Capnography and Ventilation for the EMS Professional

Advanced concepts in the ventilation of the acutely ill patient
Raymond L. Fowler, M.D., FACEP

Associate Professor of Emergency Medicine
The University of Texas Southwestern

Chief of Medical Operations
The Dallas Metropolitan BioTel System

Co-Chief in the Section on
EMS, Disaster Medicine, and Homeland Security
UT Southwestern Medical Center
The Objective Question:

What is the relationship between 
exhaled carbon dioxide 
and 
cardiac output?
The Objective Question:
Directly proportional
or
Inversely proportional ??
What is Carbon Dioxide?

- Capnos comes from the Greek word for “smoke”
  - smoke from the fire of metabolism
  - a natural waste product of cellular activity
- CO$_2$ is a compound molecule
  - 2 elements of oxygen and 1 element of carbon
  - colorless and heavier than air
  - green plants clean up after our exhaled CO$_2$
Carbon dioxide physiology

\[
\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^- 
\]
More specifically...

Oxygen $\rightarrow$ lungs $\rightarrow$ alveoli $\rightarrow$ blood

breath

$\mathrm{CO}_2$

lungs

$\mathrm{CO}_2$

blood

energy

$\mathrm{CO}_2$

Oxygen

muscles + organs

cells

Oxygen + Glucose
Carbon dioxide physiology

- 0.03% concentration in air
- Resting adult produces 2.5 mg/kg/min
- In a 70 kg adult, that is about 175 mg per minute, or about 4% of a teaspoonful
Carbon dioxide physiology

- **Transported in blood**
  - 60-70% bicarbonate ion after conversion in RBCs using carbonic anhydrase
  - 20-30% bound to proteins (e.g., Hb)
  - 5-10% in physical solution (PCO$_2$)

- **Cleared by alveolar ventilation**
Alveoli: The Place Where Gas Exchange Happens
Largely Dependent on Oxygen Delivery...  
...in low flow states
Oxygenation

- Adequate Lung Inflation
- Supplemental O₂
Largely Dependent on Oxygen Consumption
Need to Ventilate

- CO₂ Production
  \[O₂\text{ Consumption}\]
  \& Venous Return

- Dead Space
  \(\text{wasted ventilation}\)
Thus!!!
The “Speed”
of Ventilation

• CO₂ Production
• Increased Dead Space
Blood pressure = (Cardiac output) x (Volume) x (Peripheral resistance)
Shock

Cardiogenic
- Rapid pulse
- Distended neck veins
- Cyanosis

Volume Loss
- Rapid pulse
- Flat neck veins
- Pale

Vasodilatory
- Variable pulse
- Flat neck veins
- Pale or pink
Signs of Shock

Early
- Weak, thirsty, lightheaded
- Pale, then sweaty
- Tachycardia
- Tachypnea
- Diminished urinary output

Late
- Hypotension
- Altered LOC
- Cardiac arrest
- Death
As circulation fails, the ability of the heart to “blow on the coals” that are the cells of the body is reduced
Examples:

• Shock of any cause
• Tension pneumo
• Massive hemorrhage
• Cardiac arrest
• Sepsis
Consider Cardiac Arrest

- Little O$_2$ Delivery & Consumption
- Little CO$_2$ Production & Venous Return

...Little Need to Ventilate!!
We went to California to watch them practice CPR training.

**FIG. 105. ARTIFICIAL RESPIRATION.**
Raising and lowering arms. Third Method.
Cardiac Arrest….

8 breaths / min

Little CO\textsubscript{2} Excretion
Where did this hyperventilation thing come from anyway?

