Principle of Fick – Utilities and Limitations

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Introduction

Fick principle is the most commonly and conveniently used method to measure cardiac output in clinical practice. In this article, we briefly discuss its utilities and limitations.

Fick Principle

The Fick principle was first described by Adolph Eugen Fick, a German physiologist in 1870. Fick described the following relationship:

\[ Q = \frac{M}{V - A} \]

Where Q is the volume of blood flowing through an organ in a minute, M the number of moles of a substance added to the blood by an organ in one minute, and V and A are the venous and arterial concentrations of that substance. This principle can be used to measure the blood flow through any organ that adds substances to, or removes substances from, the blood.

In the determination of cardiac output (L/min), the substance most commonly measured is the oxygen content of blood. Thus by using the values of oxygen ‘added across the pulmonary circulation’ (ml/min) and arteriovenous oxygen content difference (ml/L), the flow across the pulmonary system is calculated. Presuming there is no shunt lesion, the pulmonary blood flow is the same as the systemic blood flow (i.e. Cardiac output). This gives a simple way to calculate the cardiac output:

\[
\text{Cardiac Output} = \frac{\text{Oxygen consumption}}{\text{arteriovenous oxygen difference}}
\]

Measurement of the arterial and venous oxygen content of blood involves sampling of blood from the pulmonary artery (low oxygen content) and from the pulmonary vein (high oxygen content). In practice, sampling of vena caval (mixed venous) and peripheral arterial bloods are surrogates for pulmonary arterial and venous samples, respectively. When one or more pulmonary veins drain into the Superior Vena Cava or Inferior Vena Cava, venous blood has to be collected before their entry into either. Determination of the oxygen consumption of the peripheral tissues is more complex. Hence, in the steady state, the amount of oxygen supply by the lungs is the surrogate of oxygen consumption of the entire body.

Oxygen consumption

\[ \text{VO}_2 \text{, the oxygen consumption, is simply the difference between the inspired and expired } \text{O}_2. \]

In Fick original method, \( \text{VO}_2 \) in ml per minute is measured using a spirometer within a closed rebreathing circuit incorporating a CO2 absorber. The methods employed for measuring oxygen uptake are the Douglas bag and the Polarographic methods.

In reality, \( \text{VO}_2 \) is rarely measured due to the difficulty of collecting and analyzing the gas concentrations. Nevertheless, by applying an accepted value for oxygen consumption, cardiac output can be closely approximated without the cumbersome and time-consuming oxygen consumption measurement. This is sometimes called as assumed Fick determination. Many laboratories use the data derived by LaFarge and Miettinen in 1970 to assume oxygen consumption from the estimated body surface area. A commonly assumed value for \( \text{O}_2 \) consumption at rest is 125ml \( \text{O}_2 \) per minute per square meter or 3.5 ml of \( \text{O}_2 \) per kg per minute.

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Arterio venous oxygen difference

The A-V oxygen difference refers to the difference in their oxygen content (ml/L), not the saturation. Using the fact that each gram of hemoglobin (Hb) can carry 1.36 ml of O₂, the oxygen content of the blood (either arterial or venous) can be estimated by the following formula.

\[
\text{Oxygen Content of blood (in ml/L)} = [\text{Hb}] \times 1.36 \text{ (ml O}_2/\text{g Hb)} \times \text{O}_2\text{ saturation fraction} +0.03 \times \text{P}_O_2 (\text{torr})
\]

**Note:**
1 torr for all practical purposes = 1mm Hg
O₂ saturation fraction = oxygen saturation (%) x 0.01 (i.e. if 95% saturation, fraction is 0.95)
Dissolved oxygen in blood is 0.003ml/mmHg O₂/decilitre of blood.
When we convert to ml/L, it is 0.03ml/mmHg O₂/L of blood.

Almost all the oxygen in the blood is carried by Hb and when breathing room air, the component of dissolved oxygen is negligible. However when the fractional inspiration of oxygen (FiO₂) is higher, as occurs during oxygen inhalation, the dissolved oxygen should be added to the oxygen carried by Hb to calculate Oxygen Content of the blood².

For example,
Assuming Hb concentration of 15 g/dl and an oxygen saturation of 99%, the oxygen content of arterial blood is approximately 200 ml of O₂ per litre. The saturation of mixed venous blood is approximately 75% in health. Using this value in the above equation, the oxygen content of mixed venous blood is approximately 150 ml of O₂ per litre. The arteriovenous oxygen difference is 50 ml/L. If the oxygen consumption (VO₂) is 250 ml/min, cardiac output is 5 L/min (250/50 = 5).

Oxygen saturation is measured spectrophotometrically. Oximeters measure the absorption at 650nm to represent the amount of oxidized hemoglobin and the absorption at 805nm to represent total hemoglobin; the ratio of these two numbers is the oxygen saturation by pulse oximetry (SpO₂). The method is accurate at oxygen saturations between 60% and 95%, if there is no carboxyhemoglobin. The oxygen saturation (SaO₂) in blood gas is derived by using the pH, partial pressure of CO₂ (pCO₂), and pO₂, using the oxygen dissociation curve.

However, factors that affect the affinity of oxygen for hemoglobin (i.e., temperature, hydrogen ion, fetal hemoglobin, and levels of 2,3-DPG) are difficult to measure accurately, which makes this method inaccurate in neonates and cyanotic children. When the arteriovenous oxygen difference is large, the errors inherent in measuring oxygen content or saturation do not result in major errors in calculation of flow. However, when the arteriovenous difference is small, small errors in measurement may result in large errors of flow measurement.

