

## Technical Note

# A Respiratory Nomogram

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A nomogram was constructed for quick and accurate derivation of the  $\dot{V}_A/\dot{V}_E$  ratio,  $V_D/V_T$  ratio,  $\dot{V}_A$ ,  $\dot{V}_{CO_2}$ , and  $\dot{V}_{O_2}$  from measured  $P_{aCO_2}$ ,  $F\dot{E}CO_2$ , and  $\dot{V}_E$  values. The use of the nomogram is described and exemplified. (Key words: Nomogram;  $\dot{V}_A/\dot{V}_E$  ratio;  $\dot{V}_A$ ,  $\dot{V}_D/V_T$  ratio;  $\dot{V}_{CO_2}$ ;  $\dot{V}_{O_2}$ )

FREQUENT AND RAPID ESTIMATIONS of respiratory values such as alveolar ventilation ( $\dot{V}_A$ ), alveolar ventilation-to-exhaled volume ratio ( $\dot{V}_A/\dot{V}_E$ ), deadspace-to-tidal volume ratio ( $V_D/V_T$ ), carbon dioxide exhaled ( $\dot{V}_{CO_2}$ ) and oxygen uptake ( $\dot{V}_{O_2}$ ) may be essential during respiratory care of critically ill patients. In many instances, however, repeated determinations are not done because of the cumbersome and time-consuming computations necessary. Recognition of this problem stimulated us to develop a simple respiratory nomogram for rapid calculation of respiratory values at the bedside.

$\dot{V}_A$ ,  $\dot{V}_{O_2}$  and  $\dot{V}_{CO_2}$  values obtained are converted from ATPS to BTPS and STPD, respectively.<sup>1</sup> Since the correction factors depend on the conditions present during measurement they are not included in the nomogram.

The nomogram (fig. 1) consists of linear scales arranged along the ordinate and the abscissa and curved scales describing a section of a circle with its center at the intersection of the ordinate and the abscissa. From the nomogram it is possible to read off directly, in a stepwise manner: alveolar ventilation-

to-minute ventilation ratio ( $\dot{V}_A/\dot{V}_E$ );  $V_D/V_T$  ratio; alveolar ventilation ( $\dot{V}_A$ ); and  $CO_2$  elimination ( $\dot{V}_{CO_2}$ ) and oxygen consumption ( $\dot{V}_{O_2}$ ), when mixed expired  $CO_2$  concentration ( $F\dot{E}CO_2$ ),<sup>2</sup>  $P_{aCO_2}$ , and  $\dot{V}_E$  have been measured.

The  $\dot{V}_A/\dot{V}_E$  ratio can be determined by measuring  $F\dot{E}CO_2$  and  $P_{aCO_2}$  simultaneously.<sup>3</sup> Since the ordinate of the nomogram represents  $F\dot{E}CO_2$  and the abscissa,  $P_{aCO_2}$  converted into fractional concentrations at a given PB, the ratio of  $F\dot{E}CO_2$  to  $P_{aCO_2}$  is given in a point. There is an infinite number of possible combinations for the same ratio, represented by points along a straight line radiating from the intersection of the ordinate with the abscissa. Any given slope represents all points for a given ratio. The ratio indicated by the slope can be directly read off the curved scale as  $\dot{V}_A/\dot{V}_E$  and as  $V_D/V_T$ . The determination of the ratio is based on the following equations.<sup>1</sup>

$$\dot{V}_{ABTPS} = \frac{\dot{V}_{CO_2} STPD \cdot K}{F_{aCO_2}} \quad (1)$$

$K = 0.863$ , where  $K$  is the factor needed to relate BTPS to STPD. The equation can also be used with  $P_{aCO_2}$  instead of per cent alveolar  $CO_2$ ; however, this necessitates use of a new correction factor, "u."

$$\dot{V}_A = \frac{\dot{V}_{CO_2} \cdot u}{P_{aCO_2}} \quad (2)$$

$u = 0.83$ , and

$$\dot{V}_{CO_2} = F\dot{E}CO_2 \cdot \dot{V}_E \quad (3)$$

By substituting from 3 into 2:

$$\dot{V}_A = \frac{F\dot{E}CO_2 \cdot \dot{V}_E \cdot u}{P_{aCO_2}} \quad (4)$$

$$\frac{\dot{V}_A}{\dot{V}_E} = \frac{F\dot{E}CO_2 \cdot u}{P_{aCO_2}} \quad (5)$$