- All of the head trauma discussion dating back to the 80’s and before
- Grief and relief after dealing with a difficult airway
EFFECT OF HYPERVENTILATION ON INTRACRANIAL PRESSURE

Higher ICP

Lower ICP

Hypoxemia or Hypotension

PaCO₂ (mmHg) PaCO₂ (mmHg)
The Response of Intracranial Pressure to changes in carbon dioxide is less when the patient is in circulatory compromise.
EFFECT OF HYPERVENTILATION ON INTRACRANIAL PRESSURE

Higher ICP

Hypoxemia or Hypotension

Lower ICP

PaCO2 (mmHg)
Let’s think about a Cardiac Arrest case...
A 55 year old man is found down in Cardiac Arrest by his wife. EMS is called. Citizen CPR is being done.

He was well until this happened. He has no medical problems and takes no medications.
After defibrillation the patient remains in this rhythm. He does not improve after CPR and the administration of epinephrine or amiodarone.
What do you do??
REMEMBER:
The heart only pumps out what it gets back!
The negative pressure in the thorax PULLS blood back!
The negative pressure in the thorax PULLS blood back!

AGAIN!!!!
Blood pressure = (Cardiac output) x (Volume) x (Peripheral resistance)
Cardiac Output = Pulse Rate \times Stroke Volume
Understanding the body by regions

Positive pressure

Negative pressure

Positive pressure
The negative pressure inside the thorax “pulls” blood back from the positive pressure areas.
Maintaining the “negativity” of the pressure inside of the thorax is one of the most vital areas of understanding resuscitation.
Positive Pressure in the Thorax decreases Venous Return!!
Much of what we do for patients during resuscitation is bad physiology!!
Positive pressure breaths

Chest compressions
Breathing the patient too fast INCREASES pressure inside the chest!
It seems that we have been over-ventilating people in circulatory collapse for years.
Coronary perfusion pressure drops with over-ventilation
Chest Compressions & Coronary Perfusion Pressure

5:1 Ratio

- 20 mmHg
- 40 mmHg

15:2 Ratio

- 20 mmHg
- 40 mmHg
Venous return drops with over-ventilation
Intrathoracic pressure is raised with over-ventilation
Sanders, *et al*

- **15:2** (e.g., former standard CPR)
- **50:5** (e.g., Great Britain)
- **CC** (chest compressions only)
- **4 min CC only; then 100:2**
Neurological Outcomes...

- 4 min CC only; then 100:2 Did Significantly Better than 15:2 (e.g., standard CPR)

- CC (chest compression only) Did Much Worse
It appears that a one hand squeeze at a rate of one every eight seconds is ALL the ventilation that a patient in circulatory collapse needs!
This is the minute ventilation that you are breathing right now!

About five liters per minute
Breathing the patient faster than that may reduce venous return, worsen shock, and kill the patient!
Let capnography guide you!
First-generation sidestream instruments continuously draw sample gases via an endotracheal tube adapter, through a sampling tube, to an IR light source and detector within a remote bedside monitor.

Sidestream sampling tubes and adapters frequently become clogged and contaminated by respiratory secretions unless the tubes are routinely and frequently replaced.
Second-generation mainstream capnographs mount the IR source and detector lateral to an adapter at the end of the patient's endotracheal tube.
Microstream® technology addresses this problem in this way:

The filter line airway adapters collect air from the middle, not the side, of the air stream through three hollow sampling ports oriented in different directions.
Microstream® technology:
Minimizes aspiration of secretions in the device and makes sampling less dependent on patient posture and device orientation.
Colorimetric method

- A (purple) = \(< 4 \text{ mm Hg}\)
- B (tan) = 4-15 mm Hg
- C (yellow) = \(> 15 \text{ mm Hg}\)
Physiology Reminder

Oxygen $\rightarrow$ lungs $\rightarrow$ alveoli $\rightarrow$ blood

breath

CO$_2$

lungs

CO$_2$

blood

Oxygen

muscles + organs

cells

energy

Oxygen + Glucose

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Normal Capnogram
Prolonged Exhalation Capnogram
Capnography shows:

