

TABLE 3. Viral and Bacterial Studies

Drug	pH	Viral			Bacteriological	
		Cells Employed			Thioglycolate Media	Antibacterial Activity
		HEK	BKC	BSC		
Atropine sulfate	3.69	Neg	Neg	Neg	Neg	Bacteriostatic
Lidocaine hydrochloride	6.11	Neg	Neg	Neg	Neg	None
Phenylephrine hydrochloride	6.13	Neg	Neg	Neg	Neg	Bactericidal
Succinylcholine chloride	2.32	Neg	Neg	Neg	Neg	Bactericidal
Tubocurarine chloride	2.03	Neg	Neg	Neg	Neg	Bacteriostatic

and low pH values and are handled with good aseptic technique.

Vials of succinylcholine and phenylephrine are apparently bactericidal, while tubocurarine and atropine are bacteriostatic.

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## REFERENCES

- Martin, E. W. (ed.): Remington's Pharmaceutical Sciences. 13th edition. Easton, Mack Publishing Company, 1965, p. 504.
- Lachman, L., Weinstein, S., Hopkins, G., Slack, S., Elsmann, P., and Cooper, J.: Stability of antibacterial preservatives in parental solution: I. Factors influencing the loss of antimicrobial agents from solutions in rubber-stoppered containers, *J. Pharm. Sci.* 51: 224, 1962.
- Lachman, L., Weinstein, S., Urbanyi, T., Ebersold, E., and Cooper, J.: Stability of antibacterial preservatives in parental solution: II. Relationship between chemical loss and microbiological activity in multiple-dose vials, *J. Pharm. Sci.* 52: 241, 1963.
- Lachman, L., Urbanyi, T., and Weinstein, S.: Stability of antibacterial preservatives in parental solutions: IV. Contribution of rubber closure composition in preservative loss, *J. Pharm. Sci.* 52: 244, 1963.
- Kohan, S., Carlin, H., and Whitehead, R.: A study of contamination of multiple-dose medication vials, *Hospitals* 36: 78, 1962.
- Rdzok, E. J., Grundy, W. E., Kirchmeyer, F. J., and Sylvester, J. C.: Determining the efficacy of preservatives in pharmaceutical products, *J. Amer. Pharm. Ass.* 44: 613, 1955.
- LeMar, L. E., and White, A. L.: A study of the effect of hydrogen-ion concentration in certain ointments and lotions, *J. Amer. Pharm. Ass.* 33: 134, 1944.
- Entrekin, D. N.: Relation of pH to preservative effectiveness. I. Acid media, *J. Pharm. Sci.* 50: 743, 1961.

## Simplified Versions of the Shunt and Oxygen Consumption Equations

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When blood traverses the pulmonary circuit some bypasses the gas exchange surfaces. This pulmonary physiologic shunt, or venous

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admixture effect, is due not only to certain inevitable anatomic pathways but also to a variable amount of ventilation-perfusion inequality. Because of the shunt a negative gradient in oxygen content exists between end-pulmonary-capillary blood and systemic arterial blood. Figure 1 shows the relationships in a conventionally stylized form.

SHUNT EQUATION

From the Fick principle<sup>1</sup> it follows that the ratio of the pulmonary physiologic shunt to cardiac output may be represented by<sup>2</sup>:

$$\frac{\dot{Q}_s}{\dot{Q}_t} = \frac{C\dot{c}O_2 - CaO_2}{C\dot{c}O_2 - C\bar{v}O_2}$$

Though the arterial and mixed venous oxygen contents may be measured directly<sup>3,4</sup> they are often derived indirectly from electrode measurements of oxygen tension, pH, base excess and the hemoglobin content after reference to a standard oxyhemoglobin dissociation curve to obtain oxygen saturation.<sup>5,6,7</sup>

