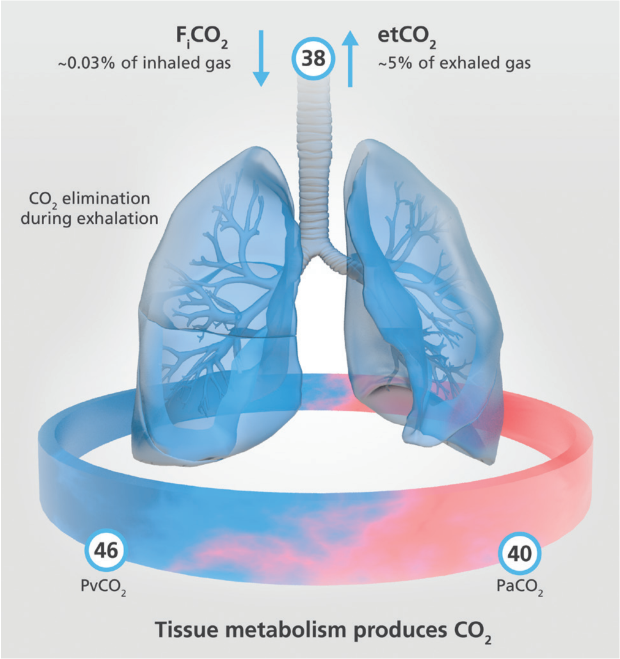
Understanding the Arterial to End-Tidal CO_2 Gradient, $P(a\text{-}et)CO_2$

Processes that influence $etCO_2$ values

Carbon dioxide (CO_2) is a byproduct of metabolism and returned to the lungs via perfusion, and then removed via alveolar ventilation.

Figure 1. Diagram of processes influencing CO_2



The gradient in healthy lungs

The gradient is the difference between the arterial carbon dioxide partial pressure ($PaCO_2$) and end-tidal carbon dioxide partial pressure ($etCO_2$) values. It is a result of the relationship between ventilation ($\dot{V}$), which is airflow to the alveoli, and perfusion ($\dot{Q}$), blood flow to the pulmonary capillaries. This is referred to as ventilation-perfusion matching or $\dot{V}$. Calculating the gradient requires obtaining a simultaneous arterial blood gas sample and an $etCO_2$ measurement. In normal, healthy lungs there is a good match of alveolar ventilation and perfusion to the pulmonary capillaries, resulting in an $etCO_2$ that closely correlates with or matches the $PaCO_2$. (Figure 2A).

When a normal match of alveolar ventilation and perfusion to the pulmonary capillaries exists, $etCO_2$ closely correlates with $PaCO_2$, running 2-5 mm Hg below the arterial value. (Figure 2A).

Figure 2A.* Normal match of ventilation ($\dot{V}$) and perfusion ($\dot{Q}$) in healthy lungs

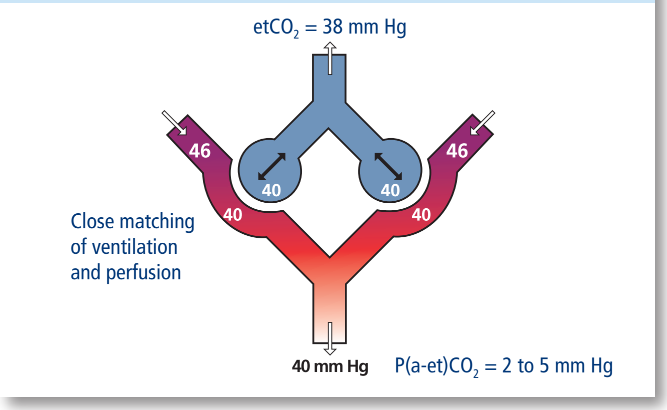


Figure 2B.* Acute decrease in alveolar perfusion (deadspace ventilation)

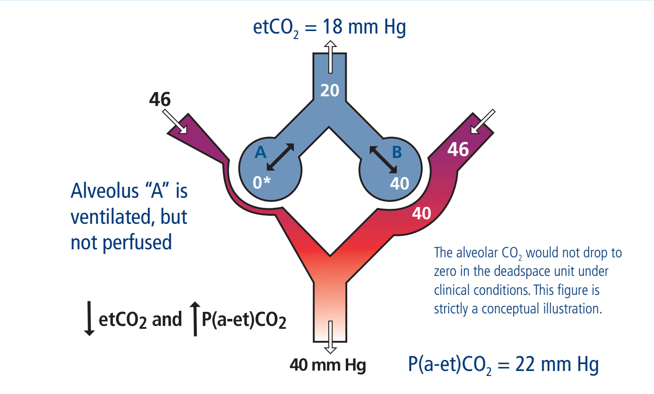
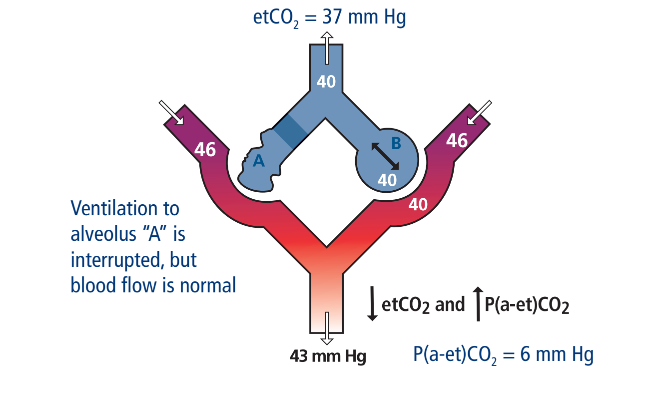


