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ERRATUM

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Estimation of $\dot{V}O_{2max}$ from the ratio between HR_{max} and HR_{rest} – the Heart Rate Ratio Method

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The Appendix contained errors that were overlooked in the proof. The correct version is printed below.

Appendix

Derivation of an equation for a relationship between $\dot{V}O_{2max}$ and the ratio between HR_{max} and HR_{rest}

According to the Fick principle, $\dot{V}O_2$ may be expressed as the product of cardiac output ($\dot{Q}$)and the arterio-venous O_2 difference ($CaO_2{-}C\bar{v}O_2$).

$$\dot{V}O_2 = \dot{Q} \cdot (C_aO_2 - C\bar{v}O_2) \quad (1)$$

Thus, since $\dot{Q}$ is the product of HR and stroke volume (SV), $\dot{V}O_2$ can be expressed as:

$$\dot{V}O_2 = HR \cdot SV \cdot (C_aO_2 - C\bar{v}O_2) \quad (2)$$

When applied to rest $\dot{V}O_2$ can be expressed as:

$$\dot{V}O_{2rest} = HR_{rest} \cdot SV_{rest} \cdot (CaO_2 - C\bar{v}O_2)_{rest} \quad (3)$$

implying that:

$$\frac{\dot{V}O_{2rest}}{HR_{rest} \cdot SV_{rest} \cdot (CaO_2 - C\bar{v}O_2)_{rest}} = 1 \quad (4)$$

During maximal exercise the Fick equation reads:

$$\dot{V}O_{2max} = HR_{max} \cdot SV_{max} \cdot (CaO_2 - C\bar{v}O_2)_{max} \quad (5)$$

By multiplying the right side of Eq. 5 with 1 in the form of Eq. 4 it follows that:

$$\dot{V}O_{2max} = \frac{HR_{max} \cdot SV_{max} \cdot (CaO_2 - C\bar{v}O_2)_{max}}{HR_{rest} \cdot SV_{rest} \cdot (CaO_2 - C\bar{v}O_2)_{rest}} \cdot \dot{V}O_{2rest} \quad (6)$$

or

$$\dot{V}O_{2max} = \left(\frac{HR_{max}}{HR_{rest}}\right) \cdot \left(\frac{SV_{max}}{SV_{rest}}\right) \cdot \left(\frac{(CaO_2 - C\bar{v}O_2)_{max}}{(CaO_2 - C\bar{v}O_2)_{rest}}\right) \cdot \dot{V}O_{2rest} \quad (7)$$

This implies that $\dot{V}O_{2max}$ may be calculated as the product of $\dot{V}O_{2rest}$ and the ratios of maximal versus resting values of, respectively, HR, SV, and ($CaO_2{-}C\bar{v}O_2$).

$\dot{V}O_{2rest}$ is dependent on and increases with the individual's body mass. Åstrand and Rodahl (1986) suggest that, relative to body mass (BM), resting $\dot{V}O_2$ equals about 3.5 ml·min^{-1}·kg^{-1} (one MET), but slightly lower values were reported by McCann and Adams (2002) (3.3 for men and 3.1 for women, respectively). As a compromise we chose 3.4 ml·min^{-1}·kg^{-1} to represent the mass-specific resting $\dot{V}O_2$. Accordingly, $\dot{V}O_{2rest}$ (ml·min^{-1}) may be expressed as 3.4 ml·min^{-1}·kg^{-1} times BM in kg.

$$\dot{V}O_{2max} = \left(\frac{HR_{max}}{HR_{rest}}\right) \cdot \left(\frac{SV_{max}}{SV_{rest}}\right) \cdot \left(\frac{(CaO_2 - C\bar{v}O_2)_{max}}{(CaO_2 - C\bar{v}O_2)_{rest}}\right) \cdot BM \cdot 3.4\ ml \cdot min^{-1} \cdot kg^{-1} \quad (8)$$

From a test perspective only the HR_{max}-to-HR_{rest} ratio is readily obtainable. The other two ratios in the equation involve complicated measurements, in fact

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more complicated than the measurement of $\dot{V}O_2$ itself. Equation 8 suggests, however, that if the max-to-rest ratios of SV and ($CaO_2-C\bar{v}O_2$) were approximately constant across individuals, $\dot{V}O_{2max}$ per kg BM may be estimated by experimentally determining the HR_{max}-to-HR_{rest} ratio, and multiplying this ratio with these constants and 3.4 $ml \cdot min^{-1} \cdot kg^{-1}$. Nottin et al. (2002) and Chapman et al. (1960) reported the average $SV_{max} \cdot SV_{rest}{}^{-1}$ to be 1.28 and 1.29, respectively, in men, when measured in the supine position. Thus, according to the studies mentioned it appears that $SV_{max} \cdot SV_{rest}{}^{-1}$ may be replaced by a dimensionless value of approximately 1.3.

The arterio-venous oxygen difference increases from rest to maximal exercise. Chapman et al. (1960) found the average ratio between maximal and resting ($CaO_2-C\bar{v}O_2$) to be 3.4 in men. We therefore replaced $(CaO_2-C\bar{v}O_2)_{max} \cdot (CaO_2-C\bar{v}O_2)rest^{-1}$ in Eq. 8 with 3.4. Altogether, data from the literature suggest that Eq. 8 may be simplified to the approximation:

$$\begin{aligned}\dot{V}O_{2\,max} &= \left(1.3 \cdot 3.4 \cdot 3.4\,\mathrm{ml} \cdot \mathrm{min}^{-1} \cdot \mathrm{kg}^{-1}\right) \cdot \mathrm{BM(kg)} \cdot \tfrac{HR_{max}}{HR_{rest}} \\ &= 15.0\,\mathrm{ml} \cdot \mathrm{min}^{-1} \cdot \mathrm{kg}^{-1} \cdot \mathrm{BM\ (kg)} \cdot \tfrac{HR_{max}}{HR_{rest}}, \text{ or}\end{aligned} \tag{9}$$

Mass - specific

$$\dot{V}O_{2\,max} = \left(15.0\ \mathrm{ml} \cdot \mathrm{min}^{-1} \cdot \mathrm{kg}^{-1}\right)\frac{HR_{max}}{HR_{rest}} \tag{10}$$