1. Is the airway in?
2. What’s the shape?
3. What’s the absolute height of the wave?
Capnography:

1. Verification
2. Bronchoconstriction
3. Circulatory collapse
Quick Review of Causes of a Decreased \( \text{EtCO}_2 \)

**Decreased Metabolism**
- Analgesia / sedation
- Hypothermia

**Circulatory System**
- Cardiac arrest
- Embolism
- Sudden hypovolemic or hypotension

**Respiratory System**
- Alveolar hyperventilation
- Bronchospasm
- Mucus plugging

**Equipment**
- Leak in airway system
- Partial airway obstruction
- ETT in hypopharynx
Quick Review of Causes of an Elevated $\text{EtCO}_2$

- **Increased Metabolism**
  - Pain
  - Hyperthermia
  - Malignant hyperthermia
  - Shivering

- **Circulatory System**
  - Increased cardiac output with constant ventilation

- **Respiratory System**
  - Respiratory insufficiency
  - Respiratory depression
  - Obstructive lung disease

- **Equipment**
  - Defective exhalation valve
  - Exhausted $\text{CO}_2$ absorber
Misplaced Endotracheal Tubes by Paramedics in an Urban EMS System

Steven H. Katz, M.D.
Jay L. Falk, M.D., FACEP, FCCM
Marybeth Wash, R.N.

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Orlando Regional Medical Center
Orlando, FL
Misplaced Endotracheal Tubes by Paramedics in an Urban EMS System

Of 108 patients presenting to their emergency department with an endotracheal tube in place, 27 of the tubes were misplaced.

Of the 27 misplaced, 18 were in the esophagus, or 17% of the intubation.
Misplaced Endotracheal Tubes by Paramedics in an Urban EMS System

Conclusions

• Alarming rate of unrecognized, misplaced ETTs in the field
• Unique to Orange County?
• Under-reported national problem?
What Happened in Block 2?

The endotracheal tube became dislodged!
Marked bronchospasm
Warning, Warning!!!

All good things can go wrong!
The filter line can either not be hooked up correctly or can get clogged.
The Height of the Curve

Non-survivors of Cardiac Arrest
Average ETCO2: 4-10 mmHg

Survivors (to discharge)
Average ETCO2: >30 mmHg
• Flat waveform may indicate PEA if an EKG complex is present.
• ROSC shows increasing ETCO₂.
• Waveform configuration changes with bronchoconstriction.
The Impedance Threshold Device
The ITD together with waveform capnography should show an additive effect in improving survival from cardiac arrest.
American Heart Association in the 2005 Guidelines recommended slower ventilations during cardiac compressions.
My recommendations

• Start with the rate of eight, and then measure capnography every five minutes.

• If below 20 mmHg CO2, then slow to 1 every 10 seconds.

• If above 40 mmHg CO2, then increase rate to 1 every 6 seconds.
<table>
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<th>Time</th>
<th>Event</th>
<th>HR</th>
<th>SpO2•PR</th>
<th>EtCO2(mmHg)•RR</th>
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So, what do we do with this guy??
Make SURE that his ventilation rate is a one hand squeeze every eight seconds.
Evaluate capnography or capnometry five minutes later
Adjust the ventilation rate from there.
...and, if you do this...

...AND YOU MUST...
you will likely be the only
guy or gal on the team
who understands that
this is now the standard
The Objective Question:
What is the relationship between exhaled carbon dioxide and cardiac output?
The ANSWER!!

ETCO2 and Cardiac Output are **DIRECTLY PROPORTIONAL** when assisting the patient with positive pressure breathing such as Bag to ET tube in cardiac arrest.
EMS is leading the emergency medicine industry in critical care ventilation.
Early AHA standards for the use of ventilators during resuscitation required that the ventilator be removed during cardiac compressions.
EMS and Mechanical Ventilators

“These devices should be available on every ambulance, and the ability to use ETVs should be part of each EMS provider's skill set.”

