pH & pO$_2$ monitoring during mechanical ventilation: ABG, VBG, or etCO2?

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@PulmCrit
blog: PulmCrit.org

no conflicts of interest 💰
**Introduction**

- Routine (ABG) sampling in patients on mechanical ventilation (MV) rarely leads to dynamic changes in management. This practice contributes to increased cost, patient discomfort, and unneeded blood loss. In healthy patients, end tidal carbon dioxide (ETCO2) typically correlates with measured arterial PaCO2, but in critically ill patients, increased dead space creates a larger ETCO2-PaCO2 differential ($\Delta$). We aimed to reduce ABG sampling by adjusting MV settings according to ETCO2 and the $\Delta$ETCO2-PaCO2.

**Methods**

- A policy was developed for respiratory therapists (RTs) to adjust MV by ETCO2 in our intensive care units. A baseline ABG was obtained upon initiation of MV to allow calculation of the $\Delta$ETCO2-PaCO2. Once this $\Delta$ was determined, RTs could adjust MV to maintain this $\Delta$. ABGs were obtained at any time per the discretion of the treatment team. The option for routine serial ABGs was removed from all order sets. The number of ABGs, ventilator days and adverse events were tracked throughout the initiative via the electronic medical record (EMR).

**Results**

- ABG data were collected from the EMR from September 2014 to September 2017. Prior to our intervention (9/14 to 8/15), 1,752 ABGs were collected (mean: 146/month). Following implementation of universal ETCO2 monitoring, 1,886 ABGs were collected from 9/15 to 8/16 (mean: 140/month). Following initiation of our new ETCO2 protocol, 1,219 ABGs were collected from 9/16 to 8/17 (mean: 101/month). Total MV days declined over the period, but ABGs/1000 MV days still declined from 710 (14'-15) and 777 (15'-16) to 552 (16'-17) following the intervention (ANOVA, p<0.05). There was a 30.8% reduction in testing and direct costs declined from $83,409 and $80,296 to $58,052; a total cost savings from 2014 to 2017 of $25,357.

**Discussion**

- MV guided by continuous ETCO2 monitoring and the $\Delta$ETCO2-PCO2, combined with removal of routine scheduled ABGs from EMR order sets, and education of ICU providers, was temporally associated with a reduction in ABGs in our MICU. Via these means, we project an estimated savings of ~$125,000 in direct medical center costs over the next five years without any anticipated increase in MV days or ICU length of stay, and reduced potential for unnecessary patient discomfort and ICU-acquired anemia.

**Acknowledgements**

1. Division of Pulmonary and Critical Care Medicine, Larner College of Medicine at the University of Vermont, Burlington, VT, USA
2. Department of Anesthesiology, Larner College of Medicine at the University of Vermont, Burlington, VT, USA
3. Department of Respiratory Therapy, UVM Medical Center, Burlington, VT, USA
4. Jaffe’s Institute for Quality, The University of Vermont, Burlington, VT, USA
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YEAH?

WELL, YOU KNOW, THAT'S JUST LIKE, YOUR OPINION, MAN!
goals

• monitoring oxygenation: \( pO_2 \) vs. pulse oximetry?
• ventilation: what is our target pH?
• VBG vs. ABG?
• etCO\(_2\) strengths & weaknesses
• putting it together: algorithm
goals

• monitoring oxygenation: pO$_2$ vs. pulse oximetry?
• ventilation: what is our target pH?
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• etCO$_2$ strengths & weaknesses
• putting it together: algorithm
tissue oxygen delivery = 13.4 \text{(cardiac output)(hemoglobin)(oxygen saturation)}
tissue oxygen delivery = 13.4 \times (\text{cardiac output})(\text{hemoglobin})(\text{oxygen saturation})
(Haldane effect: O₂ displaces CO₂ from Hb)

↑ pH
↓ DPG
↓ Temp

(Bohr effect: ↑ CO₂, ↓ pH)

Oxyhaemoglobin (% Saturation)

PO₂ (mmHg)
<table>
<thead>
<tr>
<th>Time</th>
<th>Temp</th>
<th>Temp Source</th>
<th>HR</th>
<th>Resp Rate</th>
<th>SpO2</th>
<th>FIO2</th>
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<td>04:00</td>
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</table>

