Optimum Strategies for Mechanical Ventilation

A Practical Update

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Things derive their being and nature by mutual dependence and are nothing in themselves.

Nagarjuna
Second-century Buddhist philosopher

An elementary particle is not an independently existing, unanalyzable entity. It is, in essence, a set of relationships that reach outward to other things.

H. P. Stapp
Twentieth-century physicist

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The discussion and the protocol are very different. The protocol is meant to be instructive at the bedside for the housestaff. The references at the end of the protocol are meant to be resources for further reading and as such are heavily weighted toward review articles. The discussion covers two optimum ventilation strategies in ARDS. If anyone wishes references for the discussion, please contact me directly.

In 1991, Dr. Alan Pierce gave a medical Grand Rounds entitled Mechanical Ventilation of the Critically Ill Patient: Conventional and New Techniques. (1) He presented forty pages of text with over 200 references. There have been a huge number of articles published since that time. However, there is a paucity of randomized controlled trials comparing one method of mechanical ventilation against another. There are no conclusive studies that demonstrate the optimal mode of ventilation for a given type of acute respiratory failure. Most studies use intermediate endpoints rather than survival. Intermediate variables are not definitive indicators of ultimate patient outcome. Important ultimate outcomes, such as long-term survival and functional state should be the determinants in most clinical situations. Unfortunately, intermediate therapeutic endpoints, such as $PaO2$, thoracic compliance, and frequency of premature ventricular contractions (PVCs) are commonly used to assess interventions because they are frequently more easily measured than are ultimate outcomes. However, intermediate outcome variables are frequently poor reflections of the ultimate outcomes. The intermediate outcome of suppression of post-myocardial infarction PVCs was accepted as a reflection of the ultimate outcome of these patients until a randomized controlled study was performed looking at survival. The Cardiac Arrhythmia Suppression Trial (CAST) performed in post-myocardial infarction patients is a striking example of how misleading intermediate outcome variables can be. Patients with effective pharmacological suppression of PVCs had a higher death rate than that experienced by the placebo group. (2)

A few years ago Dr. Yarbrough gave a Grand Rounds entitled Medicine in the Information Age. In that Grand Rounds there were studies discussing information overload and physician information needs. The Rand Corporation undertook a detailed, random survey of doctors in this country concerning reading habits as part of an evaluation of the NIH consensus development process. Their conclusions were that doctors read virtually nothing in journals not even the abstracts. This was also shown in a study of physicians in private practice, 20 to 50% of whom were unaware of advances such as hemoglobin-A1C for diabetic control. The Rand surveys revealed that doctors basically want guidelines or short statements available to them at the point in time when they need them. Robert Brook, of the Rand Corporation suggested that what the physician needs is a "talking wall" that a doctor can ask a question of while examining a patient. The wall would then respond with an answer. The Grand Rounds suggested that clinical information systems were one step toward the realization of that "talking wall."(3)

The outcome of patients with complicated clinical problems is determined by multiple factors. This contributes to a low signal to noise ratio for outcome results and reduces our ability to recognize the effects of our clinical interventions. The multiple mechanisms active in the cellular and other inflammatory responses in ARDS are complicated and interactive. In addition to the potential harm that may be produced by the application of high pressures or volumes, the therapeutic use of oxygen exposes the patient to additional risks. Oxygen is a well-known pulmonary toxin and can produce endothelial cell damage and lung inflammation which is grossly and microscopically indistinguishable from those found in ARDS. Oxygen can also potentiate inflammation in an already damaged lung and may play an important role in the outcome of ARDS patients. (1) If this complexity is coupled with the complexity and variation in medical practice, then it should be obvious that signals about patient outcome would be difficult to detect. Indeed, great variation in clinical practice is characteristic of modern critical care medicine. Some of this variation is probably necessary and important.

Controlled randomized double-blinded trials provide the most credible means of defining what does and what does not work in the clinical setting. The major advantage of such studies over observational studies is the strength of the causal inference that can be drawn. Precision and accuracy can be affected by random errors. The subject, the observer, or the instrument may introduce these random errors. In order to decrease noise and insure that the care we give is doing more good than harm, we need to standardize the care of our patients, so that variation is minimized. This necessitates giving up some of our personal style in patient care.

It is impossible to choose the "right way" when developing a specific protocol. The right way is generally unknown and unknowable. It is possible to choose one of the possible and reasonable approaches. This protocol gives possible and reasonable approaches for several modes of ventilation. The approaches are presented in guidelines and short statements. When such protocols have been agreed upon, they will be placed in a dynamic form within the clinical information system in the VA's intensive care units.