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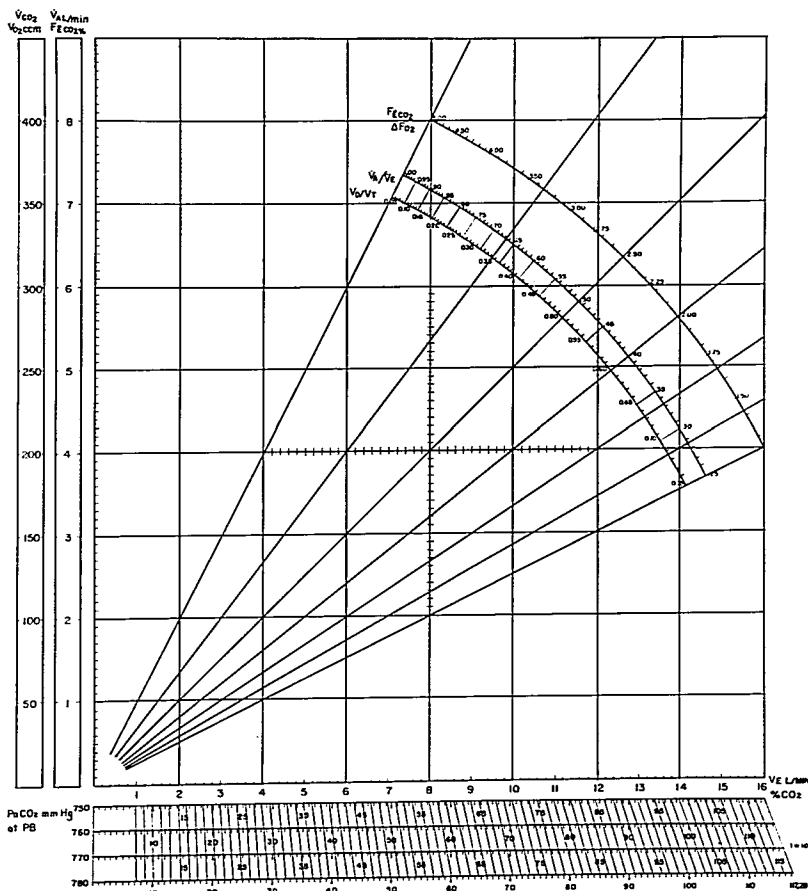


FIG. 1. Scales along the ordinate are for  $\dot{V}E_{CO_2}$ ,  $\dot{V}_A$ ,  $\dot{V}CO_2$ , and  $\dot{V}O_2$ . On the abscissa are scales for  $\dot{V}_E$ ,  $P_{aCO_2}$ , and per cent  $CO_2$ . Values for  $P_{aCO_2}$  measured at the PB from 750 mm Hg can be entered directly into the nomogram. The  $P_{aCO_2}$  in mm Hg is entered at the given PB and a sloped line is followed upward to the per cent  $CO_2$  scale. The sloped lines are drawn at 0.2 per cent intervals. For an intermediate value, a parallel to the nearest sloped line is followed.

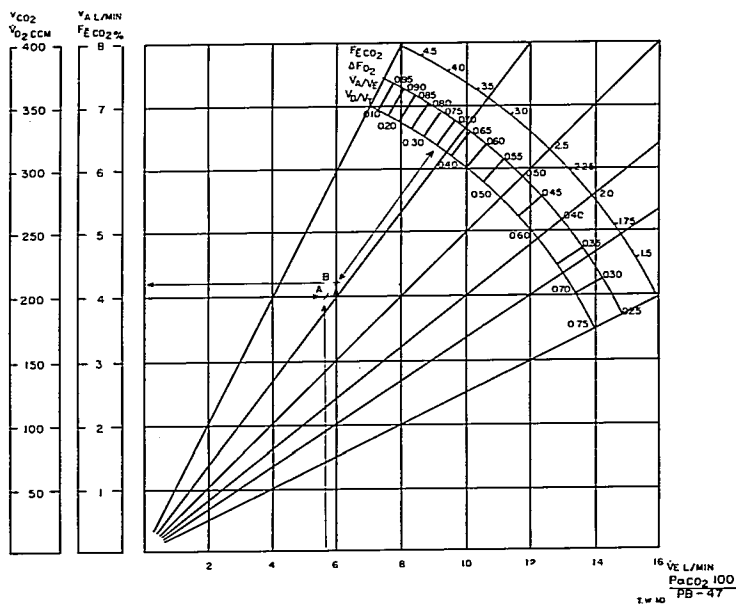


FIG. 2.  $\dot{V}_A/\dot{V}_E$ ,  $V_D/V_T$  derivation, and  $\dot{V}_A$ . Enter  $F\dot{E}CO_2$  and  $P_{aCO_2}$  as described for  $V_A/\dot{V}_E$  ratio determinations. Once the ratio is obtained, enter the scale on the abscissa marked " $\dot{V}_E$ " in l/min. A vertical line through a point indicating  $\dot{V}_E$  l/min intersects with the line nomogram gives  $V_A$  in l/min. A horizontal line going from this point to the scale at the left side of the nomogram gives  $\dot{V}_A$  in l/min. Measured data:  $F\dot{E}CO_2$  4 per cent;  $P_{aCO_2}$  40 mm Hg;  $P_B$  760 mm Hg;  $\dot{V}_E$  6 l/min. Derived data:  $V_A/\dot{V}_E = 0.7$ , and  $V_D/V_T = 0.3$ , point A;  $V_A = 4.26$ /min, point B.