**Vitals**

- Temp
- Temp Source
- HR
- Resp Rate
- SpO2
- FIO2

**Oxygenation**

- FIO2
- Mode
- VT
- I-Time
- Slope
- PEEP
- PS
- Trigger

**Ventilator Set**

- Mode
- FIO2
- VT
- I-Time
- Slope
- PEEP
- PS
- Trigger

**Ventilator Measure**

- Sport VT
- MEE
- Total RR
- Sport RR
- PIP
- Plateau
- MAP
- ETCO2

**Intake**

**Output**

**Blood Gases**

- O2 Saturation
- pH
- pCO2
- pHCO2
- pO2
- TCO2
- Sample Type
- Base Ex.
"Are you sure you're from the hospital lab?"
limitations of pulse oximetry

- Low Perfusion
- Noise Artifact
- Motion Artifact
goals

• monitoring oxygenation: $pO_2$ vs. pulse oximetry?
• ventilation: what is our target pH?
• VBG vs. ABG?
• etCO$_2$ strengths & weaknesses
• putting it together: algorithm
pH vs. pCO2
respiratory alkalosis

Signs of a Panic Attack

- Nausea
- Chills or hot flashes
- Sweating
- Trembling or shaking
- Heart palpitations
- Numbness and tingling
- Hyperventilation
- Dizziness
### Apneic oxygenation in man, Anesthesiology 1959, Nov/Dec;789-798

<table>
<thead>
<tr>
<th>Subject</th>
<th>Apnea duration (Minutes)</th>
<th>Lowest arterial saturation</th>
<th>Lowest pH</th>
<th>Highest PaCO2</th>
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<td>100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
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<td>Parameter</td>
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<td>BP</td>
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<td>TEMP</td>
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</tr>
<tr>
<td>HB</td>
<td>15.0 g/dl</td>
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<td></td>
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<tr>
<td>HCT</td>
<td>45.0 %</td>
<td></td>
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<tr>
<td>FIO2</td>
<td>20.9 %</td>
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<td>RQ</td>
<td>0.85</td>
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<td>PO2</td>
<td>62.1 mmHg</td>
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<td>PCO2</td>
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<td>H+</td>
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<tr>
<td>K</td>
<td>5.1 nmol/l</td>
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<tr>
<td>NA</td>
<td>149 mmol/l</td>
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<td>HCO3A</td>
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<tr>
<td>BE</td>
<td>57.8 mmol/l</td>
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<tr>
<td>SHE</td>
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</tbody>
</table>
permissive hypercapnia
Targeted therapeutic mild hypercapnia after cardiac arrest

Glenn M. Eastwood¹, ²*, Alistair Nichol², ³, ⁴ and Matt P. Wise⁵
contraindications to permissive hypercapnia
\[ \text{pH} = 6.1 + \log_{10} \left( \frac{[\text{HCO}_3^-]}{0.03 \times \text{pCO}_2} \right) \]
pCO₂ 64 mmHg

Bicarbonate 24 mEq/L

pCO₂ 32 mmHg

pH = 6.1 + \log_{10} \left( \frac{[\text{HCO}_3^-]}{0.03 \times \text{pCO}_2} \right)
Bicarbonate 35 mEq/L

\[ \text{pH} = 6.1 + \log_{10} \left( \frac{[\text{HCO}_3^-]}{0.03 \times \text{pCO}_2} \right) \]

\( \sim 7.2 \)

\( 7.5 \)

pCO2 93 mm?

pCO2 46 mm
goose-chase principle: if there is no solid evidence regarding a therapeutic goal (e.g. pH in ARDS), don’t go crazy trying to chase it with high accuracy.
goals

• monitoring oxygenation: \( pO_2 \) vs. pulse oximetry?
• ventilation: what is our target pH?
• **VBG vs. ABG?**
• etCO\(_2\) strengths & weaknesses
• putting it together: algorithm
Respiratory Quotient (RQ) = \frac{\Delta CO_2}{\Delta O_2}

RQ \approx \text{stable} \approx 0.8

\Delta CO_2 \propto \Delta O_2
CO$_2$: direct comparisons

![Graphs showing comparisons between arterial and venous pCO$_2$ for different studies.](image-url)
\[ \Delta pCO_2 \text{ vs. } \Delta O_2\% \]

\[ \Delta pCO_2 = (\text{venous } pCO_2 - \text{arterial } pCO_2) \]

\[ \Delta O_2\% = (\text{arterial } O_2\% - \text{venous } O_2\%) \]
Use of **venous oxygen saturation** to qualify reliability of VBGs

**What is the venous oxygen saturation?**

- **Venous O2% > 75%**: VBG is probably very close to ABG
- **Venous O2% 50-75%**: VBG may be a bit off compared to ABG
  - venous pH may be low
  - venous pCO2 may be high
- **Venous O2% <50%**: VBG may be unreliable
goose-chase principle: if there is no solid evidence regarding a therapeutic goal (e.g. pH in ARDS), don’t go crazy trying to chase it with high accuracy.
goals

