INDIRECT DETERMINATION OF THE IDEAL ALVEOLAR OXYGEN
TENSION DURING AND AFTER NITROUS OXIDE ANAESTHESIA

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SUMMARY

The conventional form of the alveolar air equation assumes that inert gases are in
equilibrium. It is therefore inapplicable during nitrous oxide uptake and elimination. An
alternative form of the equation avoids this assumption and may be used for calculation
of the ideal alveolar tension of oxygen or inhalational anaesthetic agents.

A recent publication by Nunn and Pouliot (1962)
has described a method for the measurement of
gaseous exchange and respiratory exchange ratio
during nitrous oxide anaesthesia. Conventional
methods cannot be used since nitrous oxide is
seldom in equilibrium and furthermore interferes
with the usual chemical methods of gas analysis.
The same paper continued with a discussion of
the indirect determination of the ideal alveolar Po2
by solution of the following conventional form of
the alveolar air equation :

$$P_{A_2} = P_{A_2} - \frac{P_{ACO_2}}{R} \left(1 - F_{1O_2} (1 - R)\right)$$  (i)

It has been pointed out by Dr. W. E. Young of
Toronto that this equation cannot be used during
uptake or elimination of nitrous oxide, since it is
based on the assumption that the inert gas (nitro-
gen or nitrous oxide) is in equilibrium. That is to
say that the number of molecules inhaled is the
same as the number exhaled. Now the uptake of
nitrous oxide is usually in excess of 100 ml/min
for the first 2 hours of anaesthesia (Severinghaus,
1954) and the rate of elimination appears to be of
the same order (Frumin, Salanitre and Rackow,
1961). It would therefore appear incorrect to use
the form of the alveolar equation shown above
during the first few hours of nitrous oxide anaes-
thesia or during the early phase of elimination.

A more general form of the alveolar air equation
may be derived without assuming equilibrium of
the inert gas (Filley, MacIntosh and Wright, 1954).
This is based on two assumptions :

1. The expired tidal volume consists of a
mixture of two components, ideal alveolar
gas and deadspace gas. The latter com-
ponent includes alveolar deadspace, anatomical
deadspace and apparatus deadspace (fig. 1).

2. This effective deadspace is the same for
carbon dioxide, oxygen and any other
unspecified gas.

From the first assumption it follows in the case of
oxygen that

$$V_E.P_{E_2} = V_D.P_{1O_2} + (V_E - V_D)P_{A_2}$$  (ii)

(This is not strictly correct since gas from the
alveolar deadspace will contain slightly more
carbon dioxide and less oxygen than inspired gas
due to reinhalation of some end-tidal gas from the
anatomical and apparatus deadspace. Nevertheless
the effect of this is probably negligible.)

Converting to tension and then clearing and
solving for alveolar oxygen tension:

$$P_{A_2} = \frac{V_E.P_{E_2} - V_D.P_{1O_2}}{V_E - V_D}$$  (iii)

(The righthand side may be adapted to use minute
volumes rather than tidal volumes.)

From the second assumption, the value for the
deadspace is indicated by the following form of
Bohr's equation:

$$PA_2 = PA_2 - P_{ACO_2} + (P_{ACO_2} - P_{ACO_2}$$  (iv)

Substituting for VD in equation (iii):

$$P_{A_2} = P_{A_2} - P_{ACO_2} \left(\frac{P_{1O_2} - P_{E_2}}{P_{ACO_2}}\right)$$  (v)

Derivation of the alveolar Po2 from equation (iii)
or (v) requires no more data than are required for
DETERMINATION OF THE IDEAL ALVEOLAR OXYGEN TENSION

APPROACH TO THE IDEAL ALVEOLAR OXYGEN TENSION

DEAD SPACE

ALVEOLAR

DEAD SPACE

ANATOMICAL

DEAD SPACE

LIE

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\(\text{ANATOMICAL DEAD SPACE} / \text{IDEAL ALVEOLAR GAS} / \text{COLLAPSED ALVEOLUS WITH SHUNTED BLOOD} / \text{MIXED ARTERIAL BLOOD}\)

FIG. 1

Schematic representation of the components of expired air. The heavy black line encloses the volume determined by solution of Bohr’s equation.

