Because the ETCO2 Waveform Told Me to...

By

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I have no actual or potential conflict of interest in relation to this presentation.
Objectives

A review of how the ETCO2 waveform is created (the boring stuff)
- Path CO2 takes to get out of the body
- How the ETCO2 waveform is created

What you can learn from being able to accurately read an ETCO2 tracing (cool stuff)
- When to use ETCO2 and when not to (avoid the dumb stuff)
- Possibly more obscure, yet totally cool, stuff that I found while researching ETCO2 for this talk.
The Path CO2 Takes to Get Out of the Body
Ventilation Diffusion Gradient

- CO₂ is produced in the cells and diffuses out into the blood.
- 35 to 45 mmHg is normal in your PaCO₂.
- Your primary drive to breathe stimulated in your central and peripheral chemoreceptors by your PaCO₂.
- CO₂ diffuses into the lungs and is exhaled.
- ETCO₂ is the amount of CO₂ excreted at the end of exhalation. It is normally < 6 mmHg lower than PaCO₂.
Cellular Respiration
CO2 Chemoreceptors
Into the Lungs
What Affects Respiration in the Lungs: Shunt, Normal and Deadspace

Venous Blood
\[ O_2 = 40 \quad CO_2 = 45 \]

Inspired Air
\[ O_2 = 150 \quad CO_2 = 0 \]

V/Q = 0
R-L Shunt

V/Q = 1
Normal

V/Q = \infty
Dead Space
A Review of How the ETCO2 Waveform is Created
Why Use ETCO2 if You Have a Pulse Oximeter?

- It measures CO₂, not oxygen.
- It is an immediate indicator of changes in ventilation (disconnections, etc.)
- If you want to know which is more helpful to have, imagine you are hooked up to both and hold your breath. Would you rather wait for the alarm from the ETCO₂ detector or would you rather wait for your SpO₂ to drop?
- Early indications of problems help you avoid emergencies rather than react to them.
Some Lingo First…
Two Types of ETCO2 Analyzers: Main Stream vs. Side Stream Analyzers
End Tidal CO2

The nasal prong line measures CO2 through a flap that hangs over the mouth. It also can deliver oxygen to the patient.

The advanced airway line connects to the top of the LMA or endotracheal tube. The line can become clogged and un-useable if the patient vomits.
Main Stream ETCO2 Analyzer
Main Stream Monitor with Secretions

This is frequently the problem that causes the “Clean cuvette” error.
There are ETCO2 Detectors That Have Different Purposes

- Mainly numeric
- Limited use
- Battery operated
- **Good for codes and intubations**
• Numeric and waveform
  • In codes, ER, OR and ICU
  • Capnograph types
    • Built into the vent (Mainstream)
    • Built into the monitors (Sidestream and mainstream)
    • Handheld versions for transports and codes
• Numeric, waveform and calculated in ICU only
  • Novametrix NICO CO₂ monitor
    • Capable of much more than a standard capnograph
      • Volumetric calorimetry (We will hit this later.)
    • Deadspace
    • Cardiac output using the Fick equation
    • REE
ETCO₂

- This measures the CO₂ (or ventilation) aspect of breathing - not oxygenation.
- Simple definition: Exhaled CO₂ as a function of time.
- There is a lot of information you can reason out if you know where to look.

The Normal Capnograph
How Do They Work?

- Magic! Just like your TV
- Capnography uses infrared waves to measure CO₂
  - Some nice pics from http://www.howequipmentworks.com
Infrared

ultra violet (invisible to human eye)

infra red (invisible to human eye)
Infrared waves are blocked by CO2 molecules
Certain wavelengths are absorbed by certain molecules. 4.25 micrometers is CO2.
Normal ETCO2 Waveform

Phase I

Phase II

Phase III

Phase IV

The Normal Capnograph
Phase I

Just anatomic deadspace.

The Normal Capnograph
Phase II

50% deadspace, 50% alveolar

The Normal Capnograph
Alveolar Diffusion
Phase III

- Mostly alveolar gas
- Contains the end point of the breath!

