Computations of Expired Gas Analysis Indirect Calorimetry

Yes, we are approaching some math topics. Do not be overly concerned about such calculations, for if I teach you correctly you will understand this material and not need to memorize equations. Furthermore, as I stress to all of my students, understanding physiology and scientific principles makes knowing and using the equations far more logical. For example, if you understand the principles of indirect calorimetry you should be able to derive all of equations 1 to 11 that are presented in this Topic without having to memorize any of them!

So far you should have learned the fundamental computations for quantifying each of VO_2 and VCO_2, as presented in Equations 1 and 2.

$$VO_2 = inspired\ VO_2 - expired\ VO_2 = (VI \times FIO_2) - (VE \times FEO_2)$$
$$= (VI \times 0.2095) - (VE \times FEO_2)$$

Equation 1

$$VCO_2 = \text{expired VCO}_2 - \text{inspired VCO}_2 = (VE \times FECO_2) - (VI \times FICO_2)$$
$$= (VE \times FECO_2) - (VI \times 0.00031)$$

Equation 2

To use these equations, there are four variables that are required to be measured.

1. inspired ventilation
2. expired ventilation
3. FEO_2
4. $FECO_2$

Despite the simplicity of these equations, most laboratories do not measure both inspired and expired ventilation. The main reason for this is expense, as such a procedure would require the purchase of two ventilation measurement systems. Ironically, these systems are not that expensive today. Nevertheless, most commercial and custom made systems still operate on using one ventilation measurement device from which the other is calculated. Thus, most systems of EGAIC measure only 3 variables, from which everything else is calculated. Of course, added measurements can be made and integrated into the system, such as heart rate, pulse oximetry, electromyography, etc.

Before added equations of indirect calorimetry are presented, you need to learn how one ventilation measurement allows the calculation of the second.

The Haldane Transformation

Within the body, of the three main gases in air, oxygen, carbon dioxide and nitrogen, only oxygen and carbon dioxide are physiologically relevant. This is because nitrogen gas is not produced or consumed by the body, and as such nitrogen gas is physiologically **inert**. Therefore, we can express the inspiration and expiration of nitrogen to be equal as done via the **Haldane transformation** as shown in Equation 3.

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$$Expired\ N_2 = inspired\ N_2\ ;thus$$
$$(VE \times FEN_2) = (VI \times FIN_2)$$ Equation 3

Rather than require the added investment and complexity of now measuring the fraction of nitrogen in expired air, the fractions of expired O_2 and CO_2 are used to calculate **FEN_2** as follows in Equation 4. Note that the total gas fraction consisting of O_2, N_2 and CO_2 is not 1.0 but 0.9906 ($FIN_2 + FIO_2 + FICO_2 = 0.9906$).

$$Expired\ N_2 = \text{inspired } \mathrm{N}_2\ ;thus$$
$$FEN_2 = 0.9906 - (FEO_2 + FECO_2)$$ Equation 4

Remember that the fraction of inspired nitrogen (**FIN_2**) is 0.7808!

Thus, we can now re-write Equation 3 as follows in Equation 5;

$$VE \times (0.9906 - (FEO_2 + FECO_2)) = VI \times 0.7808$$ Equation 5

This means we can solve for VI based on FEO_2 and $FECO_2$, as follows in Equation 6;

$$VI = (VE \times (0.9906 - (FEO_2 + FECO_2))) / 0.7808$$ Equation 6

Calculating VO_2

Now that VI can be expressed based on a modification of VE, we can now express Equation 1 as follows in Equation 7.

$$VO_2 = \left(\left((VE \times (0.9906 - (FEO_2 + FECO_2))) / 0.7808\right) \times 0.2095\right) - (VE \times FEO_2)$$ Equation 7

Equation 7 is therefore the final equation to compute the volume of oxygen consumption (**VO_2**) when measuring expired ventilation.

What if you want to measure inspired ventilation?

