Control of breathing during mechanical ventilation

D. Georgopoulos, Professor of Medicine, Intensive Care Medicine Department, University Hospital of Heraklion, University of Crete, Heraklion, Crete, Greece
Disclosures

Research grants
Covidien
Draeger
Basic principles of control of breathing
Multi-sources

Medullary respiratory controller

Spinal motor neurons

Pmus = V′xR + ΔVxE

Volume-time profile

PaO₂, PaCO₂, pH

Ventilation

Chemical feedback

Reflex and Mechanical feedback

Behavioral feedback

Diseases

Therapy

Pres, Pel
Multi-sources

Medullary respiratory controller

Spinal motor neurons

\[ \text{Paw} + \text{Pmus} = V'xR + \Delta VxE \]

Volume-time profile

\[ \text{PaO}_2, \text{PaCO}_2, \text{pH} \]

Ventilation

Diseases

Therapy
Response of ventilator to $P_{mus}$

Ventilator and Patient factors

$P_{mus} + P_{aw} = P_{rs} + P_{el}$

Response of $P_{mus}$ to ventilator delivered breath

Volume-time profile

- Mechanical
- Chemical
- Reflex
- Behavioral
- Feedback
Response of ventilator to Pmus

1) The mode of mechanical ventilation
2) The mechanics of the respiratory system
3) The characteristics of Pmus waveform
Modes of assisted mechanical ventilation

• Assist volume control (AVC, $V_T$ constant)
• Pressure support or control (PS, Pressure constant)
• Proportional modes (PAV, NAVA. Neither pressure nor volume are pre-set but the patient effort drives ventilator pressure)

Proportional modes will help us to clarify the issue of control of breathing in mechanically ventilated patients
Interaction between ventilator delivered volume and patient effort with different modes of support at high assist levels.

Patient effort [PTPPmus (cmH$_2$O·sec)]

Figure based on Data from: 1) Mitrouskas et al. Eur Respir J 1999
3) Meric et al. Respir Physiol Neurobiol 2014
Response of ventilator to Pmus

1) The mode of mechanical ventilation
2) The mechanics of the respiratory system
3) The characteristics of Pmus waveform

How do these factors affect the response of the ventilator? (i.e. output)
A patient with dynamic hyperinflation due to COPD on PSV

Ventilator rate = 12 b/min

Fr = 33 b/min
Double triggering due to expiratory asynchrony between patient and ventilator

Ventilator rate = 2 x patient’s rate
Response of ventilator to $P_{mus}$

Message

Direct extrapolation of the ventilator output to the patient’s control of breathing system (i.e. input) may be misleading, guiding inappropriate therapeutic decisions.
Response of ventilator to Pmus

Pmus + Paw = V’xR + VxE

Volume-time profile

Mechanical
Chemical
Reflex
Behavioral
Feedback

Response of Pmus to ventilator delivered breath

Ventilator and Patient factors
Chemical – Reflex feedback

Prevents derangement in arterial blood gases and acid-base balance (hypoxia, hypercapnia, hypocapnia)

Reflex feedback

Mainly prevents over-distention (Hering-Breuer reflex)


Does mechanical ventilation affect the operation (effectiveness) of these feedback systems?

- Reflex
- Chemical

Wakefulness
Sleep (and sedation)
Respiratory response to CO\textsubscript{2} during mechanical ventilation in awake humans

The ventilatory response to CO\textsubscript{2} is expressed mainly by the intensity of respiratory effort.

\(f\) is relatively insensitive to CO\textsubscript{2} over a wide range of PCO\textsubscript{2}.

Data from Georgopoulos et al. Am J Respir Crit Care Med 1997;156:146
$V_T/\text{effort per breath}$ (neuroventilatory coupling per breath) and not per min is the main determinant of the respiratory response to chemical feedback.
Chemical feedback during mechanical ventilation - Wakefulness

$V_T$/effort per breath is important

- Consequences?
$V_T$/effort per breath (neuroventilatory coupling) with low and high respiratory drive at various modes of support (at high assist)

Data from Mitrouska et al. Eur Respir J 1999; 13:873
Independent on assist level: RR constant on both modes

$V_T$ increased $\approx 500$ ml

$\text{PtCO}_2$ decreased by $\approx 10$ mmHg (severe hypocapnia)

$V_T$ constant

$\text{PtCO}_2$ constant

Meric et al. Respir Physiol Neurobiology 2014;195:11
Chemical feedback during mechanical ventilation - Wakefulness

Consequences

• Modes of support that permit the intensity of patient effort to be expressed on the $V_T$ delivered by the ventilator increase the effectiveness of chemical feedback to regulate $\text{PaCO}_2$


Meric et al. Respir Physiol Neurobiology 2014; 195:11
Chemical feedback during mechanical ventilation - Wakefulness

Consequences

• Modes of ventilation that impair the neuroventilatory coupling ($V_T$/effort) may cause either hypocapnia or hypercapnia and/or distress.

