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Abbreviating the Alveolar Gas Equation: 
An Argument for Simplicity*

Lawrence Martin MD

The long form of the alveolar gas equation involves several assumptions that make precise calculation of PAO₂ virtually impossible. Despite this, past attempts to abbreviate the equation have sought an unwarranted degree of precision. In addition, well-defined normal values are not known for alveolar-arterial PO₂ difference at all FIO₂ levels and for all ages. Based on these considerations, any abbreviation of the alveolar gas equation should be simple, yet accurate enough for clinical purposes. The one equation that meets these criteria is PAO₂ = PIO₂ - 1.2(PaCO₂). When FIO₂ is above 0.60, the factor 1.2 can be eliminated for increased accuracy. (Respir Care 1986;31:40-44.)

The alveolar gas equation (commonly called the “alveolar air equation”) provides a calculated alveolar oxygen pressure (PAO₂) with which to compare measured arterial oxygen pressure (PaO₂) in the assessment of gas exchange in the lungs. Without reference to PAO₂, an isolated PaO₂ measurement conveys little gas-exchange information. The difference between the PAO₂ and the PaO₂—the P(A-a)O₂—provides an indication of gas-exchange abnormality. A P(A-a)O₂ above the normal range indicates pulmonary gas-transfer dysfunction, a result of ventilation-perfusion imbalance, diffusion barrier, or a shunt of blood through or past the lungs.

It is time to reassess clinical use of the alveolar gas equation. Several authors have discussed abbreviated forms of the rather forbidding equation. Their intent was to provide a more ready method of calculating PAO₂. I wish to make three points concerning use of the equation and these past attempts to simplify it.

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Point 1: The original alveolar gas equation includes several variables whose precise measurements are seldom known.

The equation states

\[ PAO₂ = PIO₂ - PACO₂ \left[ FIO₂ + \left( 1 - \frac{FIO₂}{R} \right) \right] \]

where

- \( PIO₂ \) = pressure of inspired oxygen in the trachea, which equals \( (FIO₂) (PB - PH₂O) \);
- \( PACO₂ \) = pressure of alveolar carbon dioxide;
- \( FIO₂ \) = fractional concentration of inspired oxygen;
- \( R \) = respiratory exchange ratio (CO₂ excretion/O₂ uptake by the lungs);
- \( PB \) = barometric pressure;
- \( PH₂O \) = airway water-vapor pressure.

Another way of expressing the alveolar gas equation is Equation 2, which is a different arrangement of the same variables:

\[ PAO₂ = PIO₂ - \frac{PACO₂}{R} + \left[ (PACO₂)(FIO₂) \left( 1 - \frac{R}{FIO₂} \right) \right] \]

Both arrangements (Equations 1 and 2) are presented here because they help explain the abbreviated versions discussed hereafter.

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Dr Martin is Chief, Pulmonary Division, The Mt Sinai Medical Center, and Associate Professor of Medicine, Case Western Reserve University School of Medicine—Cleveland, Ohio.

Reprints: Lawrence Martin MD, Pulmonary Division, The Mt Sinai Medical Center, University Circle, Cleveland OH 44106.

*This paper as it was originally published (Respir Care 1985; 30:964-968) contained serious typographical errors. It is reprinted here with the errors corrected.
In everyday clinical use, the original alveolar air equation (either Equation 1 or 2) involves enough assumptions to make a precise calculation impossible (Table 1). For example, FIO₂ is not always measured; yet even with venturi oxygen-delivery systems, the assumed FIO₂ may vary widely from that actually received by the patient. Also, although it is easier to measure, PB is not usually measured precisely each time the alveolar gas equation is used; furthermore, the increase in PB when a patient is artificially ventilated is seldom taken into account.

In addition, a value of 47 torr is usually used for PH₂O; however, PH₂O changes with body temperature, a fact that is seldom considered when PAO₂ is calculated in patients who are hypo- or hyperthermic, even though PaO₂ may be temperature-corrected.

Another major assumption is that arterial PCO₂ (PaCO₂) is equal to PACO₂. PACO₂ is a component of the alveolar gas equation; PaCO₂ is not. Although the two may be nearly identical in normal lungs, in diseased lungs there can be a difference of several torr. Finally, a frequent assumption is that the respiratory exchange ratio (R) equals 0.8. This is true only when the metabolic R value = 0.8 and the patient is in a steady state. Because of either changes in metabolism (largely diet-dependent) or deviations from a steady state (when respiratory exchange ratio does not equal metabolic R, as in acute hyperventilation), the R used in the alveolar gas equation can vary widely from 0.8. In one study of 54 patients with stable chronic obstructive pulmonary disease, R ranged from 0.68 to 0.97. The potential variability of R thus invalidates the use of a single value for all patients, although this is the common practice.