The Normal Capnograph
Phase IV

- Inhalation of new breath
- Rapid drop to zero
Contraindications

- **Side stream**
  - It may syphon off too much of the tidal volume on the ventilator (not good on neonates). Watch your aspiration sample rates. 50-200 ml/min
  - Deadspace is too much (not good on neonates)

- **Mainstream**
  - Deadspace is too much (not good on neonates)
  - Not good in MRI.

- **Both**
  - Excessive secretions.
CO2 Monitoring with Neonates

Transcutaneous CO2 – Slower, but safer
How Is It In Practice?
A.K.A. Charting and Orders...
Code Blue Note

Respiratory Code Blue

Time: [Timestamp]

Place: [Location]

Intubated: [INTUBATED YES/NO]

Summary of Events: ***
ETCO2 range was *** through *** and was measure throughout CPR.

MARK BACHAND, RT 02/01/19
ETCO2 Protocol Defaults to Yes
How to Document Target ETCO2s

Current ETCO2 Reading: 
Corresponding ABG PaCO2: 
ABG pH: 
Discussion: 
Agreed upon target ETCO2

***
***
***
I spoke to Dr *** regarding the ETCO2 goals of therapy.
*** to ***
Points to Remember

- The PaCO₂ – PetCO₂ gradient:
  - Usually < 6 mmHg
  - Can be close to equal if the slope of phase III is flat or has minimal slope
- ETCO₂ is never supposed to be more than PaCO₂
- The difference depends on the number of under-perfused alveoli
What You Can Learn From Being Able to Accurately Read an ETCO2 Tracing (Cool Stuff)
Indications

- Prehospital
  - A standard of care. Especially in obtunded patients
- Intraoperatorively
- In MRI, for sedated and/or vented patients
- During Codes: you can tell if your patient has ROSC or loss thereof
  - “Get with the Guidelines” is an AHA reporting system that recommends ETCO2 monitoring in codes and is supported by UVM’s Resuscitation Committee.
- ED – conscious sedations, intubations, ODs
- ICU
  - Sudden changes (big stuff you shouldn’t miss)
    - PEs
    - ETT plugged
  - Trends (subtle stuff)
    - Warming, sepsis, weaning, etc.
    - To reduce blood gasses on intubated patients
- You can infer a lot of information. (If you are a ninja level)
  - Like if your neb is working...
  - Degree of lung injury
Disclaimer

- Being able to read waveforms is a skill to be developed. It is not something that you will be able to do immediately after this talk.

- You *should* be able to tell what a normal wave looks like after this talk.
ETCO2 Monitoring
When It’s Abnormal...

- Look at your patient? Do they jive with the monitor?
- What phase of expiration is it? Inspiration or expiration?
- Speed of change
  - For example...
    - Decrease in CO2
      - Gradual
        - Hyperventilation
        - Decrease in metabolic rate
        - Decrease in body temperature
      - Rapid
        - Embolism (air or thrombus)
        - Sudden hypotension
        - Circulatory arrest