the solution of equation (i), provided that R was determined and not assumed. Equation (v) is in fact a recognized alternative form of the alveolar air equation (Comroe et al., 1962). There is, however, an important difference. The customary equation (i) assumes that the inert gas present is in equilibrium, while equations (iii) and (v) make no such assumption and may be used during uptake or elimination of nitrous oxide. Furthermore, in the following general forms they may be used for indirect determination of the ideal alveolar tension of any inhalational anaesthetic gas or vapour (\(x\)):

\[
P_{A_X} = \frac{V_E \cdot P_{E_X} - V_D \cdot P_{I_X}}{V_E - V_D} \quad \ldots \ldots \quad (vi)
\]

\[
P_{A_X} = P_{I_X} - P_{ACO_2} \left(\frac{P_{I_X} - P_{E_X}}{P_{ECO_2}}\right) \quad \ldots \ldots \quad (vii)
\]

APPLICATIONS OF THE EQUATIONS

Equation (i) will indicate the ideal alveolar \(P_O_2\) in the absence of appreciable exchange of nitrous oxide or other inert gas. Equations (iii) and (v), however, indicate the true alveolar \(P_O_2\) influenced as it must be by exchange of nitrous oxide. We may, therefore, calculate the magnitude of the change in alveolar \(P_O_2\) which results from exchange of nitrous oxide. This effect is well known as “diffusion anoxia” and has been described by Fink (1955), Fink, Carpenter and Holaday (1954) and Rackow, Salanitre and Frumin (1961). For example, a patient was studied after 45 minutes of nitrous oxide anaesthesia. The oxygen consumption was 210 ml/min and the carbon dioxide output 130 ml/min. The inspired tidal volume was 155 ml of which 100 ml comprised physiological and apparatus deadspace. (All gas volumes are expressed under the same conditions of temperature and pressure.) The respiratory frequency was 32 b.p.m. and the inhaled oxygen concentration 27 per cent at a dry barometric pressure of 713 mm Hg. Were there no nitrous oxide uptake, the alveolar \(P_{CO_2}\) would be 53 mm Hg and alveolar \(P_O_2\) 117 mm Hg. However, at that time the nitrous oxide uptake was found to be 180 ml/min. In consequence the alveolar \(P_{CO_2}\) was slightly increased (55 mm Hg) but the alveolar \(P_O_2\) was substantially increased to 134 mm Hg (i.e. from 16 to 19 per cent of 1 atmosphere). These values have been found typical during anaesthesia with spontaneous respiration. Clearly, allowance for this factor must be made when attempting to predict oxygen levels during uptake and elimination of nitrous oxide. However, in practice the effect on arterial blood \(P_O_2\) is minimized by the increase in alveolar-arterial \(P_O_2\) difference which results from an increase in alveolar \(P_{CO_2}\). In the example quoted above, assuming an 8 per cent shunt and normal arterial-venous difference, the arterial \(P_O_2\) would only change by about 5 mm Hg. The effect on arterial \(P_O_2\), however, depends on the position of the arterial point on the oxygen dissociation curve. In the example quoted on page 761 by Nunn and Pouliot (1962), the calculated alveolar \(P_O_2\) is actually 101 mm Hg when allowance is made for nitrous oxide uptake. The alveolar-arterial \(P_O_2\) difference is therefore 44 mm Hg instead of 5.6 mm Hg and the calculated shunt much larger than it originally appeared. Diffusion hypoxia could not have been a
major factor in the postoperative hypoxia described by Nunn and Payne (1962). Many of their patients did not receive nitrous oxide.

Determination of the tension of an inhalational anaesthetic agent in blood is tedious if not difficult. On occasions it may be advantageous to calculate the alveolar tension of the agent from equation (vi) or (vii). For example, if a patient is inhaling 1 per cent halothane and exhaling 0.75 per cent, with an expired tidal volume of 330 ml of which 140 ml is deadspace (apparatus plus physiological) we may compute that the alveolar tension of halothane is 4 mm Hg. It is believed that the tension of halothane in the end-pulmonary capillary blood equals the ideal alveolar tension. The arterial tension, however, will differ slightly from the end-pulmonary capillary tension as a result of physiological or pathological shunting of pulmonary blood flow away from ventilated alveoli.

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APPENDIX

Symbols are in accord with the recommendations of the Committee for the Standardization of Definitions and Symbols in Respiratory Physiology (Pappenheimer et al., 1950).

Large capitals:
P Tension or pressure
F Fractional concentration
V Gas volume
R Respiratory exchange ratio

Small capitals:
i Inspired gas
e Expired gas
f Mixed expired gas
A Alveolar gas
d Deadspace

REFERENCES


SOMMAIRE

La forme conventionnelle de l'équation de l'air alvéolaire suppose que les gaz inertes soient en équilibre. Voilà pourquoi elle n'est pas applicable pour l'entrée et l'élimination du protoxyde d'azote. Une forme alternative de l'équation évite cette hypothèse et peut servir à calculer la tension alvéolaire idéale de l'oxygène ou des anesthésiques généraux volatils.

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