Taken in the aggregate, the assumptions inherent in clinical use of the alveolar gas equation can easily cause calculated PAO₂ to vary several torr above or below the value that would be obtained were everything precisely measured.

Point 2: Commonly used abbreviated versions of the alveolar gas equation are either needlessly complex or, if simple, do not properly account for supplemental oxygen.

Given the imprecision of calculating PAO₂ with the original alveolar gas equation (Equations 1 and 2), it is amazing that some 'abbreviated' versions of the equation are still complicated enough to require a calculator, while others require measurement of expired gases! Assumptions inherent in clinical use of the alveolar gas equation in any form mock the precision sought by some authors.

Unfortunately, simplified versions lose some validity when a patient is receiving supplemental oxygen. Equation 3, a widely employed 'short form' of the original equation, leaves off the bracket factor of Equation 2:

$$PAO_2 = PFI_2 - \frac{PACO_2}{R}$$

Equation 3 has all the assumptions of the original equation (Equations 1 and 2), and because it incorporates R, it remains fairly close to the original equation for all variations of R. However, this is not a valid reason for its clinical use over other formulas—for if one takes the trouble to measure R, one is not in need of a shortcut for calculating PAO₂. Also, if R is assumed to be 0.8, then the lack of the bracket factor in Equation 3 presents a calculation error that increases as FIO₂ increases. In Equation 2, when R=0.8 and FIO₂=0.21, the bracket factor added to PACO₂/R is 2 torr; when FIO₂=1.00, the bracket factor is 10 torr.

More commonly, Equation 3 is presented as a shortened version of Equation 1. This is because when R equals 0.8, 1/R approximates the correcting factor (bracket value) of Equation 1. The correcting factor in Equation 1 accounts for the change in nitrogen's partial pressure resulting from unequal exchange of oxygen and carbon dioxide, ie, when R is less than 1.0; the correcting factor becomes 1.0 when R equals 1.0. Also, as nitrogen is washed out of the lungs with increasing FIO₂, the correcting factor decreases. With a patient on room air and R equal to 0.8, the correcting factor in Equation 1 is 1.2; with an FIO₂ of 1.00, the correcting factor is 1.0. Using an R value of 0.8 in the denominator of Equation 3 gives an unvarying correcting factor of 1.25, regardless of FIO₂; this is close to the
abbreviating the alveolar gas equation

correcting factor of 1.2 that is called for when a patient is breathing room air, but it leads to increasing error in PAO₂ calculation as FIO₂ increases (Table 2).

Another popular shortcut, this one for calculating P(A-a)O₂, is to subtract the sum of arterial PO₂ and PCO₂ from the sum of ideal alveolar PO₂ and PCO₂:

\[ P(A-a)O₂ = (PAO₂ + PCO₂) - (PaO₂ + PaCO₂) \]  

Equation 4 assumes that at any given altitude and R value, PAO₂ + PACO₂ will be a constant (eg, 140 torr at sea level with an R of 0.8). By subtracting the sum of measured PaO₂ and PaCO₂ from this constant (which is memorized for any given altitude), one can readily calculate P(A-a)O₂. But, as supplemental oxygen is inhaled, PAO₂ increases, invalidating the shortcut and requiring further calculation.

Point 3: Normal P(A-a)O₂ values are not known for all ages and at all FIO₂ levels.

Normal P(A-a)O₂ can range from 5 torr to more than 30 torr on room air, with the higher values found in elderly subjects and in young, otherwise healthy smokers. Also, the normal values for some groups differ according to body position; for example, asymptomatic smokers and the elderly have a lower PaO₂— and hence higher P(A-a)O₂— when supine than when sitting.

The lack of precise normal values for P(A-a)O₂ in subjects inhaling supplemental oxygen is even more apparent. There are only scant data for normal P(A-a)O₂ values when FIO₂ is greater than 0.21 and less than 1.00. One paper reported P(A-a)O₂ in subjects of different ages and breathing at various FIO₂s (0.21, 0.40, 0.60, and 1.00). For a given age range (20-80 years),

Table 2. Effect of FIO₂ Level on PAO₂ Calculated by the Original Alveolar Gas Equation and by Three Abbreviated Versions of the Equation

<table>
<thead>
<tr>
<th>FIO₂</th>
<th>By Original Equation</th>
<th>By Abbreviated Equations (with Variations from Original Equation PAO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Equations 1 &amp; 2</td>
<td>Equations 3</td>
</tr>
<tr>
<td>0.21</td>
<td>99</td>
<td>97 (-2)</td>
</tr>
<tr>
<td>0.30</td>
<td>163</td>
<td>160 (-3)</td>
</tr>
<tr>
<td>0.40</td>
<td>234</td>
<td>230 (-4)</td>
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<tr>
<td>0.50</td>
<td>305</td>
<td>300 (-5)</td>
</tr>
<tr>
<td>0.60</td>
<td>376</td>
<td>370 (-6)</td>
</tr>
<tr>
<td>0.70</td>
<td>447</td>
<td>440 (-7)</td>
</tr>
<tr>
<td>0.80</td>
<td>518</td>
<td>510 (-8)</td>
</tr>
<tr>
<td>0.90</td>
<td>589</td>
<td>580 (-9)</td>
</tr>
<tr>
<td>1.00</td>
<td>660</td>
<td>650 (-10)</td>
</tr>
</tbody>
</table>