Types of Acute Respiratory Failure

- ☯Failure of Ventilation
  - Respiratory Center (overdose, sedatives)
  - Neuromuscular Apparatus (Guillian Barre, etc)
- ☯Failure to Eliminate Carbon Dioxide
  - Usually airway obstruction (COPD/Asthma)
- ☯Failure to Oxygenate Arterial Blood
  - Widely distributed parenchymal disease (ARDS)

Indications for Intubation

- ☯Protection of airways and lung parenchyma
- ☯Relief of upper airway obstruction
- ☯Improved Pulmonary toilet
- ☯Connection to mechanical ventilation

Modes of Ventilation

☯ Continuous mandatory ventilation	(CMV)
☯ Assisted mandatory ventilation	(AMV)
☯ Intermittent mandatory ventilation	(IMV)
☯ Synchronized IMV	(SIMV)
☯ Pressure controlled ventilation	(PCV)
☯ Inverse ratio ventilation	(IRV)
☯ Non-invasive positive press vent.	(NIPPV)

Operator Decisions While Initiating Mechanical Ventilation

☯ Tidal Volume	(V_T)
☯ Respiratory Rate	(f)
☯ Inspiratory Flow	(V_I)
☯ Inspired Oxygen Conc.	(F_IO_2)

Tidal Volumes

	V_T ml/kg IBW	V_T ml/70kg
Normal Spontaneous Breath	7	500
Normal Sigh Breath	14-21	1000-1500
CMV for Vent. Failure	10-15	700-1000
CMV for CO_2 failure	10-12 (see below)	700-850

Measurement of Compliance ıV/ıP in Ventilator Patients

- Dynamic Comp. = V_T/Peak inflation Press = 79 $\pm$ 15 ml/cm H_2O
  - Chest Wall
  - Ventilated lungs
  - Airway resistance (flow dependent)
- Static Comp = V_T/Inflation Hold Press = 97 $\pm$ 18 ml/cm H_2O
  - Chest Wall
  - Ventilated lungs

Respiratory Rate Settings

Type of Resp Failure	f (VT/min)	VT (ml/kg)
CMV for Vent Failure	5-6	15
CMV for CO2 failure	8-10	10-12
CMV for O2 failure	12-14	See Below

Inspiratory Flow Rates

Condition	Peak V_I (L/min)
Spont at rest	24
Spont at exercise	90
CMV for Vent failure	30-40
CMV for CO_2 failure	100
CMV for O_2 failure	See Below

Considerations with Inspiratory Flow Rates

- A slow flow tends to maximize the distribution of ventilation and help improve ventilation-perfusion ratios.
- A short inspiratory-expiratory ratio (I:E) minimizes the cardiovascular effects of positive pressure
- The expiratory time must be sufficiently long to insure complete lung emptying.

Auto-PEEP

- Auto-PEEP occurs when the time required for complete expiration is longer than the available expiratory time imposed by the ventilator settings.
- Low levels of ventilator applied PEEP (85% of auto-PEEP) may be beneficial in decompressing auto-PEEP, however, it is preferable to give a more rapid inspiratory flow to allow a longer time for exhalation.

Mechanisms of Hypercapnea

- Ventilatory Pump Failure
  - Central Drive
  - Impaired Ventilatory muscle function
  - ↑ respiratory work load
- ↑ CO_2 Production
- Venous Admixture
  - R → L shunt
  - V/Q mismatch
- ↑ Dead Space
  - Anatomic / Physiologic

Vent. Settings - Assist Control

- Trigger Sensitivity
  - Minimum pressure that does not cause auto-cycling (usually 1 to 2 cm H_2O)
  - Flow trigger may be quicker, better
    - If auto-PEEP develops, cautious addition of extrinsic PEEP to 85% of auto-PEEP levels may help sensitivity
- Flow Settings
  - Flow rates should be set above the patient's peak flow demands (usually 60-65 L/min)
    - If auto-PEEP develops, may need ↑flow rates to ↓inspiratory time.

