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A nomogram for venous shunt ($\dot{Q}s/\dot{Q}_T$) calculation

S. T. CHIANG

From the Pulmonary Laboratory, Department of Medicine, National Defence Medical Centre, Taipei, Taiwan, Republic of China, and the Pulmonary Laboratory, Department of Medicine, Taiwan Veterans' General Hospital, Taipei, Taiwan, Republic of China

A nomogram for calculating venous shunt has been devised. The details of the derivation of the shunt formula according to which the nomogram is prepared have been reviewed. The simplicity of shunt study using the O_2 breathing method and the example for using this nomogram are described.

Venous shunt in cardiopulmonary physiology means that a fraction of the total cardiac output from the right side of the heart does not take part in gas exchange in the lungs and so passes unchanged into the arterial circulation (Berggren, 1942; Riley and Cournand, 1951; and McIlroy, 1965). Since the shunted blood is mixed venous blood, the terms venous admixture, right-to-left shunt, and venous-to-arterial shunt are commonly used. When a patient has such a shunt, his arterial blood contains excessive mixed venous blood which has bypassed the lungs and mixed with well-oxygenated blood.

Normally, there is some mixed venous blood bypassing the lungs into the arterial stream through (1) normal true shunts of bronchial veins and Thebesian veins, and (2) normal virtual shunts due to slight deviations of the ventilation–perfusion ratio from the ideal value. But the total amount of such shunts is less than 7% of the cardiac output from the right ventricle (Comroe, Forster, DuBois, Briscoe, and Carlsen, 1962) and this has been called physiological shunt. In abnormal conditions, mixed venous blood can enter the arterial stream through (1) an abnormal anatomical right-to-left shunt due to a congenital cardiac anomaly, and (2) an abnormal virtual shunt from the alveoli which has a low ventilation–perfusion ratio. The magnitude of such a shunt is dependent on the size of the communication or ratio of regional uneven ventilation to perfusion.

The venous-to-arterial shunt originating from a congenital cardiac anomaly is easily demonstrated by the injection of dye or contrast medium during cardiac catheterization. Venous-to-arterial shunt due to pulmonary disease can be determined by the oxygen method, provided alveolar ventilation is adequate to produce an alveolar oxygen tension of 100 mm. Hg or more and there is no significant diffusion barrier across the alveolar–capillary membrane.

The relationship of shunted blood to the total cardiac output can be analogous to dead space ventilation to total pulmonary ventilation. The basis of the calculation, stated in words, is similar to Bohr's equation for the calculation of respiratory dead space. The total blood flow (Q_T) is equal to the amount of blood that has travelled the pulmonary capillaries (Qc) plus the amount of blood shunted ($\dot{Q}s$) (Comroe *et al.*, 1962). Similarly, the amount of oxygen in arterial blood is the sum of the amount of oxygen in blood that flows through the pulmonary capillaries and the amount of oxygen in shunted blood. Because the amount of oxygen is the production of the oxygen content (Co_2) and blood flow ($\dot{Q}$), the above statement, written as an equation, will be:

$$Ca_{O_2} \cdot Q_T = Cc_{O_2} \cdot Qc + C\bar{v}_{O_2} \cdot Qs \quad (1)$$

Since $$Q_T = Qc + Qs \quad (2)$$

$$Qc = Q_T - Qs \quad (3)$$

Therefore equation (1) becomes

$$Ca_{O_2} \cdot Q_T = Cc_{O_2} \cdot (Q_T - Qs) + C\bar{v}_{O_2} \cdot Qs \quad (4)$$

or

$$Ca_{O_2} \cdot Q_T - C\bar{v}_{O_2} \cdot Qs = Cc_{O_2} \cdot Q_T - Cc_{O_2} \cdot Qs \quad (5)$$

Rearranged

$$Ca_{O_2} \cdot Q_T - Cc_{O_2} \cdot Q_T = C\bar{v}_{O_2} \cdot Qs - Cc_{O_2} \cdot Qs \quad (6)$$

or

$$Q_T(Ca_{O_2} - Cc_{O_2}) = Qs(C\bar{v}_{O_2} - Cc_{O_2}) \quad (7)$$

This can be arranged to give the standard shunt formula

$$\frac{\dot{Q}s}{\dot{Q}_T}=\frac{Ca_{O_2}-Cc_{O_2}}{C\bar{v}_{O_2}-Cc_{O_2}} \text{ or } \frac{Cc_{O_2}-Ca_{O_2}}{Cc_{O_2}-C\bar{v}_{O_2}} \quad (8)$$

$\dot{Q}s/\dot{Q}_T$ can be calculated as the fraction of the total cardiac output that flows through the shunt. If $\dot{Q}_T$ is known, $\dot{Q}s$ can be calculated in absolute quantity.