Figure 2C.* Acute decreased lung ventilation (intrapulmonary shunt)



These simple models are designed to illustrate what occurs at the alveolar level. The degree of deadspace/shunting typically varies across individual alveoli in the lung parenchyma, depending on the cause. All values are for illustrative purposes only.

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The $PaCO_2$ can be estimated by using actual $etCO_2$ measurements in patients without significant cardiopulmonary disorders. For example, if the $P(a\text{-}et)CO_2$ value is 5 mm Hg and the $etCO_2$ measurement is 43 mm Hg, the estimated $PaCO_2$ would be 48 mm Hg. The estimate is generally reliable if the $etCO_2$ trend is stable. A blood gas to recheck the gradient should be considered if the $etCO_2$ trend becomes unstable or the patient's respiratory status changes significantly.[1]

The gradient in patients with diminished cardiopulmonary function

In diseased or unhealthy lungs or in cases of impaired cardiac function, there is a ventilation-perfusion ($\dot{V}/\dot{Q}$) mismatch that causes the gradient to increase or widen. In this scenario, the $etCO_2$ does not closely match the $PaCO_2$. An increased gradient can occur to varying degrees with increased deadspace ventilation, shunt perfusion and other causes. An increased gradient occurs with increased deadspace ventilation and shunted perfusion.

Increased deadspace ventilation occurs when areas of the lung are ventilated but not perfused. (See Figure 2B) This can happen with conditions that cause a significant drop in pulmonary blood flow, such as pulmonary embolism or decreased cardiac output.

Shunted perfusion occurs when areas of the lung are perfused but not ventilated. (See Figure 2C) This can happen with mainstem intubation, bronchoconstriction, retained airway secretions, pulmonary edema or atelectasis.

Regardless of the reason, abnormal increases in the gradient greater than 2-5 mm Hg indicate CO_2 removal by ventilation is not keeping up with CO_2 production by metabolism.

Clinical benefits and utility for the gradient

Once the baseline carbon dioxide partial pressure gradient is determined, monitoring $etCO_2$ could reduce the need for arterial blood gas sampling, enabling safe, comfortable, continuous monitoring with alarm limits that provide an early warning for intervention before the patient is compromised. A sudden change in $etCO_2$ can prompt the clinician to measure $PaCO_2$ via an arterial blood gas sample.

Using the $P(a\text{-}et)CO_2$ gradient

Normal $\dot{V}/\dot{Q}$*

- If the gradient is normal, this is a good indication that $\dot{V}/\dot{Q}$ matching is good.[2]
- In individuals with normal $\dot{V}/\dot{Q}$ ratio, $etCO_2$ may work as an indicator for $PaCO_2$ once the gradient is established. This may reduce the need for costly and painful arterial blood gas (ABG) sampling and its associated risks.

Stable $\dot{V}/\dot{Q}$ mismatch (widened but stable gradient)*

- In patients with stable $\dot{V}/\dot{Q}$ mismatch, while gradient is increased, the trend (difference) between $etCO_2$ and $PaCO_2$ remains reliable in most patients.[3]

Changing $\dot{V}/\dot{Q}$ mismatch*

- An increasing gradient is an indication that $\dot{V}/\dot{Q}$ mismatching is worsening.
- A decreasing gradient is an indication that $\dot{V}/\dot{Q}$ matching is improving.
- An increasing or decreasing gradient may provide a useful measure for monitoring response to treatment aimed at reducing deadspace and shunt,[2] such as:
  - PEEP optimization
  - Bronchodilators and airway hygiene
  - Treatments to improve cardiac output and pulmonary perfusion

*If a change is noted in the patient's $etCO_2$ trend or respiratory status (increased symptoms), $P(a\text{-}et)CO_2$ should be reconfirmed.

References

1. Cheifetz IM, Myers TR. Respiratory therapies in the critical care setting. Should every mechanically ventilated patient be monitored with capnography from intubation to extubation? *Respir Care.* 2007;52(4):423-438.
2. Kodali B. Capnography website. www.capnography.com
3. McSwain SD, Hamel DS, Smith PB, et al. End-tidal and arterial carbon dioxide measurements correlate across all levels of physiologic dead space. *Respir Care.* 2010;55(3):288-293.

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