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Technical note

Respiratory gas exchange using a triaxial alveolar gas diagram

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Abstract
A triaxial alveolar gas diagram to depict fractional concentration of oxygen, carbon dioxide and nitrogen is described, in which the R = 1 line is always implicit. Although it is not claimed that this representation leads to new insights into respiratory physiology, a method of plotting on a triaxial coordinate system has been found to be well suited to many applications when a direct display of fractional nitrogen concentration is required.

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Graphic analysis of respiratory gas exchange,[1–6] especially the oxygen-carbon dioxide diagram of Fenn, Rahn and Otis,[1 3 4] is an important tool for the interpretation of respiratory gas exchange leading to new insights in respiratory physiology. Although mathematical and computer treatment has reduced the need for graphical representations with respect to quantitative approaches in respiratory gas analysis, these are still useful for instructive purposes and may help to illustrate the trends and relations of the data plotted.

A method of graphical representation on triaxial coordinate paper has been designed to be well suited for the simple display of any ternary gas mixture, and has been applied to alveolar gas to show fractional concentrations of oxygen (O_2), carbon dioxide (CO_2), and nitrogen (N_2). Although it is not claimed that this method of representation contains any new ideas in gas exchange physiology in the way the classical oxygen-carbon dioxide diagram certainly did, we believe that this is a simpler tool for a three gas mixture when a direct reading of nitrogen gas concentration is required. On the oxygen-carbon dioxide diagram it is possible to read the alveolar partial pressure for nitrogen (P_{N_2}) by measuring the horizontal distance between the alveolar point and the R = 1 line and adding it to the inspired P_{N_2}; however, this may be a little cumbersome for the non-respiratory physiologist who is not familiar with this representation.

The use of partial pressures instead of fractional concentrations has provided many advantages in quantitative analysis of gas exchange, which were already demonstrated by Fenn *et al*,[1] and allow the study of gas exchange between the gas and blood phase. To simplify the method and for didactic purposes we have scaled the axes of the triaxial diagram as fractional concentrations. In place of fractional concentrations we may substitute partial pressures, since the two quantities can be readily interconverted.

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The triaxial gas diagram

Three main gases (nitrogen, oxygen, and carbon dioxide) are present in inspired air as well as in alveolar gas or blood samples. For convenience, trace gases (argon, neon, helium, krypton, hydrogen, and xenon) are usually considered together with, and designated as, nitrogen[3]; nevertheless, for greater rigor the term "nitrogen + inert gases" will be used. If fractional concentrations are used as units of measurement, two points should be taken into account: firstly, the proportion of each gas will be between 0% and 100% of the total volume of the dry gas mixture, and secondly, the sum of the percentages of the three gases will always be 100%. These factors will be shown to be very useful in the analysis. Obviously, the most appropriate diagram to display such a ternary mixture must be a three-sided polygon or, more precisely, an equilateral triangle in which the scale of the three axes is maintained to avoid visual deformations. In this triangle (fig 1) each vertex represents a pure component, each side a binary mixture, and the inside points all the possible ternary compositions. The sum of the length of the lines traced from any internal point, F, each parallel to one of the three sides, is always the same and is equal to the length of one side of the triangle. Thus, in fig 1 the sum of these lengths is equal to one (FC + FO + FN = 1). Taking this side as unity and expressing the length of the three components as a fraction of the total, the composition of any ternary system can always be represented by one, and only one, point on the diagram. If the value of two components is known (F_{CO_2}, F_{O_2}) then the third component (F_{N_2}) can be read directly on the graph (see reading method in fig 1).

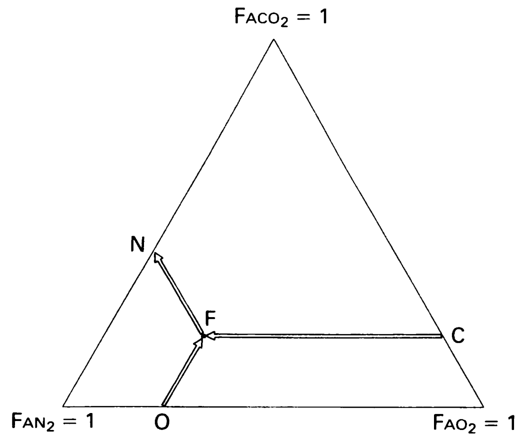

Figure 1 The full triaxial gas diagram with an example of the reading method. If $FACO_2$ and FAO_2 are known, the value of FAN_2 may be read directly. F_A—alveolar fractional concentration.