Vent. Settings - Assist Control

- Tidal Volume V_T
  - Most patients can be ventilated with 10-15 ml/kg (smaller tidal volumes with sighs is fine, but less tolerated), however:
    - smaller V_T (7-9 ml/kg) for severe obstruction
    - smaller V_T (6-8 ml/kg) in ARDS (see lung protective strategy below)

Vent. Settings - Assist Control

- Inspiratory to Expiratory Ratio (I:E)
  - Usually set indirectly (usually 1:2)
    - less in Obstructive disease
    - greater in ARDS (see lung protective strategy)
- Waveform
  - Usually square wave waveform is used(no data)
  - ?decelerating ramp may be helpful to decrease peak inspiratory pressure

Ventilator Settings - Pressure Support

- Pressure Level
  - No "best" guidelines, but this should be set at the bedside and look for the following:
    - adequate tidal volume (8-12 ml/kg)
    - spontaneous frequency < 25-30 breaths/min
    - stable breathing pattern
    - no use of accessory muscles
    - use some minimum level to overcome circuit (5 to 8 cm H_2O)

SIMV

- Low rate SIMV results in excessive patient effort
- Maintain mandatory rate $\geq$ 80% of patient's total rate
- Use pressure targeted mandatory breaths when available
- Instead of using pressure support ventilation (PSV) with SIMV, simply use PSV

Pressure Controlled Ventilation

- Pressure controlled time cycled ventilation is the prototype and the machine's contributions can be determined from just three variables:
- The magnitude of the constant applied pressure
  - Driving pressure
  - Keep below 35 to 40 cm H_2O (see lung protective strategy)
- The frequency of airway pressurization
- The inspiratory duty cycle (inspiratory time/total time)
  - Extension of inspiratory time beyond 0.5 produces inverse ratio

Pressure Controlled Ventilation

- Time cycled ventilation modes can invite dyssynchrony when the patient breathes spontaneously.
- Sedation is usually needed
- ↑frequency can ↓tidal volume, ↑dead space, and ↑ $PaCO_2$

PEEP

- Advantages
  - Alveolar recruitment
  - Vascular derecruitment
  - Improvement in PaO_2
  - ↓ lung injury
  - ↓Inspiratory work load
- Disadvantages
  - Alveolar over-distension
  - ↓ Cardiac output (DO_2)
  - ↓ inspiratory muscle force

PEEP

- Few data to guide setting PEEP levels and no conclusive studies showing benefit (outcome)
- Main use is to increase PaO_2
- Minimum PEEP is set above lower inflection point on pressure-volume curve (usu. ~8cm H_2O) or
- Minimum PEEP is what is required to have an adequate PaO_2 (60-70mm Hg) on $FiO_2 < 0.6$
- Maximum PEEP < dorsal-ventral height of patient in cm. (usu. 15-20cm H_2O)

Inverse Ratio Ventilation

- Inspiratory time > 0.5
- Ratios greater than 2:1 are rarely used and over 3:1 may not be safe
- IRV can be applied with a volume-cycled algorithm, but is difficult to maintain, and therefore it is usually used with pressure controlled ventilation
- Usually used in deeply sedated, paralyzed patients

Lung Protective Strategy

- Recruitment maneuvers
- PEEP set to above the lower inflection point on the compliance curve or other method (see PEEP)
- Limit over-distension of the lung by restricting the plateau pressure of tidal breaths to below ~ 35 cm H_2O.

Lung Protective Strategy

- **Recruitment maneuver** - this is performed after intubation, but also after any loss of PEEP or airway integrity.
  - Increase CPAP to 35-40 cm H_2O
  - Hold this for 30 to 40 seconds
  - Restart tidal breaths and rapidly decrease PEEP to target level (use PCV to avoid over-distension).

Prone Positioning

- Suction the patient
- 3 people - one on each side, one at head
- Soft bed
- Pull patient to one side of bed
- Turn patient to lateral decubitus position (first stage)
- Turn prone (second stage)
- One arm up, one arm down, head to one side - alternate
  - (patient is usually not completely prone)
- Turn back supine 1 to 2 times a day for nursing care

Prone Positioning

- Protect the patient's eyes
- Watch for extubation, esp. when turning
- Maximum effect may take many hours
- Can usually progress to half supine and half prone after a day or two
- Back to supine after 3 to 5 days

Permissive Hypercapnea

- Contraindications and adverse effects
  - Cerebral edema/high intracranial pressure
  - Convulsions
  - ↓ Cardiac function
  - Arrhythmia
  - ↑ Pulmonary vascular resistance
  - Tachypnea and ↑ work of breathing
  - Dyspnea, resp. distress, headache, sweating

Permissive Hypercapnea

- Sedation is of extreme importance
- Reduce CO2 production
  - sedation +/- paralytics
  - ↑ fat, ↓ total calorie feeding
  - temperature regulation
- I.V. bicarbonate given slowly (continuous infusion is usual) if pH < 7.20

Non-Invasive Positive Pressure Ventilation

- Usually used for COPD
- Decisions include
  - Mask - nasal, orofacial, etc.
  - Ventilator device
  - FiO_2
- Should not be used as a substitute for other therapy (inhaled bronchodilators, etc.)