Then we just need to re-write Equation 5 to solve for VI, as done in Equation 8.

$$VE = (VI \times 0.7808) / (0.9906 - (FEO_2 + FECO_2))$$ Equation 8

Equation 8 is then inserted into Equation 1 as follows for Equation 9.

$$VO_2 = (VI \times 0.2095) - \left(\left((VI \times 0.7808) / (0.9906 - (FEO_2 + FECO_2))\right) \times FEO2\right)$$ Equation 9

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Even though expired ventilation is routinely measured in indirect calorimetry, there are important reasons that preference should be given to the measurement of VI. Expired air is saturated with **water vapor**, and such moisture can impair the operation of many air flow measurement devices. Some exercise conditions might also raise body core temperature, and therefore expired air temperature above the assumed 37 °C. Air volume increases with increasing temperature and this could make VE measurement inaccurate.

The draw back for measuring VI is that you need to know the exact inspired air temperature and relative humidity so that temperature and moisture corrections to inspired air volumes can occur. Such issues are explained in the next Topic on conditions for measuring gas volumes.

Calculating VCO_2

It is best to compute VO_2 first so that you already complete data for both VI and VE. Thus, computation of the volume of carbon dioxide production (**VCO_2**) is relatively simple as Equation 2 can be used directly as shown in Equation 10.

$$VCO_2 = (VE \times FECO_2) - (VI \times 0.00031)$$ Equation 10

Even though the right side of this equation is small due to the 0.00033 $FICO_2$ constant, make sure you complete this adjustment, as it does become meaningful during intense exercise when VI is very large (>120 L/min)!

Calculating the Respiratory Exchange Ratio

The **respiratory exchange ratio (RER)** computed from EGAIC is expressed in Equation 11.

$$RER = \frac{VCO_2}{VO_2}$$ Equation 11

Although the RER is the same formula as the measurement of the **respiratory quotient (RQ)**, it is given a different name, as the maximal range of the RQ for cellular metabolism is approximately 0.7 to 1.0. The RQ cannot go above 1.0 as pure carbohydrate catabolism in cells produces the same number of CO_2 molecules as O_2 molecules consumed. For the RER, which is based on gas exchange within the lungs and not at the cell, added CO_2 can come from the bicarbonate buffering of protons (H^+) that are produced within and transported out of muscle into the blood during intense exercise. Thus, the maximal range of RER is much larger than for RQ, with RER values going as high as 1.2 during intense exercise, and even higher to 1.7 during the recovery from intense exercise.

The impact of metabolic acidosis on the RER makes the RER a useful computation from EGAIC to detect the onset of **metabolic acidosis** (RER > 1.0).

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The RER is also used to calculate the contribution of fat and carbohydrate catabolism during exercise, but prior to this content, you need to understand the applied nutrition background of EGAIC. This in turn allows you to understand the connections between EGAIC, energy expenditure and heat production. These issues are explained in the next Topics.

Gas Conditions

Prior to discussion of the connections between EGAIC, energy expenditure and heat production, comment and added explanation needs to be give to the gas conditions prevalent during data collection with EGAIC. This is important, as VO_2 and VCO_2 refer to gas volumes, and gas volumes vary in direct proportion to gas temperature, and inversely with gas pressure and the water vapor content of the gas. Thus, to compare gas volumes for VO_2 and VCO_2 to each other when collected under different conditions for temperature, atmospheric pressure and/or water vapor content of air, gas volumes must be standardized. These issues are explained in the next Topic.

Glossary Words

physiologically inert refers to a compound, such as gaseous nitrogen (N_2), that is neither produced or consumed by the body.

Haldane transformation is the algebraic computation of either of inspired or expired ventilation from each other based on the fact that over a given time period, the volume of inspired nitrogen must equal the volume of expired nitrogen.

FEN_2 is the fraction of expired nitrogen gas.

FIN_2 is the fraction of inspired nitrogen gas.

VO_2 is the volume of oxygen consumed, typically expressed as a volume (L) per min (L/min or $L{\cdot}min^{-1}$).

water vapor is water, in the form of a gas (water vapor), present in the air.

VCO_2 is the volume of carbon dioxide production, typically expressed as a volume (L) per min (L/min or $L{\cdot}min^{-1}$).

respiratory exchange ratio (RER) is the ratio of VCO_2 to VO_2 (VCO_2/VO_2) when measured from expired gas analysis indirect calorimetry.

respiratory quotient (RQ) is the ratio of VCO_2 to VO_2 (VCO_2/VO_2) based solely on cellular metabolism.

metabolic acidosis is the condition of a decreasing muscle and/or blood pH resulting from the increased metabolism supporting increased cellular metabolic stress.