In this large triangle only a small area has a physiological meaning. For example, FO_2 values higher than 0·21 units or FN_2 values lower than 0·80 units are hard to find if they are not experimentally produced. It is proposed, therefore, to use a triangle with sides of only 21 divisions (fig 2). If partial pressures are used, the same divisions may correspond to a fraction of a side of barometric pressure minus 47 mm Hg (water vapour pressure at 37°C).

A straight line parallel to one of the sides of the triangle represents a constant percentage of the component of the opposite vertex. Thus any line parallel to the FCO_2 axis has the same FN_2 value; these lines correspond to a respiratory gas exchange equal to one. Thus, the R = 1 line is always implicit in the diagram and it does not need to be drawn additionally as in the oxygen-carbon dioxide diagram.

We have found it instructive, as an example, to plot the data from the breath holding pathway described by Otis *et al*[7] (fig 2). During the decline in apnoea FO_2 does not correspond to an equivalent increase in FCO_2 because part of the carbon dioxide produced is stored in tissues or in the blood. This fact produces an increment in alveolar FN_2 and a progressive decrease in the gas exchange ratio illustrated by the increasing distance between the breath holding pathway and the FCO_2 axis (R = 1 line), which leads to a progressive decline in the gas exchange slope referred to the inspired point. The mean alveolar exchange ratio for a breath holding interval can be computed, applying the traditional equation described by Otis *et al*,[7] in which it is calculated as a function of FN_2, FCO_2, and FO_2.

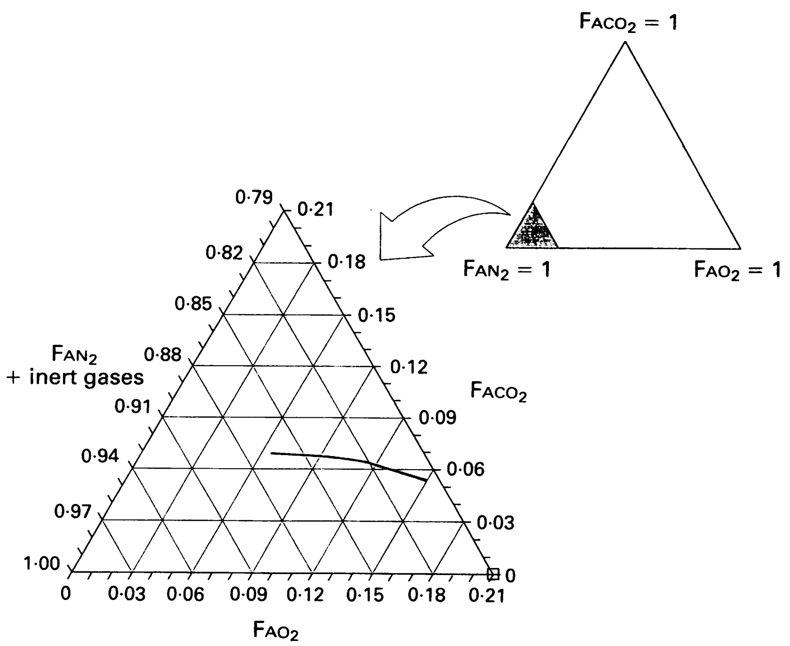

Figure 2 Top: the full triaxial gas diagram (shaded triangle represents the area with a physiological meaning). Bottom: the physiological triaxial gas diagram amplified. Units of the axes can be interchanged with partial pressures. The curve represents a period of breath holding based on the data of Otis et al.[7] Point (□) in bottom right hand corner corresponds to the composition of the inspired air.

Conclusions

The triaxial gas diagram can be used for the graphical representation of different respiratory conditions. Thus, the graph can be used to visualise lung gas distribution inhomogeneity, lung volume variations, or changes in the composition of alveolar and expired gases under various physiological and experimental conditions (age, smoking, diving, extreme altitude, rebreathing, lung diseases, or anaesthesia). This is of special interest in the fields of aviation and environmental medicine.

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