Non-Invasive Positive Pressure Ventilation

- Inclusion Criteria
  - Acute or chronic respiratory failure
  - Sleep related breathing disorders
- Relative Contraindications
  - Prior failure with NIPPV
  - Hemodynamic instability
  - Aspiration risk
  - ↓ Mental Status
  - Inability to use mask
  - Life-threatening refractory hypoxemia

Non-Invasive Positive Pressure Ventilation

- A ventilator (with alarms) is preferable if using an orofacial mask, otherwise a ventilator or BiPAP machine can be used.
- BiPAP requires oxygen to be entrained so FiO_2 cannot be accurately set. Start with a liter flow twice the level provided by nasal canula, adjust with ABG.

Non-Invasive Positive Pressure Ventilation

- Start with low pressures and increase levels of inspiratory pressure (usually to 8-14 cm H_2O) and expiratory pressure (usually 4-6 cm H_2O). Expiratory pressure of at least 4 cm H_2O reduces rebreathing.
- Clinical improvement should be evident within two hours.

Ventilator Factors Affecting Synchrony

- Trigger sensitivity
- Initial flow delivery
- Ability to alter flow
- Inspiratory time
- Tidal volume
- FiO_2
- PEEP

Sudden Respiratory Distress in a Ventilated Patient

- Remove the patient from the ventilator
- Use manual ventilation with Ambu-bag with 100% oxygen
- Perform a rapid physical and assess monitored indices
- Check patency of the airway (pass a suction catheter)
- If death is imminent, consider and treat the most likely causes (pneumothorax, airway obstruction, etc.)
- Once the patient is stabilized, perform a more detailed assessment and manage accordingly.

Proportional Assist Ventilation (PAV)

This form of ventilation has only recently become available commercially, and is included here only for interest.

Proportional assist ventilation has recently become commercially available as a proportional pressure support (Evita 4, Drager, Telford, PA). It is proposed to provide ventilator output commensurate with patient effort and improved patient/ventilator synchrony due to the flow and volume delivered in proportion to the demand and impedance.

Younnes and coworkers (4,5) introduced PAV. It uses the equation of motion to control the ventilator. PAV requires the measurement or estimation of elastance (the reciprocal of compliance) and resistance. The clinician sets PEEP, FiO2, volume assist, and flow assist. The volume assist overcomes the elastic work of breathing and the flow assist overcomes the resistive work of breathing. If each of these were set at 80%, then they would overcome 80% of the resistive and elastic load. These two parameters also allow the ventilator to change its output in proportion to patient demand. An analogy is that of the cruise control on an automobile. When the cruise control is set, the accelerator changes position to maintain a constant speed regardless of terrain (uphill or downhill). With PAV, if the volume and flow assist are set at 80%, then as the patient's tidal volume increases, the pressure applied by the ventilator increases. Thus, the percentage of patient work stays the same, regardless of the volume. In the original description by Younnes and coworkers the device utilized a piston (4,5). As the patient's demand for volume increased, the piston would move forward providing the increased volume. However, if volume remained constant, but inspiratory flow increased, the piston would move to the same position, only quicker, thus meeting the increase in flow demand. In essence, the ventilator attempts to maintain the fraction of work the patient performs per breath, regardless of the volume or inspiratory flow of the breath. The successful introduction of PAV will require that elastance and resistance be measured instantaneously breath to breath.

The measurement of elastance and resistance in a spontaneously breathing patient is difficult. The necessity of accurate measurements of these variables represents the limitations of PAV. When PAV performs appropriately, the pressure output of the ventilator is less than the pressure required to overcome the impedance of the respiratory system. (The patient does some of the work.) However, if measured incorrectly, the ventilator's output will exceed the pressure required to overcome the impedance of the respiratory system. This leads to greater errors in measurement of elastance and resistance and greater errors in ventilator output, a term called "runaway." The ventilator then continues to deliver flow after the patient has ended inspiration. The elastance and resistance in mechanically ventilated critically ill patients fluctuates making the measurement of these values more difficult. Also, the algorithm for control of PAV assumes that the characteristics of elastance and resistance are linear. This assumption can lead to inappropriate pressures and volumes. Leaks in the patient/ventilator system also complicate PAV.

Numerous reports in the literature have suggested advantages of PAV over pressure support ventilation in reducing the work of breathing, matching patient demand and ventilator supply, and facilitating a normal ventilatory pattern in patients (4-7). Unfortunately, most of these trials have been of a relatively short duration and none have shown advantages in days on the ventilator, length of stay, or mortality. However, now that this mode is commercially available, these studies may be undertaken.

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