End-pulmonary capillary samples are unobtainable. The assumption is made that the non-shunted blood ( $\dot{Q}_s - \dot{Q}_t$ ) is in ideal equilibrium with the alveolar gas so that the ideal alveolar oxygen tension is equal to end-pulmonary-capillary tension.<sup>8</sup> This tension is then used to calculate the end-pulmonary-capillary content indirectly. The oxygen content of whole blood is derived from the content expression:

total content = hemoglobin content + plasma content,

i.e.,

$$\text{content}/100 \text{ ml} = \frac{1.390 \times \text{Hb} \times \text{So}_2}{100} + 0.0030 \times \text{Po}_2$$

where

1.390 = oxygen capacity of hemoglobin in ml/g calculated for a molecular weight of hemoglobin of 64,458.<sup>9</sup>

Hb = measured hemoglobin content in g/100 ml whole blood.

So<sub>2</sub> = oxygen saturation of hemoglobin.

0.0030 = ml oxygen dissolved in the plasma of 100 ml whole blood of normal hemoglobin content/mm Hg applied oxygen tension at 3SC.<sup>10</sup>

Po<sub>2</sub> = measured oxygen tension

The shunt equation is thus most often solved in the following unwieldy form:

$$\frac{\dot{Q}_s}{\dot{Q}_t} = \frac{(0.0139 \text{ Hb} \times \text{SA}_{O_2} + 0.003 \text{ PA}_{O_2}) - (0.0139 \text{ Hb} \times \text{Sa}_{O_2} + 0.003 \text{ Pa}_{O_2})}{(0.0139 \text{ Hb} \times \text{SA}_{O_2} + 0.003 \text{ PA}_{O_2}) - (0.0139 \text{ Hb} \times \text{S}\bar{v}O_2 + 0.003 \text{ P}\bar{v}O_2)}$$

However, this may be simplified to:

$$\frac{\dot{Q}_s}{\dot{Q}_t} = \frac{0.0139 \text{ Hb}(\text{SA}_{O_2} - \text{Sa}_{O_2}) + 0.003(\text{PA}_{O_2} - \text{Pa}_{O_2})}{0.0139 \text{ Hb}(\text{SA}_{O_2} - \text{S}\bar{v}O_2) + 0.003(\text{PA}_{O_2} - \text{P}\bar{v}O_2)}$$

Dividing through by 0.003 results in the final expression, which is easier to handle:

$$\frac{\dot{Q}_s}{\dot{Q}_t} = \frac{4.63 \text{ Hb}(\text{SA}_{O_2} - \text{Sa}_{O_2}) + (\text{PA}_{O_2} - \text{Pa}_{O_2})}{4.63 \text{ Hb}(\text{SA}_{O_2} - \text{S}\bar{v}O_2) + (\text{PA}_{O_2} - \text{P}\bar{v}O_2)} \quad (i)$$

OXYGEN CONSUMPTION EQUATION

If cardiac output is measured by dye dilution, then oxygen consumption ( $\dot{V}O_2$ ) may be calculated from the Fick principle<sup>1</sup> (cf fig. 1).

$$\dot{V}O_2 = \frac{\dot{Q}_t}{100} (CaO_2 - C\bar{v}O_2) \text{ ml/min}$$

If the arterial and mixed venous oxygen contents are derived indirectly, then substituting the content expressions yields:

$$\dot{V}O_2 = \frac{\dot{Q}_t}{100} [(0.0139 \text{ Hb} \times \text{SA}_{O_2} + 0.003 \text{ PA}_{O_2}) - (0.0139 \text{ Hb} \times \text{S}\bar{v}O_2 + 0.003 \text{ P}\bar{v}O_2)] \text{ ml/min}$$

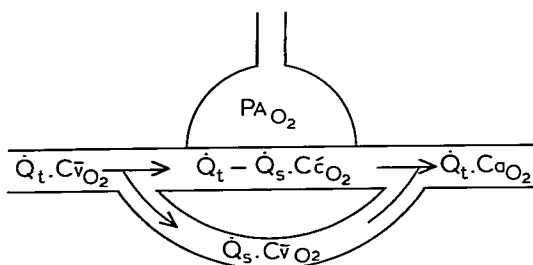


FIG. 1

which can be similarly simplified to:

$$\dot{V}O_2 = 30 \dot{Q}_t [4.63 \text{ Hb} (\text{Sa}_{O_2} - \text{S}\bar{v}O_2) + (\text{Pa}_{O_2} - \text{P}\bar{v}O_2)] 10^{-6} \text{ ml/min}$$

### CONCLUSION

Since ideal alveolar oxygen content is purely conceptual and values of arterial and mixed venous oxygen content are often derived indirectly, the fact that oxygen contents do not appear implicitly in equations (i) and (ii) is of little consequence.