Utilities of Fick principle:

1. Cardiac Output
2. Shunt quantification in congenital heart disease

Cardiac output

The gold standard method for measuring human cardiac output is the Fick principle. The other methods for measuring cardiac output are indicator dilution, thermal dilution, pulse Doppler echocardiography, radionuclide angiography, conventional angiography and impedance cardiography.

Fick method and thermodilution technique are both performed during cardiac catheterization. Fick method is considered more reliable in the presence of tricuspid regurgitation and in the low-output state.

Shunt quantification

In patients with congenital heart disease (CHD), the Fick method has been used to calculate pulmonary and systemic blood flows and the magnitude of the shunts. The equations used are as follows:

\[
Q_p = \frac{V_O}{C_{pvo} - C_{pao}}
\]
\[
Q_s = \frac{V_O}{C_{sao} - C_{mvo}}
\]
\[
Q_e = \frac{C_{sao} - C_{mvo}}{C_{pvo} - C_{pao}}
\]
\[
Q_p = \frac{C_{mvo} - C_{mvo}}{C_{pvo} - C_{pao}}
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In patients with a congenital heart disease (CHD), the Fick method has been used to determine pulmonary and systemic blood flow and the magnitude of the shunts. The equations used are as follows:

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\[
Q_e = \frac{C_{sao} - C_{mvo}}{C_{pvo} - C_{pao}}
\]

In left to right shunt lesion like an atrial septal defect, there is a recirculation in pulmonary circulation. Qp includes systemic venous return (Qs) and left to right shunt. Similarly, in right to left shunt lesion, there is a recirculation in systemic circulation, Qs includes systemic venous return (Qs) and right to left shunt. In some complicated cases of CHD, blood may be shunted left to right at one level and right to left at another level or even in a bidirectional manner through the same defect. In order to attempt to assess the magnitude of shunt in each direction, the concept of effective pulmonary blood flow has been introduced. Effective pulmonary blood flow (Qep) is the quantity of mixed venous blood that eventually reaches the lungs to be oxygenated. It can be calculated from the following equation:

\[
Q_{ep} = \frac{V_O}{C_{pvo} - C_{mvo}}
\]
Similarly, Effective systemic blood flow (Qes) is the quantity of pulmonary venous return that gets utilized at systemic circulation. Qep is equal to Qes. Total pulmonary flow (Qp) is a combination of effective pulmonary flow (Qep) and left to right shunt. So,

$$Q_{L,R} = Qp - Qep$$

**Limitations of Fick Principle.**

The limitations of the Fick principle lie in both oxygen consumption (VO₂) and A-V oxygen content. The accuracy of calculation of flow by the Fick method is determined, by the accuracy with which VO₂ and arteriovenous oxygen difference can be measured.

**Limitations due to VO₂:**

1. Due to the nonlinearity of VO₂ with body surface area, it is not surprising that correlations between measured and assumed oxygen consumptions are poor. The calculation of cardiac output or blood flows by the Fick method based on assumed oxygen consumption is thus likely to yield unreliable estimates.

2. It is assumed that the volume of oxygen being taken up in the body is in equilibrium with the volume of oxygen being taken up from air in the lungs. Thus, there must be a ‘steady state’ of oxygen exchange during the whole period over which the measurement is being taken. Practically, it is difficult to maintain ‘steady state’ during the whole study in catheterization laboratory.

3. VO₂ is for the entire body, it cannot be used for measuring flow in individual segments of the body. **Examples.**
   a) Individual pulmonary arteries as in hemitruncus
   b) Lower and upper body sections as in PDA with right to left shunt.

**Limitations due to A-V oxygen content:**

The reliability of Fick principle for flow is poor, if the A-V oxygen difference is narrow. If mixed venous saturation is high (example- mechanical ventilation with high FiO₂), then we cannot appreciate any step up within the cardiac chambers or great arteries. The same is true if the pulmonary venous sample is desaturated. Hence, to obtain a reliable calculation of flow, the mixed venous and pulmonary venous samples saturations should as far as apart. This should be at least 25% to 35%, which is the normal A-V oxygen difference. Next, the common caveat is the sample obtained from a site may not be representative of it.

1. Mixed venous saturation is assumed from the vena cava saturations: Flamm’s formula = [(3x SVC saturation) + IVC saturation /4]. It may not always represent the true mixed venous saturation, especially when there is a gross difference in venacava saturation.
2. Inferior vena cava saturation is affected by site sampling. IVC saturation is higher if measured inferiorly near the renal veins and lower if measured superiorly near the hepatic veins, as compared to the entire lower body.
3. Right atrium is the site of streaming with variable saturation (lowest near the coronary sinus). Hence it is not ideal for mixed venous saturation.
4. Branch pulmonary artery saturations are different in the presence of patent ductus arteriosus. If there are bronchial collaterals as in Transposition of great arteries (TGA) or Tetralogy of Fallot (TOF), the Qp calculated is incorrect. It is underestimated in TOF and overestimated in TGA.

**Conclusion**

Fick principle is still the gold standard for estimation of cardiac output and vascular shunt. It can be utilized to the maximum, if we use it prudently by knowing its limitations.

**References**

6. Allen, Hugh D.; Driscoll, David J.; Shaddy, Robert E.; Feltes, Timothy F. Title: Moss and Adams' Heart Disease in Infants, Children, and Adolescents: Including the Fetus and Young Adults, 7th Ed Lippincott Williams & Wilkins; 2007: 212

**List of abbreviations**

| CHD | Congenital heart disease |
| IVC | Inferior vena cava |
| PDA | Patent ductus arteriosus |
| SVC | Superior vena cava |
| TGA | Transposition of great arteries |
| TOF | Tetralogy of Fallot |