During O_2 breathing, after washout of nitrogen, alveolar O_2 tension (P_{AO_2}) will then be inspired O_2 tension (P_{IO_2}) minus alveolar CO_2 tension (P_{ACO_2}).

$$P_{AO_2}=P_{IO_2}-P_{ACO_2} \quad (9)$$

Since $P_{IO_2}=F_{IO_2}\,(P_B-P_{AH_2O})$ (10)

and $P_{ACO_2}=P_{aCO_2}$ (11)

When 100% is given, F_{IO_2} will be 1

Therefore

$$P_{AO_2}=(P_B-P_{AH_2O})-P_{ACO_2} \quad (12)$$

With such a high P_{AO_2}, there will be no alveolar to capillary gradient, *i.e.*, $P_{AO_2}=Pc_{O_2}$. In other words, the pulmonary end-capillary O_2 tension (Pc_{O_2}) is the same as that of alveolar O_2 (P_{AO_2}) (Farhi and Rahn, 1955). If pulmonary end-capillary and peripheral arterial blood are both fully saturated, the difference in their oxygen content (C_{O_2}) is due solely to the oxygen in physical solution. Since the solubility coefficient for oxygen in whole blood is 0·0031 vol.% per mm. Hg P_{O_2}, thus:

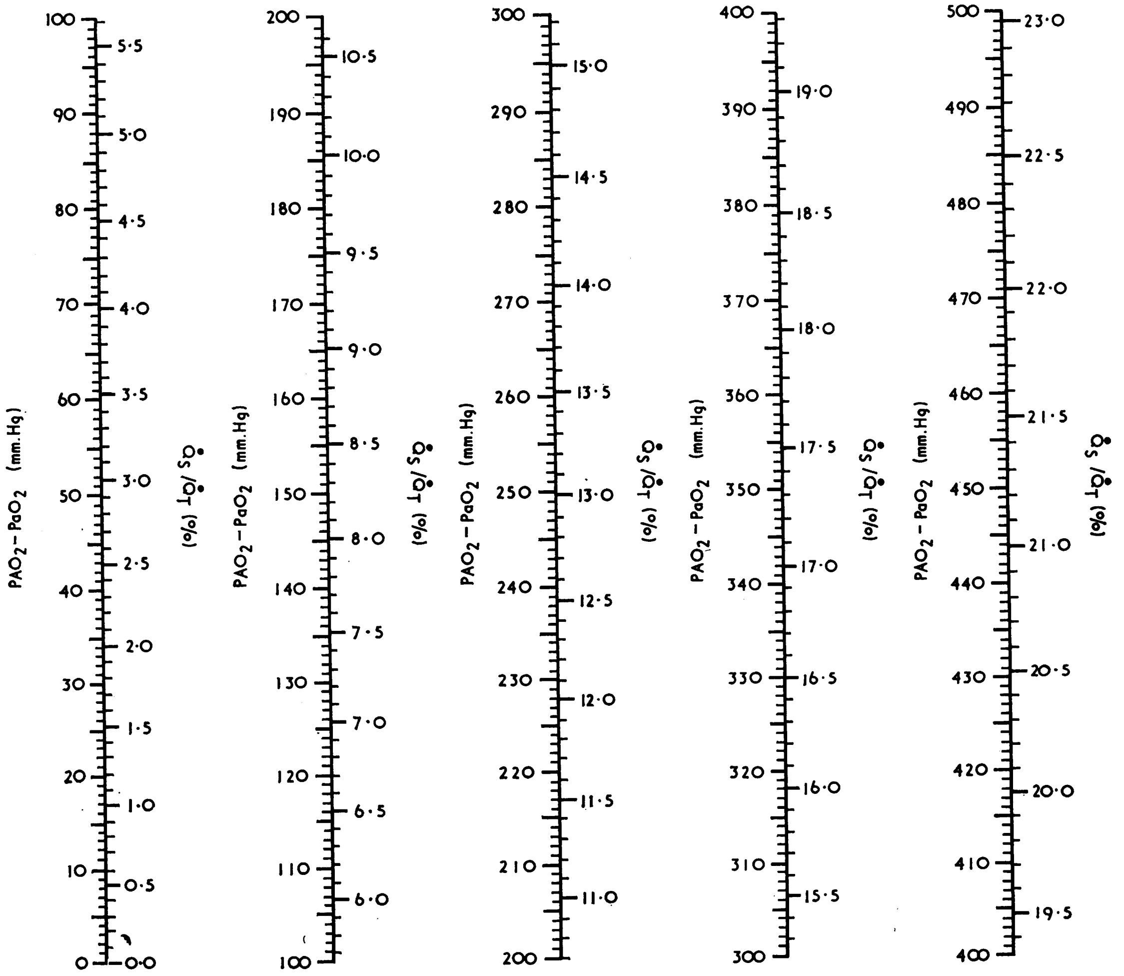

FIGURE. *Venous shunt ($\dot{Q}s/\dot{Q}_T$) calculation nomogram.*

$$C\mathrm{c}O_2 - C\mathrm{a}O_2 = (P\mathrm{A}O_2 - P\mathrm{a}O_2) \times 0{\cdot}003 \quad (13)$$

or

$$C\mathrm{c}O_2 = C\mathrm{a}O_2 + (P\mathrm{A}O_2 - P\mathrm{a}O_2) \times 0{\cdot}003 \quad (14)$$

Substitute equations (13) and (14) into equation (8)

$$\frac{Qs}{Q\mathrm{T}} = \frac{(P\mathrm{A}O_2 - P\mathrm{a}O_2) \times 0{\cdot}003}{(P\mathrm{A}O_2 - P\mathrm{a}O_2) \times 0{\cdot}003 + (C\mathrm{a}O_2 - C\bar{v}O_2)} \quad (15)$$

Assuming that the A–V difference for O_2 ($CaO_2 - C\bar{v}O_2$) is 5 vol.%,

$$\frac{Qs}{Q\mathrm{T}} = \frac{(P\mathrm{A}O_2 - P\mathrm{a}O_2) \times 0{\cdot}003}{(P\mathrm{A}O_2 - P\mathrm{a}O_2) \times 0{\cdot}003 + 5} \quad (16)$$