which means that the ratio  $\dot{V}_A/\dot{V}_E$  equals the ratio of:

$$\frac{F\dot{E}CO_2 \cdot a}{P_{aCO_2}}$$

The relation of equation 5 to  $V_D/V_T$  is then given as follows:

$$V_T = V_D + V_A \quad (6)$$

or by multiplying both sides by respiratory frequency:

$$V \cdot f = V_D \cdot f + V_A \cdot f, \text{ or } \dot{V}_E = \dot{V}_D + \dot{V}_A \quad (7)$$

and by rearranging

$$\dot{V}_D = \dot{V}_E - \dot{V}_A \quad (8)$$

and dividing both sides by  $\dot{V}_E$

$$\frac{\dot{V}_D}{\dot{V}_E} = 1 - \frac{\dot{V}_A}{\dot{V}_E} \quad (9)$$

we can also write

$$\frac{V_D \cdot f}{V_T \cdot f} = 1 - \frac{\dot{V}_A}{\dot{V}_E} \text{ or } \frac{V_D}{V_T} = 1 - \frac{\dot{V}_A}{\dot{V}_E} \quad (10)$$

$F\dot{E}CO_2$  is entered on the appropriate ordinate and  $P_{aCO_2}$  is entered on the abscissa. To avoid the necessity for conversion of  $P_{aCO_2}$  in mm Hg to per cent of fractional concentration at a given barometric pressure ( $P_B$ ), an additional conversion nomogram has been added to this scale.

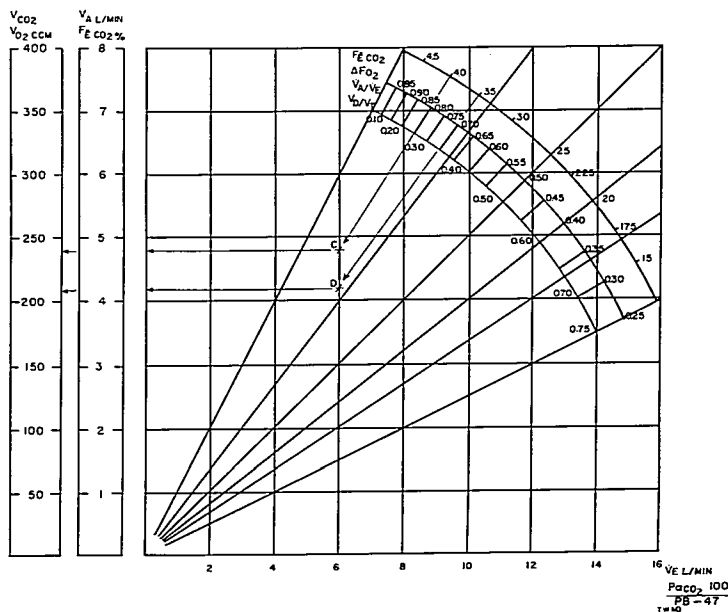


FIG. 3.  $\dot{V}_{O_2}$  and  $\dot{V}_{CO_2}$  derivations.  $\dot{V}_E$  is entered on the abscissa and mean expired  $CO_2$  or inspired-to-expired  $O_2$  difference on the curved scales marked " $\overline{FECO_2}$ ," and " $\Delta FO_2$ ." From the point of intersection of the two values (points C and D) a horizontal line drawn to the left scale marked " $\dot{V}_{O_2}$ ," and  $\dot{V}_{CO_2}$ , gives the results in ml of  $CO_2$  and  $O_2$  per minute. *Measured data:*  $\overline{FECO_2}$ , 4 per cent;  $\Delta FO_2$ , 3.5 per cent;  $\dot{V}_E$  6 l/min. *Derived data:*  $\dot{V}_{CO_2}$  = 240.0 ml/min, point C, and  $\dot{V}_{O_2}$  = 210.0 ml/min, point D.

