# Oxygen Transport in Exercise


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# Conflicts of Interests

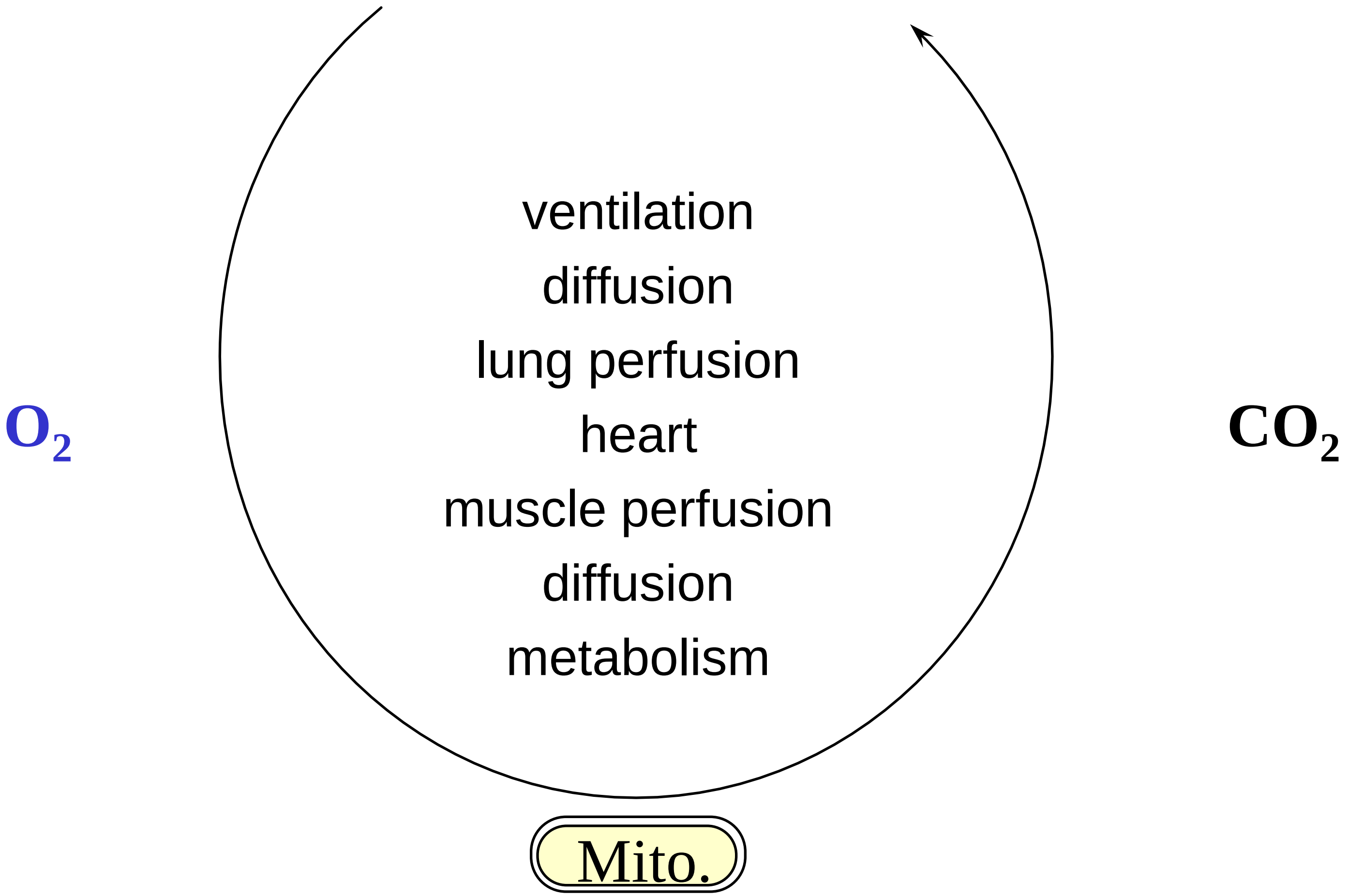
Institutional

- Contribution to clinical trials: Actelion, Medtronic, Edwards, Occlutec, Novartis, Lilly
- Unrestricted grants for investigator initiated trials: Pfizer, GlaxoSmithKline, Abbott, Actelion

