Understanding the arterial to end-tidal CO$_2$ (etCO$_2$) gradient, P(a-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.

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 (V), which is airflow to the alveoli, and perfusion (Q), blood flow to the pulmonary capillaries. This is referred to as ventilation-perfusion matching or V/Q. 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).\textsuperscript{1-2}

When a normal match of alveolar ventilation and perfusion to the pulmonary capillaries exists, etCO$_2$ closely correlates with PaCO$_2$, running 2 to 5 mm Hg below the arterial value (Figure 2A).\textsuperscript{1-3}

![Diagram of processes influencing CO$_2$](image)

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.
The PaCO₂ can be estimated using actual etCO₂ measurements in patients without significant cardiopulmonary disorders. For example, if the P(a-et)CO₂ value is 5 mm Hg and the etCO₂ measurement is 43 mm Hg, the estimated PaCO₂ would be 48 mm Hg. The estimate is generally reliable if the etCO₂ trend is stable. A blood gas to recheck the gradient should be considered if the etCO₂ trend becomes unstable or the patient’s respiratory status changes significantly.²

**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 (V/Q) mismatch that causes the gradient to increase or widen. In this scenario, the etCO₂ does not closely match the PaCO₂. 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.¹ ²

**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.¹ ²

**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.

Whatever the reason, abnormal increases in the gradient greater than 2 to 5 mm Hg indicate CO₂ removal by ventilation is not keeping up with CO₂ production by metabolism.¹ ³

**Clinical benefits and use for the gradient**

Once the baseline carbon dioxide partial pressure gradient is determined, monitoring etCO₂ could reduce the need for arterial blood gas sampling. This enables safe, comfortable, continuous monitoring with alarm limits that provide an early warning for intervention before the patient is compromised. A sudden change in etCO₂ can prompt the clinician to measure PaCO₂ via an arterial blood gas sample.

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**Using the P(a-et)CO₂ gradient²**

- **Normal V/Q**
  - Normal gradient is an indication that V/Q matching is good.³
  - In individuals with normal V/Q ratio, etCO₂ may work as an indicator for PaCO₂ once the gradient is established. This may reduce the need for costly and painful arterial blood gas (ABG) sampling and its associated risks.

- **Stable V/Q mismatch (widened but stable gradient)³**
  - With a stable V/Q mismatch, while gradient is increased, the trend (difference) between etCO₂ and PaCO₂ remains reliable in most patients.³

- **Changing V/Q mismatch³**
  - An increasing gradient may indicate that V/Q mismatching is worsening.
  - A decreasing gradient may indicate that V/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,³ such as:
    - PEEP optimization
    - Bronchodilators and airway hygiene
    - Treatments to improve cardiac output and pulmonary perfusion

³If a change is noted in the patient’s etCO₂ trend or respiratory status (increased symptoms), P(a-et)CO₂ should be reconfirmed.