The Normal Capnograph
Factors in ETCO2 Waveforms

<table>
<thead>
<tr>
<th>TABLE 1: THE BASICS OF CAPNOGRAPHY</th>
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</thead>
<tbody>
<tr>
<td>Causes of Decreased ETCO₂</td>
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<tr>
<td><strong>Respiratory System</strong></td>
</tr>
<tr>
<td>• Alveolar hyperventilation</td>
</tr>
<tr>
<td>• Bronchospasm</td>
</tr>
<tr>
<td>• Mucous plugging</td>
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<tr>
<td>• Partial airway obstruction</td>
</tr>
<tr>
<td>• ETT in hypopharynx</td>
</tr>
<tr>
<td>• Pulmonary embolus</td>
</tr>
<tr>
<td>• Increased minute ventilation</td>
</tr>
<tr>
<td><strong>Circulatory System</strong></td>
</tr>
<tr>
<td>• Cardiac arrest</td>
</tr>
<tr>
<td>• Embolism</td>
</tr>
<tr>
<td>• Sudden hypovolemia</td>
</tr>
<tr>
<td>• Sudden hypotension</td>
</tr>
<tr>
<td>• Decreased cardiac output</td>
</tr>
<tr>
<td><strong>Metabolism</strong></td>
</tr>
<tr>
<td>• Analgesia and/or sedation</td>
</tr>
<tr>
<td>• Hypothermia</td>
</tr>
<tr>
<td>• Shivering</td>
</tr>
<tr>
<td><strong>Equipment</strong></td>
</tr>
<tr>
<td>• Leak in airway system</td>
</tr>
<tr>
<td><strong>Iatrogenic</strong></td>
</tr>
<tr>
<td>• NaHCO₃ infusion</td>
</tr>
<tr>
<td>• Tourniquet release</td>
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</tbody>
</table>
ETCO2 Waveform Analysis

A1: Normal Tracing
A2: Increased Slope of Phase III
A1: Spontaneous Ventilation with Dead Space
B2: Dead Space Removed
C1: Cardiogenic Oscillations
C2: After Unilateral Lung Transplant for Emphysema

5 sec
Additional Waveforms

**Sudden loss of waveform**
- ET tube disconnected, dislodged, kinked or obstructed
- Loss of circulatory function

**Decreasing EtCO₂**
- ET tube cuff leak
- ET tube in hypopharynx
- Partial obstruction

**CPR Assessment**
- Attempt to maintain minimum of 10mmHg

**Sudden increase in EtCO₂**
- Return of spontaneous circulation (ROSC)

**Bronchospasm (“Shark-fin” appearance)**
- Asthma
- COPD

**Hypoventilation**
- Hyperventilation

**Decreased EtCO₂**
- Apnea
- Sedation
ETCO2 Waveform Interpretation

Normal

Obstructive (COPD)

Curare Cleft

Dilution with another gas source

Cardiac “artifact”
Hyper and Hypo Ventilation

Hypoventilation

Hyperventilation
Pneumothorax and Tension Pneumothorax

Pneumothorax

Tension Pneumothorax
Real World Example

VC-AC
AutoFlow

14:28:10

Paw (cmH2O)

Flow (L/min)

CO2 (mmHg)

PIP (cmH2O)

Pplat

Pmean

RR (1/min)

MV (L/min)

VT (mL)

% Leak

VT/Ag BW

eTCO2 (mmHg)

VCO2 (mL/min)

FIo2

VT

Ti

RR

PEEP

Slope

60
380
0.95
24.0
10.0
0.20

30
222.6

23
40
15

25
36
10.0

389
1000
19
6.1

47
What’s This?
ETCO2 Anomalies Not Covered Already

- An increase in inspired CO₂ will look like a rising baseline
  - Calibration error
  - Water in analyzer
- Difference between PaCO₂ and ETCO₂
  - Increase
    - Age
  - Decrease
    - Pregnancy
    - In children
Points to Remember

1. Know what a normal wave form looks like.

2. That’s it.
When to Use ETCO2 and When Not to Use It
When to Use ETCO2

- Prehospital
  - A standard of care. Especially in obtunded patients
- Intraoperatively
- In MRI, for sedated and/or vented patients
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When Not To Use It

- With APRV
- With NIV
- With people with very dynamic tidal volumes
  - Example: “neuro breathing” pattern, weaning
- When ETCO₂ and PaCO₂ do not trend together
- Really large air leaks
- Mainstream
  - No MRI
  - Limited use in neonates
- Side stream
  - Limited use neonates
APRV and ETCO2

- No.
- Here is why...
- You never get to the end of expiration with APRV. You deliberately cut off expiration at 50% of the max expiratory flow.
APRV and ETCO2

Inspiratory flow

Expiratory flow

PEFR (60 lpm)

END OF THE BREATH

50% of PEFR (30 lpm)