*Assumptions: PaCO₂ = 40 torr (normal alveolar ventilation); R = 0.8; PB = 747 torr; PH₂O = 47 torr; PaCO₂ = PACO₂.

†Numbers in parentheses show amount and direction of variation.

Equation 1: \[ PAO₂ = P(O₂) - \text{PACO}_2 \left( \frac{\text{FIO}_2}{R} \cdot \left(1 - \frac{\text{FIO}_2}{R}\right) \right) \]

Equation 2: \[ PAO₂ = P(O₂) - \frac{\text{PACO}_2}{R} + \left( \text{PACO}_2 \cdot \frac{(\text{FIO}_2)(1 - R)}{R}\right) \]

Equation 3: \[ PAO₂ = P(O₂) - \frac{\text{PACO}_2}{R} \]

Equation 5: \[ PAO₂ = P(O₂) - 1.2 \left(\text{PaCO}_2\right) \]

Equation 6: \[ PAO₂ = P(O₂) - \text{PaCO}_2 \]

Conclusion: Equation 5 is the most accurate abbreviated version when FIO₂ is 0.21 to 0.60; Equation 6 is the most accurate when FIO₂ is above 0.60.
30, 40-50, and over 60 years), the P(A-a)O₂ increased as FIO₂ increased, up to FIO₂ 0.60. Between FIO₂ 0.60 and 1.00, there was no significant increase in P(A-a)O₂. Also, for a given age range and FIO₂, there was a wide range of P(A-a)O₂ values.

More data are available for subjects breathing 100% oxygen. One representative study found a mean P(A-a)O₂ of 31 torr for subjects less than 40 years old and 56 torr for subjects over 60; in the latter group one normal value was 120 torr. These data suggest that, for any given age, there is a progressively widening normal range for P(A-a)O₂ as FIO₂ is increased, at least up to about FIO₂ 0.60.

Given the wide variation of normal P(A-a)O₂ and the inherent imprecision of PAO₂ calculation, why bother with a complicated equation? At best, the precision that some seek is elusive; at worst, the search yields 'precise' values that are invalid. What those caring for sick patients need is some indication of gas-exchange abnormality,* not a precise number, especially if the precision is based on several false assumptions.

If we are to teach the concept of an alveolar gas equation and have it widely accepted, the simplest equation that is faithful to the original should be used. Unfortunately, there is no ideal 'simple' equation, but it is my conclusion that simplicity is more to be preferred than faithfulness, inasmuch as the many assumptions inherent in the original equation rule out precision in most clinical situations.

When a patient is breathing room air, the following equation best fits these criteria:

\[ \text{PAO}_2 = \text{P}_{\text{O}_2} - 1.2(\text{PaCO}_2) \]  
(5)

which is Equation 1 when R = 0.8.

When a patient is breathing supplemental oxygen at an FIO₂ above 0.60, a simpler (and more accurate) equation is

\[ \text{PAO}_2 = \text{P}_{\text{O}_2} - \text{PaCO}_2 \]  
(6)

Equations 5 and 6 can be further simplified to fit the altitude of the clinical setting. For example, in Cleveland where the mean PB is about 747 torr, \[ \text{PAO}_2 = \text{FIO}_2(700) - 1.2(\text{PaCO}_2) \]. In Denver, \[ \text{PAO}_2 = \text{FIO}_2(580) - 1.2(\text{PaCO}_2) \].

Table 2 compares results when the original alveolar gas equation (Equations 1 and 2) is used and when Equations 3, 5, and 6 are used. At all FIO₂ levels above 0.60, both Equation 3 and Equation 5 are less accurate than Equation 6. As FIO₂ is increased, Equation 6 more closely approximates the original equation, and at an FIO₂ of 1.00, their results are equal.

All points considered, both Equations 5 and 6 should be taught. This could best be accomplished by introducing Equation 5 as the basic abbreviated version and emphasizing that at high FIO₂s the factor 1.2 should be dropped.

The abbreviated alveolar gas equations proposed here result from attempts to simplify the concept of alveolar PO₂ and allow its wider clinical use. In the calculation of PAO₂ in the everyday world of clinical medicine, an abbreviated version of the alveolar gas equation is all that is really needed.

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REFERENCES