$Paco_2$  is entered at the number corresponding to the appropriate mm Hg value at the known PB. The slightly sloped lines going upward are isoconcentration lines connecting points with equal percentages of  $CO_2$  at different PB values. These lines are drawn at 0.2 per cent  $CO_2$  intervals. Intermediate values can be obtained by drawing a line parallel to the closest isoconcentration line in an upward direction. The  $CO_2$  concentration in percentage is then read off the scale marked " $CO_2$  %." Once per cent  $\overline{FECO_2}$  and  $Paco_2$  have been entered, the ratio of both values is given in point A (fig. 2). A line drawn from the lower corner of the nomogram through

point A crosses the curved scale marked " $\dot{V}_A/\dot{V}_E$ " or " $\dot{V}_D/\dot{V}_T$ ," from which the ratio wanted can be read off.

Alveolar ventilation is determined by measuring  $\overline{FECO_2}$ ,  $Paco_2$ , and  $\dot{V}_E$  simultaneously, and entering equation 1. The use of the nomogram for  $\dot{V}_A$  determination is shown in figure 2.

Oxygen consumption ( $\dot{V}_{O_2}$ ) and  $CO_2$  production ( $\dot{V}_{CO_2}$ ) are obtained in the same way (fig. 3), using the following equations:

$$\dot{V}_{O_2} = \dot{V}_E \cdot \Delta FO_2 \quad (11)$$

$$\dot{V}_{CO_2} = \dot{V}_E \cdot \overline{FECO_2} \quad (12)$$

### Comment

The accuracy of a nomogram is primarily dependent upon the ratio of the scale used. Smaller ratios give more accurate readings, since fractions of units can be entered easily. The size of the nomogram described is 7.5 × 6.5 inches with accuracy as follows:

$\dot{V}_A/\dot{V}_E$  ratio has an estimated error of  $\pm 0.01$ , since the smallest values for  $F_{iCO_2}$  and  $F_{E CO_2}$  which can be visibly interpolated are  $\pm 0.050$  per cent and  $\pm 0.025$  per cent, respectively. The estimated alveolar ventilation is in the range of  $\pm 0.0005$  l/min if the  $\dot{V}_A/\dot{V}_E$  ratio is  $\pm 0.01$  is used and  $\dot{V}_E$  is  $\pm 0.05$  l/min. The estimated error for  $\dot{V}_{CO_2}$

and  $\dot{V}_{O_2}$  is in the range of  $\pm 1$  ml/l/min  $\dot{V}_E$  when the smallest units of  $F_{E CO_2}$  and  $\Delta F_{O_2}$  which can be interpolated are  $\pm 0.025$  per cent and  $\pm 0.05$  for  $\dot{V}_E$  l/min.

### References

1. Dejours P: Respiration. First edition. Edited by C Kayser. Cambridge, Oxford University Press, 1966, p 104.
2. Jeretin S, Martinez L, Wandycz T: A carbon dioxide-mixing chamber—a simple device for continuous measurement of mean expired carbon dioxide. *ANESTHESIOLOGY* 34:479-482, 1971
3. Comroe J: The Lung. Second edition. Edited by J Comroe *et al.* Chicago, Yearbook Medical Publishers Inc., 1968, p 342

## Blood Transfusion

**BLOOD TRANSFUSION AND PULMONARY EDEMA** This is a report of two cases of normovolemic pulmonary edema following whole-blood transfusion, each attributable to noncytotoxic leucoagglutinating antibodies present in donor serum which reacted with the recipient's leukocytes. In one patient, a 21-year-old woman, the response occurred five days after an appendectomy during a single blood transfusion and was manifest in severe dyspnea, anxiety, and cyanosis. Chest x-ray showed extensive, fluffy, bilateral infiltrates compatible with pulmonary edema. At the height of the reaction  $P_{aO_2}$  was 44 torr,  $P_{aCO_2}$  27 torr, pH 7.5. The second patient received two units of whole blood because her hemoglobin was 9.7 g/100 ml secondary to metrorrhagia. Pulmonary edema occurred in the course of the second transfusion. No antierythrocytic antibodies were detected, but both donor bloods contained antibodies to the recipient's leukocytes. Both donors were multiparous women, and the authors raise possibility that multiparous women should not be used as blood donors. The reaction in the recipients was characterized by lack of eosinophilia and was strikingly similar to the acute pleuropneumonic reaction associated with nitrofurantoin administration. Since prospective antileukocyte screening is not generally available, the authors suggest that greater support should be given to administration of blood components rather than whole blood. (*Thompson, J. S., and others: Pulmonary "Hypersensitivity" Reactions Induced by Transfusion of Non-HL-A Leukoagglutinins, N. Eng. J. Med. 284: 1120-1125, 1971.*) **EDITOR'S COMMENT:** This represents the first well-documented case of pulmonary edema caused by hypersensitivity to formed elements in whole blood. The time has come to consider seriously the role of massive blood transfusions and their effect on the pulmonary circulation as a principal cause of respiratory insufficiency. Evidence against the desirability of indiscriminate transfusion of whole blood is mounting.