Wayne, Delbridge, Ornato, Swor et al
Turtle Creek Conference II
PEC Jan-Mar 2001


Johannigman JA, Branson RD, Johnson DJ, Davis K Jr, Hurst JM. Department of Surgery, University of Cincinnati Medical Center, OH

A prospective, nonrandomized, convenience sample of 160 patients requiring airway management in the out-of-hospital urban setting, an ABG study on arrival to the ED

When ET intubation was accomplished, adequate ventilation could be achieved using either bag-valve ventilation or a transport ventilator.
### Catalog Numbers & Pricing

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Product Name: LSP AutoVent 3000
Transport Ventilator

Price: $3195.00

Part Number: LSP-LSP3000

The LSP AutoVent 3000 is a portable, compact emergency transport ventilator with a variety of applications from industrial and volunteer EMS use to air and ground transport. Offering controlled ventilation at rates of 8-28 breaths per minute as well as additional inspiratory time settings, the AutoVent meets most critical emergency care situations and in-hospital transports.

The AutoVent 3000 comes with the LSP patient valve and supply tubing, the control module, six feet of oxygen hose, a non-rebreathing valve (to attach Peep), and connecting tubing. The attached patient valve allows a patient to draw supplemental gas flow (up to 48 LPM) with a spontaneous effort. The AutoVent is available as an anti-inhalation valve for use in toxic environments. The ventilator operates exclusively on source gas with no air entrainment, so specified concentrations of oxygen can be easily maintained.
Specifications

**Control Module:**
- Supply Pressure Range: 40 to 90 psig
- Storage Temperature: -40°F to 160°F
- Frequency: 8 to 28 BPM
- **Tidal Volume:** 200 to 1200 ml.
- Flow Rate: 16 to 48 LPM
- Inspiratory Time: 0.75 - 1.5 seconds
- Expiratory Time: 1.5 to 6.0 seconds
- I:E Ratio: 1:1 to 1:4

**Dead Space in Patient Valve Assembly:** 8 ml

**Weight:** 24 oz./680g.

**Expiratory Resistance:** 5 cm. H2O

**Minute Volume:** 0 to 24 LPM

**Case Material:** ABS

**Input Connection:** Plated brass

**Output Connectors:** Plated brass

**Gas Consumption Driving Gas:**
- 0.5 LPM Maximum

**Patient Valve Assembly:**
Flow: As required in demand valve mode: 0-48 LPM at 50 psig. Depends on volume setting.

**Peak Inspiratory Flow:** 48 LPM at airway pressure

Delivery Pressure: 60 ±5 cm H2O (44 mm Hg)

Crack Pressure: 0- to -2 cm H2O (0 to -.8 in H2O)

Exhalation Resistance: 0-10 LPM to 1.5 cm H2O, 11-70 LPM to 3.8 H2O

Gas Consumption Driving Gas: 0.5 LPM Max

Dead Space: 8 ml (excluding mask)

Supply Pressure: 40 to 90 psig

---

**D Cylinder holds 425 liters of oxygen, so a full tank could run an Autovent for 800 minutes, or 13 hours**

Operating Temperature: -30°F to 125°F

Storage Temperature: -40°F to 160°F

Inlet Fitting: Standard

Filter: 25 Micron Stainless Steel Mesh

Body: Anodized aluminum

Cover: Polycarbonate

Outlet: Polysulfone

Inlet Fitting: Plated brass
“Ventilation requires attention during initial training, ETVs clearly have a role in the prehospital setting.

Wayne, Delbridge, Ornato, Swor et al
Turtle Creek Conference II
PEC Jan-Mar 2001
“All patients requiring emergency ventilation must be adequately monitored, including continuous monitoring of end-tidal carbon dioxide concentrations.”

Wayne, Delbridge, Ornato, Swor et al
Turtle Creek Conference II
PEC Jan-Mar 2001
“Ventilation requires attention during initial training, continuing education and skill reinforcement, and quality review.”