75%

25%

T_{low}

Full exhalation
APRV with ETCO2

PC-APRV

ATC Ø 7.5 mm

Flow cmH2O

PIP cmH2O

Pplat

Pmean

RR

MV

C20/Cdyn

VT mL

% leak

VT/kg BW

eTCO2 mmHg

V'CO2 mL/min

FiO2

Slope

Phigh

Pflow

Thigh

Tflow

28

0.00

24.0

0.0

11.00

1.00

Aqn. Vent.
ETCO2 and CPAP Combined

Umm...No.
CPAP Effect on ETCO2
Possibly More Obscure, Yet Totally Cool, Stuff That I Would Love to See Catch on...
The Near Future of ETCO2

- Used to determine reaction to bronchodilators
- DKA - used with a glucometer in the ER to quickly establish severity
- Example of Setting Triage Category:
  - Glucose of 800 and ETCO2 of 35
  - Glucose of 800 and ETCO2 of 10 and incr MV
  - Glucose of 800 and ETCO2 of 45 and lethargic
Things Missing in Standard ETCO2 Monitoring

- It doesn’t address volume!
  - Phase III of the curve is not informative of $\dot{V}/\dot{Q}$
  - The area under the curve can’t be used to calculate $V_D/V_T$
Deadspace Fraction as Prognostic Device in ARDS

Prognostic Value of the Pulmonary Dead-Space Fraction During the Early and Intermediate Phases of Acute Respiratory Distress Syndrome

Mortality & dead-space fraction in 80 patients with early-ARDS and 49 patients with intermediate ARDS
The Solution: Volumetric Calorimetry

- Volumetric Capnography this is the exhaled CO2 as a function of volume.
- Pratik Sinha from the Imperial College London ([https://www.youtube.com/watch?v=RBIPCImzKTjY](https://www.youtube.com/watch?v=RBIPCImzKTjY))
- Advantages
  - Qualitative assessment of CO2 curve
  - More accurate measurement of expired CO2
  - Volume of CO2 excretion
  - Deadspace ventilation
Started as SBT – CO2
Two Ways of Getting Deadspace: Bohr & Enghoff Equations

Bohr’s Approach

\[ \frac{V_D}{V_T} = \frac{P_{ACO_2} - P_{ECO_2}}{P_{ACO_2}} \]

Enghoff’s Approach

\[ \frac{V_D}{V_T} = \frac{P_{aCO_2} - P_{ECO_2}}{P_{aCO_2}} \]

Fowler airway dead space
Volumetric Calorimetry

- If you enter PaCO₂, most volumetric capnographs (like the NICO) will give you deadspace with Enghoff’s method (most accurate).

- Studies have shown:
  - Can be used to assess the effectiveness of prone-positioning in respiratory failure.
  - Can be used to optimize peep
    - When peep is adjusted correctly, deadspace drops from opening up areas of functional alveoli
  - Useful in monitoring efficiency of ECCO₂R membrane in ECMO patients
Disadvantages

- If $>0.80$ deadspace, the reliability of the reading becomes compromised due to the software programming.
Volumetric Calorimetry Waveform

Visual Representation of **Deadspace**

[Diagram showing the relationship between PCO2 and Pao2 across different phases of respiratory processes, highlighting the concept of deadspace and alveolar volume.]
Normal Deadspace

Normal Patient

EtCO₂ [KPa]

PaCO₂

Exhaled Tidal Volume [mLs]

Phase I  Phase II  Phase III

B. Elective Surgery Vd/Vt 0.37
COPD Deadspace
ARDS Deadspace
So How Far Off is This?

It’s already here!

Well... Sort of.
Final Points to Remember

- You MUST:
  - Know when to use it and when not to use it
  - Know your normals
    - What is the correct normal value
    - What a normal wave form looks like
  - Use as a trending tool until accuracy has been established via an ABG
  - Use other clinical indicators to confirm what the monitor is implying!

- You can additionally:
  - Use waveforms to indicate clinical conditions

*Reading wave forms is a skill to be developed*
Thank You All