Dividing the numerator and denominator by 0·003, equation (16) becomes

$$\frac{Qs}{Q\mathrm{T}} = \frac{(P\mathrm{A}O_2 - P\mathrm{a}O_2)}{(P\mathrm{A}O_2 - P\mathrm{a}O_2) + 1{,}670} \quad (17)$$

In this case, if $PAO_2 - PaO_2$ (after 30 minutes of 100% oxygen breathing) is known, the percentage of shunted blood can be calculated simply by the above equation, provided that the assumption of 5% A–V oxygen difference in a normal subject is accepted (Saxton, 1960).

The Figure is a nomogram prepared according to the above equation, namely:

$$\frac{Qs}{Q\mathrm{T}} = \frac{(P\mathrm{A}O_2 - P\mathrm{a}O_2)}{(P\mathrm{A}O_2 - P\mathrm{a}O_2) + 1{,}670}$$

where Qs/Qт is the percentage of shunted blood, PAO_2 is O_2 pressure in the alveoli, and PaO_2 is O_2 pressure in arterial blood.

After 30 minutes of pure oxygen breathing, an arterial blood sample is withdrawn under local anaesthesia. The PaO_2 and $PaCO_2$ are determined by the Clark electrode (Clark, 1956) and Severinghaus electrode (Severinghaus and Bradley, 1958), respectively. When pure oxygen is inhaled, PAO_2 is simply calculated as $PAO_2 = PB - PAH_2O - PACO_2$, where PB is barometric pressure and PAH_2O is water vapour pressure in the alveoli which is 47 mm. Hg at a body temperature of 37° C.

For example, if a normal subject, at barometric pressure of 759 mm. Hg, breathes in 100% oxygen for 30 minutes, his PaO_2 is 592 mm. Hg, and $PaCO_2$ 40 mm. Hg, then the PAO_2 will be 759−47−40=672 mm. Hg and $PAO_2 - PaO_2 = 672 - 592 = 80$ mm. Hg. From the nomogram (Figure), at $PAO_2 - PaO_2 = 80$ mm. Hg, Qs/Qт is 4·57% of total cardiac output.

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S. T. Chiang

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