or multiple SBT trials were found to be superior in decreasing the number of days spent on a ventilator compared to patient receiving PSV, and again SIMV was shown to be the worst.

Reversible/Optimisable factors

Table 3 Strategies of treatment aimed to improve the weaning process by reducing impedance, ventilatory demands, hypoxemia and by increasing neuromuscular competence.

Strategies of treatment	
Impedance	*Ventilatory demands*
• Body position	• Sedatives
• ↓ Secretions	• ↓ Temperature
• Bronchodilators	• ↓ Pain
• Diuretics	• ↓ Acidosis
• ↓ V_E	• ↓ Dead space
• ↓ Hyperinflation/ $PEEP_i$	• Permissive hypercapnia
• ↓ Abdominal distension	
• Drainage of pnx/ pleural effusion	
• ↓ Resistance tube and ventilatory circuit	
Neuromuscolar competence	*Hypoxemia*
• ↑ Nutritional supply	• Body position (orthopnea)
• Correction of:	• ↓ Secretions
Electrolyte derangement	• Bronchodilators
Acid-base disorders	• Diuretics
Anaemia	• CPAP-PEEP
	• ↑ F_iO_2
• Sepsis therapy	
• Adequate sedation	
• Body position	
• Kinesitherapy	
• ↓ Fatigue	
• Hypothyroidism therapy	
• Neuromuscolar disease therapy	

V_E, minute volume; $PEEP_i$, intrinsic positive end expiratory pressure; CPAP, continuous positive airway pressure ventilation; PEEP, positive end expiratory pressure; F_iO_2, oxygen inspired fraction.

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PROTOCOLS

"The Clinician Problem"

The appropriate time to wean is crucial. Removing mechanical ventilatory support before the patient is capable of supporting themselves leaves them vulnerable to the risks of re-intubation and cardiovascular stress and ventilating patients longer then required exposes them to further ventilator and ICU related insults.

Clinical judgement has been shown to be ineffective in deciding the most appropriate time to wean.

- Assessment/Management strategies cause huge delays in weaning.

- Studies among patients who are accidentally or self-extubated demonstrate that 23% of patients receiving full mechanical ventilation and 69% of patients who have begun weaning do not require reintubation. In fact, 35% of patients who were considered to be unweanable when referred from one facility to another could be extubated without any additional weaning attempts.

- The percentage of patients who required weaning decreased from 80 to 10% when physician judgment was replaced by protocol management.

- Protocol-directed daily screening of respiratory function and trials of SBT decrease the time required for extubation, the incidence of self-extubation, the incidence of tracheostomy and ICU costs, and results in no increase or even a decrease in the incidence of reintubation.

- In trauma patients, Dries et al. reported a decreased incidence of ventilator-acquired pneumonia and death.

- Computer based weaning was shown to decrease duration spent on mechanical ventilation compared to clinician-led weaning. Lellouche et al shortened duration on a ventilator by 4.5 days using a computer based closed loop protocolled weaning.

- Clinicians also fail to act when they have evidence to act. Namen et al showed that when neurosurgeons were informed of the result of a positive SBT they refused to extubate in 50-87% of those patients. Moreover in two large trials despite the presence of apparent disease stability/reversal, prior to performing an SBT the managing clinician did not recognise that discontinuation was feasible in two thirds of subjects.

Protocols provide superior care for the majority of patients receiving ventilatory support.

- Decrease time spent on mechanical ventilation
- Decrease length of ICU admission
- Decrease length of hospital admission
- Decrease cost
- Decrease ventilator induced injury
- Backed by evidence and opinions of current experts in the field, clinical judgement depends on experience of the clinician.
- Specific targets and endpoints to be achieved
- Predictable standardized outcomes
- Removes human error
- Allows adherence to evidence based principles and interventions until knowledge of the new evidence formulating these protocols is synthesized and incorporated into daily clinical practice.

However, weaning protocols are less likely to be effective when the majority of patients are rapidly extubated, when physicians do not extubate patients following a successful SBT, or when the quality of critical care is already high.

CONCLUSION

Liberation from mechanical ventilation is dependant on clinical judgement and measured predictors.

Both of them are weak indicators of a successful wean.

Ventilating a patient that does not require the support, and extubating a patient that still needs the support, puts patients at increased risk.

Primum non nocere.

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NOTES