• monitoring oxygenation: $pO_2$ vs. pulse oximetry?
• ventilation: what is our target pH?
• VBG vs. ABG?
• etCO$_2$ strengths & weaknesses
• putting it together: algorithm
arterial pCO2 > etCO2
difference ~ dead space
arterial pCO2 > etCO2

- high etCO2 (60 mm)

- low etCO2 (20 mm)
narrow-gap patient

- normal lungs
  - intubated for non-respiratory reason
  - no history of lung disease
  - normal chest x-ray
- good capnograph

\[(P_{aCO2} - etCO2) < \sim 15 \text{ mm}\]
\[ pH = 6.1 + \log_{10}\left(\frac{[HCO_3^-]}{0.03 \times pCO_2}\right) \]

- Bicarbonate: 24 mEq/L
- pCO2: 64 mmHg
- pH: 7.5
- pCO2: 32 mmHg

\( \sim 7.2? \)
etCO₂ 32mm

range of possible PaCO₂ values

target pCO₂ values to achieve pH between 7.2-7.5
limitations of etCO2

- APRV 😊
- rapidly evolving lung disease
saving grace of etCO2

etCO2 32mm

range of possible PaCO₂ values

30mm 40mm 50mm 60mm 70mm

target pCO₂ values to achieve pH between 7.2-7.5
ideal monitoring: etCO2 & minute ventilation
ideal monitoring: etCO2 & minute ventilation

etCO2                    minute ventilation

etCO2                         minute ventilation

end tidal CO₂

minute ventilation (liters/min)
<table>
<thead>
<tr>
<th>Vital</th>
<th>Temp</th>
<th>Temp Source</th>
<th>HR</th>
<th>SpO2</th>
<th>CamCU</th>
<th>CAM-ICU</th>
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<td>36.4</td>
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<td>Tympanic</td>
<td>78</td>
<td>98</td>
<td>Negative</td>
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**Expiratory:**
- SpO2: 99%
- FiO2: 70%
- Device: Intub...
goals

• monitoring oxygenation: $pO_2$ vs. pulse oximetry?
• ventilation: what is our target pH?
• VBG vs. ABG?
• $etCO_2$ strengths & weaknesses
  • putting it together: algorithm
Approach to: intubated patient

Need ABG to monitor oxygenation?
- Unreliable pulse oximetry waveform
- Methemoglobinemia/carboxyhemoglobinemia

Vampire pathway
ABG, repeat PRN.
(Also follow etCO₂)

Yes
No
Approach to: intubated patient

Need ABG to monitor oxygenation?
- Unreliable pulse oximetry waveform
- Methemoglobinemia/carboxyhemoglobinemia

Criteria for etCO2-only monitoring
[1] Precise CO2 control unnecessary
- No ICP elevation
- Not hemodynamically unstable with pulmonary HTN
- Not pregnant

[2] etCO2 expected to be reliable
- Good waveform
- No chronic lung disease
- No acute lung disease (intubated for non-pulmonary reason)
- Chest X-ray shows normal-appearing lungs

Vampire pathway
ABG, repeat PRN.
(Also follow etCO2)

Anesthesiologist pathway
(No ABG/VBG!)
- Use oxygen saturation to monitor O2
- Use etCO2 to monitor CO2
- Follow minute ventilation
**Approach to:** intubated patient

- Unreliable pulse oximetry waveform
- Methemoglobinemia/carboxyhemoglobinemia

### vampire pathway

- ABG, repeat PRN.
- (Also follow etCO₂)

### anesthesiologist pathway

(no ABG/VBG!)

- Use oxygen saturation to monitor O₂
- Use etCO₂ to monitor CO₂
- Follow minute ventilation

---

**criteria for etCO₂-only monitoring**

**[1] Precise CO₂ control unnecessary**
- No ICP elevation
- Not hemodynamically unstable with pulmonary HTN
- Not pregnant

**[2] etCO₂ expected to be reliable**
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- Chest X-ray shows normal-appearing lungs

### VBG pathway

- Oxygen saturation to monitor O₂
- Initial VBG to correlate & confirm the accuracy of etCO₂
- Subsequently monitor CO₂ using minute ventilation & etCO₂
- Repeat VBG if substantial change or data not making sense (avoid lots of VBGs)
electronic handout

- https://emcrit.org/squirt/resp2019/

- link will be posted on @PulmCrit