Wayne, Delbridge, Ornato, Swor et al
Turtle Creek Conference II
PEC Jan-Mar 2001
**LSP Omni-Vent Portable Ventilator**

The Omni-Vent is a pneumatic ventilator that provides assist-controlled, continuous flow, IMV and CPAP ventilation modes. This time cycled ventilator features inspiratory/expiratory variable ratios and a pressure relief value. The Omni-Vent D is MRI compatible.

**Specifications:**
- **Power:** air/oxygen 25 psi to 140 psi
- **Rate:** 1-50 BPM Inspiratory time range 0.2 to 3.0 Expiratory time range 0.2-60 sec.
- **Volume:** 0-1.5L (volume can be limited)
- **Flow rate:** 0-80 LPM
- **Dimensions:** 4"H x 5"W x 7"D
- **Weight:** 4.5 lbs.

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Impact 750 Transport Ventilator

Designed to meet the needs of air medical and critical care transport. Powered with an internal battery, the 750 ventilation modes include Control, Assist-control, SIMV and CMV. All controls are grouped by function. Lightweight, the 750 is a perfect choice for transport ventilation applications. The 750 is EMI/RFI & air medical certified.

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Impact 754 Eagle Transport Ventilator
The best critical care transport ventilator on the market. Completely self contained, the Impact 754 Eagle is battery powered, weighs just over 12 lbs. and consumes no gas. Featuring an internal compressor and blender, the Eagle offers PEEP with Controlled Assist, SIMV, CPAP, and CMV (for Apnea backup) ventilation modes. Bright graphic LCD provides monitoring and alarm settings. An interactive demo/teaching mode assures fast startup sequence in as little as three steps. The Eagle is EMI/RFI & air medical certified.

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<td>Pediatric Disposable Circuit</td>
<td>each</td>
<td>$8.95</td>
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ParaPAC 'Medic' Automatic Transport Ventilator (ATV)

The paraPAC™ Medic Ventilator is a compact, easy to use, rugged, gas powered automatic transport ventilator (ATV). Its unique array of control functions make this product useable in situations from the first responder resuscitation scenario through the hospital transport application. Featuring a 2 point blender with SMMV* functions, this unit meets your controlled ventilation needs at an affordable price.

- SMMV - Synchronized Minimum Mandatory Ventilation
- Frequency control 8 to 40b/min
- Tidal volume control 1300 to 70ml
- Pressure monitor 0 to 100 cm H₂O
- 2 point blender 100% or 50% O₂
- Adjustable relief pressure with audible alarm
  20 to 80 cm H₂O
- Add-on PEEP option 0 to 20 cm H₂O
- Rugged structural foam plastic housing
- Anti-Shock mounting for gauge and internal pneumatics
- Bag options available

<table>
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<th>Quantity</th>
<th>Item</th>
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LSP Manual Transport Ventilator (MTV-100)

- Intelligent flow control
- Accurate, iflow-restrictive delivery
- Pressure limit terminates both pressure and flow at 60cm H2O
- Secondary pressure safeguard prevents pressures from exceeding 80cm H2O
- Anti-asphyxiation protection
- Easy to clean and service
- Compact, lightweight, durable

<table>
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ParaPAC EMT Response Kit

Suggested for BLS-trained personnel. Case holds a D-size O2 cylinder (not included).

Contents:

- paraPAC Responder
- paraPAC Regulator
- Seal Easy9 mask
- Spanner wrench
- Carrying case
- Shoulder strap
- Case has hooks for hanging on litter rail
- Weight: 10 pounds

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Oxylator EM-100

A “positive pressure” resuscitation and inhalation system that uses a patented, patient responsive technology. It requires no power source other than a 50 PSI supply of compressed oxygen or air.

The Oxylator EM-100 is not a “demand valve” or a “vent”, but it is a pressure limited/flow triggered ventilation device designed to replace the BVM during CPR and short transport. It is very small, lightweight, rugged, and easy to use/clean.

The Oxylator EM-100 is ideal for confined space or toxic environment extrication/rescue, and offers a hands free ventilation feature that operates “in-sync” with chest compressions.