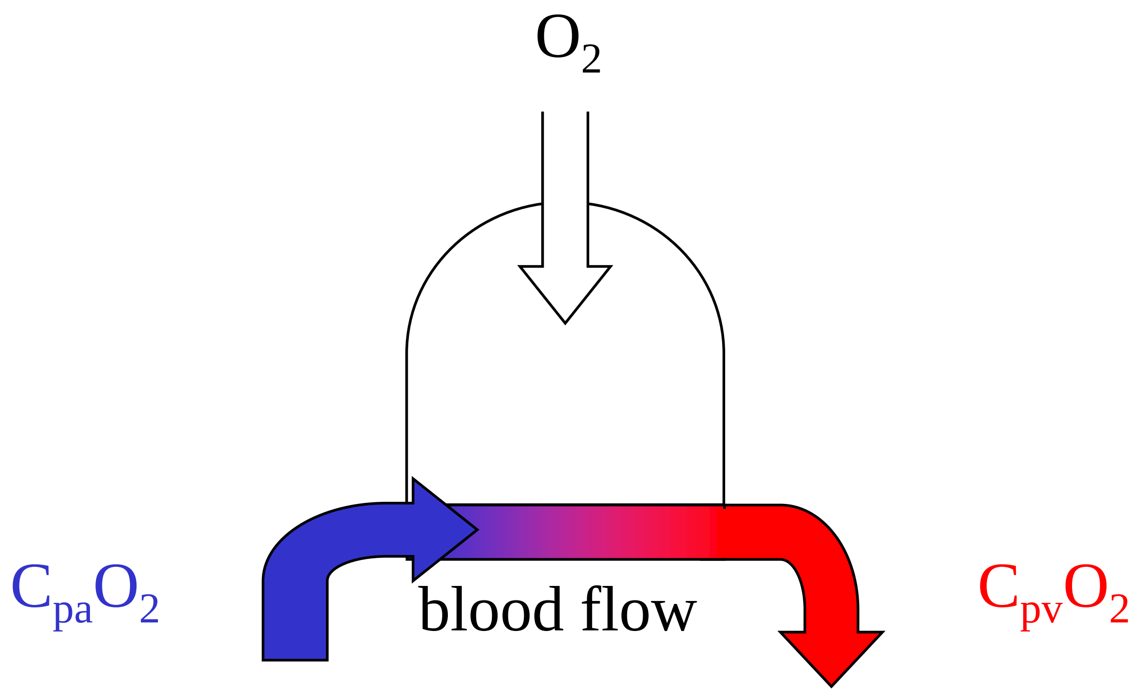
Private

- Shareholder: Celgen, Gilead, Vertex, Abbvie, Pfizer, Novartis, Johnson & Johnson, Amgen, Cerner, Lilly, Baxter, Merck, Biogen, …
- Advisory board reimbursement: Actelion
- Speakers reimbursement: Schiller, Actelion, Abbott, Pfizer, Encysive, AOP Orphan, OMT, GlaxoSmithKline, Medtronic
- Travel expense reimbursement: Pfizer, GlaxoSmithKline, AOP Orphan Pharmaceuticals, Lilly, Actelion, Medtronic, Arrows, Guidant, Fresenius