Ineffective


Meric et al. Respir Physiol Neurobiology 2014; 195:11
Chemical feedback during mechanical ventilation - Sleep

Observations

• The respiratory rhythm is critically depended on $\text{PaCO}_2$
• A drop in $\text{PaCO}_2$ by 3-4 mmHg causes apnea

During sleep breathing frequency changes minimally with decreasing PaCO\textsubscript{2} up to a point (apneic threshold)

During sleep the chemical feedback controls ventilation exclusively by changing the respiratory effort per breath (and not by changing frequency)

Meza et al. J Appl Physiol 1998;84:3
Even during sleep $V_T$/effort per breath (neuroventilatory coupling per breath) and not per min is the main determinant of the respiratory response to chemical feedback.
Chemical feedback during mechanical ventilation - Sleep

Consequences

- Modes of support that decrease the $V_T$ in response to any reduction in $P_{mus}$ promote ventilatory stability

Meza et al. J Appl Physiol 1998;84:3
Consequences

- At high assist, modes of ventilation that impair the neuroventilatory coupling ($V_T$/effort) may cause apnoeas and trigger periodic breathing.
MESSAGE
The operation (effectiveness) of chemical feedback during mechanical ventilation depends mainly on the mode of mechanical ventilatory support.
Response of ventilator to Pmus

Ventilator and Patient factors

Pmus + Paw = V’xR + VxE

Response of Pmus to ventilator delivered breath

Volume-time profile

Mechanical
Chemical
Reflex
Behavioral
Feedback
If effort drives the ventilator (PAV, NAVA) this feedback may control $V_T$.

Reflex feedback

Prevents over-distention (i.e. Hering-Breuer)

$\downarrow T_{\text{neural}}$ with increasing volume

$\Delta V$ 

$\Delta V$

Rabbits ventilated with NAVA

↑↑ assist

No assist (for one breath)

Theoretically

• Mechanically ventilated patients who express the feedback systems of control of breathing (CHEMICAL and REFLEX feedback) may choose a breathing pattern that limit the risks of lung damage.
Allowing animals with acute lung injury to “control” their ventilatory pattern (using NAVA) is at least as protective (and probably more) as a low $V_T$ strategy (i.e. protective strategy).

Mirabella et al. Crit Care 2014;18:R22

Rabbit brain does a good job
Human brain?
108 patients mechanically ventilated on controlled modes and recovering from acute respiratory failure were permitted to select their own breathing pattern by placing them on PAV+ for a maximum period of 48 hours.

Individual driving pressure ($\Delta P$) were calculated in these patients and examined how it related to $\Delta P$ when the same patients were ventilated passively using the currently accepted lung-protective strategy.

Studies in passively ventilated ARDS patients have shown that driving pressure (but not $V_T$) is associated with adverse outcomes.

Laffey et al. Intensive Care Medicine 2016
Main results:
Critically ill patients control the driving pressure to low levels \([10 \text{ cmH}_2\text{O} (8-12), \text{median (IQR)}]\) by sizing \(V_T\) to individual respiratory system compliance using appropriate feedback mechanisms aimed at limiting the degree of lung stress.
When the lung protective strategy results in high driving pressure (≥15 cmH$_2$O), the patients’ control of breathing system decreased the driving pressure in the majority (87%) of measurements.
The patients’ control of breathing system is adept at protecting the lungs by preventing high driving pressure, while not unnecessarily restricting tidal volume when this has no protective value.
Chemical Reflex

Provided that:

1) The mode of support does not interfere with their operation

2) Load-independent high respiratory drive that may override the protective mechanisms, IS NOT AN ISSUE

Doorduin et al. Am J Respir Crit Care Med 2016; Oct 17
Brochard et al. Am J Respir Crit Care Med. 2016 Sep 14

Patients selection is crucial
(be very careful in patients with severe metabolic acidosis, delirium, ongoing sepsis, etc)
Direct extrapolation of the ventilator output to the patient’s control of breathing system (i.e. input) may be misleading, guiding inappropriate therapeutic decisions.