- Alerts to airway obstruction
- Positive pressure ventilation
- Delivers more consistent AHA required volumes
- Alerts to mask or “tube leak”
- “closed” ventilation
- No stacking occurs
- Reduces gastric ventilation
<table>
<thead>
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<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal Volume:</td>
<td>0.15 - 0.6 litres</td>
</tr>
<tr>
<td>Breaths Per Minute:</td>
<td>20 - 10</td>
</tr>
<tr>
<td>I:E Ratio:</td>
<td>1:2</td>
</tr>
<tr>
<td>Manual Flow Rate Range:</td>
<td>As per VT/BPM Control Setting</td>
</tr>
<tr>
<td>Input Pressure:</td>
<td>50 PSI (+/- 10 PSI)</td>
</tr>
<tr>
<td>Audible Pressure Relief Valve:</td>
<td>60 cm H$_2$O</td>
</tr>
<tr>
<td>Operating Temperature:</td>
<td>-18°C to +50°C (0°F to 122°F)</td>
</tr>
<tr>
<td>Storage Temperature:</td>
<td>-40°C to +60°C (-40°F to 140°F)</td>
</tr>
<tr>
<td>Relative Humidity for Storage and</td>
<td>15 to 95%</td>
</tr>
<tr>
<td>Operating Use:</td>
<td></td>
</tr>
<tr>
<td>Input Connection:</td>
<td>Fixed</td>
</tr>
<tr>
<td>Hose connection to regulator:</td>
<td>9/16 DISS</td>
</tr>
<tr>
<td>Patient Valve Dead Space:</td>
<td>8 ml.</td>
</tr>
<tr>
<td>Dimensions (inches):</td>
<td>5.5 x 2.5 x 2.9 (approx.)</td>
</tr>
<tr>
<td>Dimensions (millimeters):</td>
<td>140 x 63 x 73 (approx.)</td>
</tr>
<tr>
<td>Weight:</td>
<td>0.95lbs / 0.43kg</td>
</tr>
</tbody>
</table>
Emergency mechanical ventilation at moderate altitude.

Department of Emergency Medicine, University of Vienna, Austria.

To evaluate the influence on minute ventilation and blood gas analysis of moderate altitude (3000 m) compared to 171 m in healthy volunteers during mechanical ventilation.

At 3000 m, the delivered minute volume increased by 9.8% in the air mix mode and by 14.6% in the no air mix mode.
These changes are of sufficient magnitude and importance to require monitoring of minute volume to prevent barotrauma or volume-related trauma and to monitor oxygenation by pulse oximetry during emergency mechanical ventilation at moderate altitude.

Department of Emergency Medicine, University of Vienna, Austria.
Endotracheal intubation in the field does not improve outcome in trauma patients who present without an acutely lethal traumatic brain injury.

R Adams Cowley Shock Trauma Center and University of Maryland Medical School

191 consecutive patients admitted to the trauma center with a field Glasgow Coma Scale score $\leq 8$ and a head Abbreviated Injury Scale score $\geq 3$ who were either intubated in the field or intubated immediately at admission to the hospital.
Endotracheal intubation in the field does not improve outcome in trauma patients who present without an acutely lethal traumatic brain injury.


Prehospital intubation is associated with a significant increase in morbidity and mortality in trauma patients with traumatic brain injury who are admitted to the hospital without an acutely lethal injury. A randomized, prospective study is warranted to confirm these results.
Mechanical ventilation works

It decreases rescuer fatigue

It gives consistent breaths

It ain’t a free lunch
Mechanical ventilation does not in ANY way decrease the need for monitoring of the airway.
Mechanical ventilation can be a method to prevent over-ventilation during circulatory collapse.
And...

we need more data on their use during low flow states such as shock and cardiac arrest
As EMS professionalism continues to grow...

You, the heroes of the streets, must work harder each day to stay on top of skills.
Because, someone out there...

...is waiting to be cared for by you...
Thank you for your kind attention!

Links to follow!!!