# Oxygen Transport



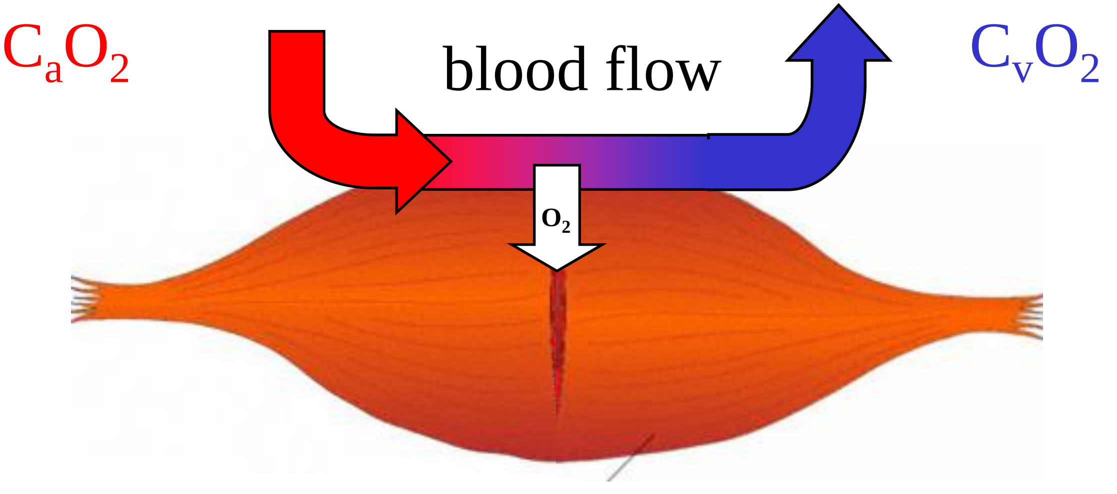
# Fick's Principle




flow = indicator uptake / concentration change

$$\text{blood flow}_{pulmonary} = \text{oxygen uptake} \;/\; (C_{pv}O_2 - C_{pa}O_2)$$

# Fick‘s Principle




$$\text{blood flow}_{\text{system}} = \text{oxygen consumption} / \text{oxygen content change}$$

$$\text{oxygen consumption} = \text{blood flow}_{\text{system}} \cdot \text{oxygen content change}$$

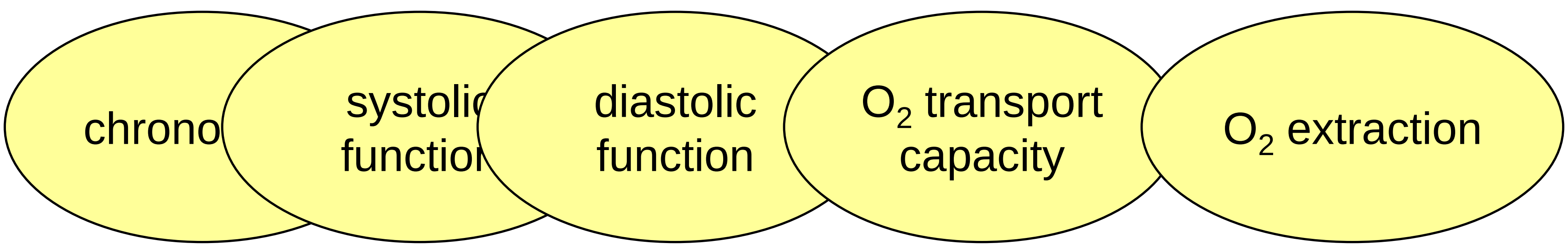
# Oxygen consumption ($\dot{V}O_2$)

= blood $\text{flow}_{\text{system}}$ · oxygen content change

= cardiac output ($\dot{Q}_s$) · 0.0136 · Hb · ($S_aO_2 - S_vO_2$)

= heart rate · stroke volume · 0.0136 · Hb · ($S_aO_2 - S_vO_2$)

= HR · EF · $LVV_{ed}$ · 0.0136 · Hb · ($S_aO_2 - S_vO_2$)