The facility of both these equations may be increased by compiling tables of a range of Hb against 4.63 Hb and a range of  $\dot{Q}_t$  against  $\dot{Q}_t (30 \times 10^{-6})$ .

### SYMBOLS

- $\dot{Q}_t$  = cardiac output in ml/min  
 $\dot{Q}_s$  = pulmonary physiologic shunt in ml/min  
 $\text{Pa}_{O_2}$  = ideal alveolar oxygen tension  
 $\text{Pa}_{O_2}$  = arterial oxygen tension  
 $\text{P}\bar{v}O_2$  = mixed venous oxygen tension  
 $\text{C}\bar{c}O_2$  = end-pulmonary-capillary oxygen content  
 $\text{Ca}_{O_2}$  = arterial oxygen content  
 $\text{C}\bar{v}O_2$  = mixed venous oxygen content  
 $\text{S}\bar{a}O_2$  = end-pulmonary-capillary oxygen saturation  
 $\text{S}\bar{a}O_2$  = arterial oxygen saturation  
 $\text{S}\bar{v}O_2$  = mixed venous oxygen saturation  
 $\dot{V}O_2$  = oxygen consumption in ml/min

### REFERENCES

1. Fick, A.: Über die Messung des Blutquantums in den Herzventrikeln. Sitzungsber. der physikalisch-med. Ges. zu Würzburg XIV: XVI, 1870.
2. Comroe, J. H., Jr., Forster, R. E., Dubois, A. B., Briscoe, W. A., and Carlsen, E.: Calculation of quantity of a venous-to-arterial shunt. *In* The Lung. Chicago, Year Book publishers, 1962, p. 343.
3. Linden, R. J., Ledsome, J. R., and Norman, J.: Simple methods for the determination of the concentrations of carbon dioxide and oxygen in the blood. *Brit. J. Anaesth.* 37: 77, 1965.
4. Van Slyke, D. D., Neill, J. M., and Plazin, J.: *In* Peters, J. P., and Van Slyke, D. D.: Quantitative Clinical Chemistry, Vol. II. Methods. Baltimore, Williams and Wilkins, 1932, p. 327.
5. Kelman, G. R., and Nunn, J. F.: Nomograms for correction of blood  $\text{P}_{O_2}$ ,  $\text{P}_{CO_2}$ , pH, and base excess for time and temperature. *J. Appl. Physiol.* 21: 1484, 1966.
6. Severinghaus, J. W.: Oxyhemoglobin dissociation curve correction for temperature and pH variation in human blood. *J. Appl. Physiol.* 12: 485, 1958.
7. Severinghaus, J. W.: Blood gas calculator. *J. Appl. Physiol.* 21: 1108, 1966.
8. Riley, R. L., and Courmand, A.: "Ideal" alveolar air and the analysis of ventilation perfusion relationships in the lungs. *J. Appl. Physiol.* 8: 825, 1949.
9. Braunitzer, G., Gehring-Mueller, R., Hilschmann, N., Hilde, K., Hohob, G., Rudloff, V., Wittmann-Liebold, B.: Die Konstitution der Normalenadulten Humanhamoglobins. *Hoppe Seyl. Z.* 325: 283, 1961.
10. Sendroy, J., Jr., Dillon, R. T., and Van Slyke, D. D.: Studies of gas and electrolyte equilibria in blood. XIX. The solubility and physical state of uncombined oxygen in blood. *J. Biochem. Chem.* 105: 597, 1934.

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