# Oxygen uptake ($\dot{V}O_2$)

$$= \text{blood flow}_{system} \cdot \text{oxygen content change}$$

$$= \text{cardiac output } (\dot{Q}_s) \cdot 0.0136 \cdot Hb \cdot (S_aO_2 - S_vO_2)$$

$$= \text{heart rate} \cdot \text{stroke volume} \cdot 0.0136 \cdot Hb \cdot (S_aO_2 - S_vO_2)$$

$$= HR \cdot EF \cdot LVV_{ed} \cdot 0.0136 \cdot Hb \cdot (S_aO_2 - S_vO_2)$$

chrono

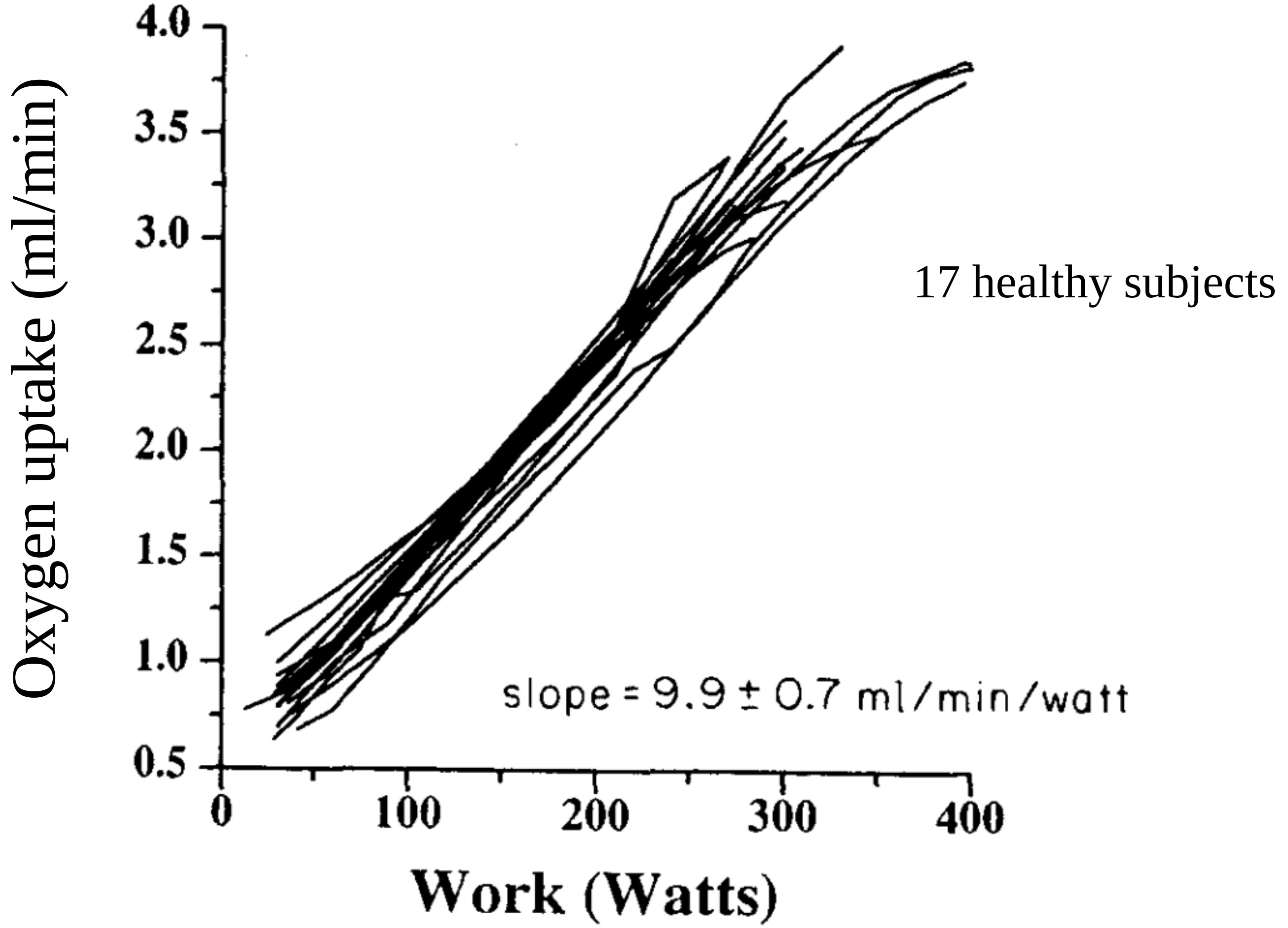
systolic
function

diastolic
function

$O_2$ transport
capacity

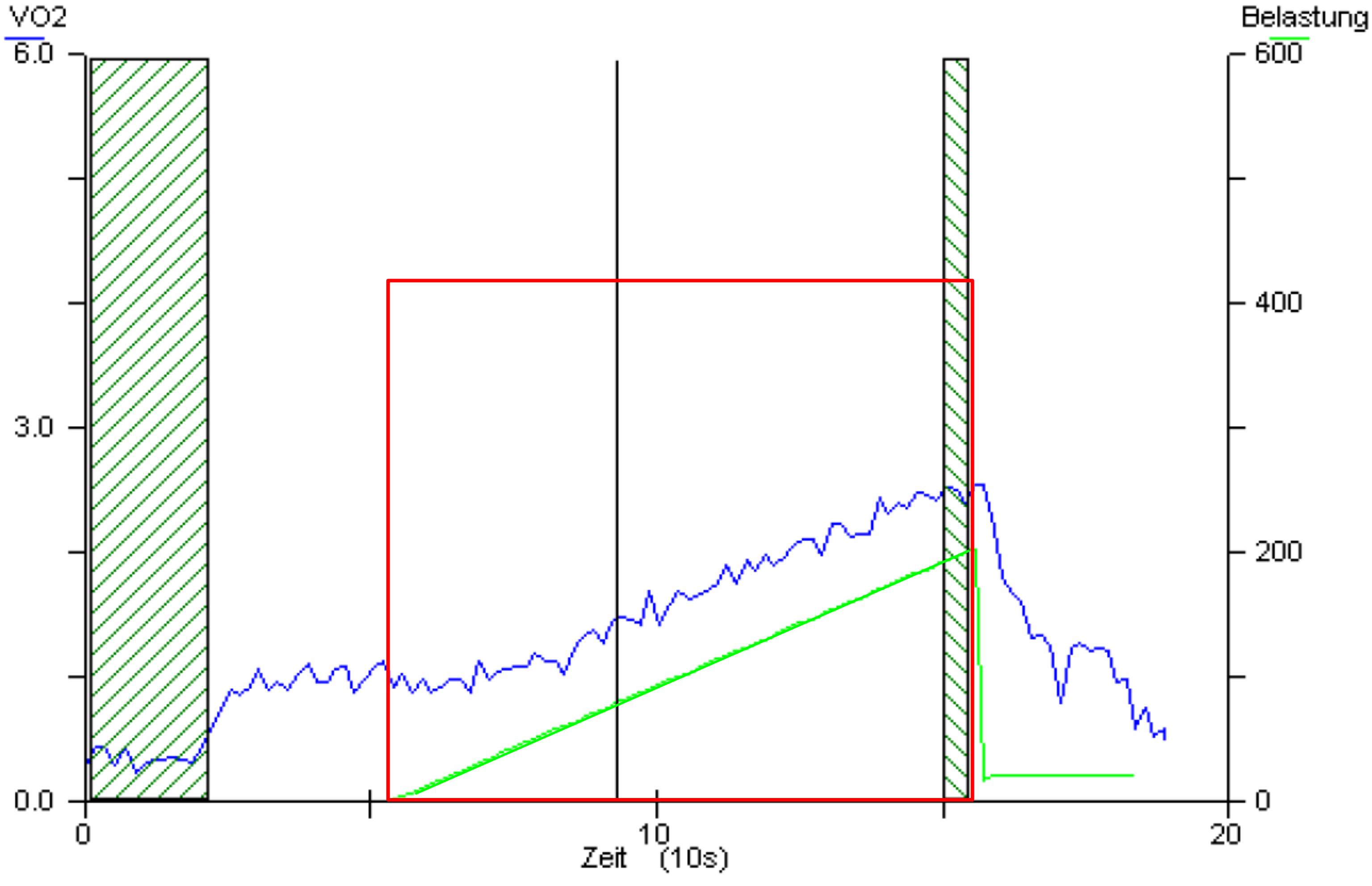
$O_2$ extraction

# Oxygen Cost for Work

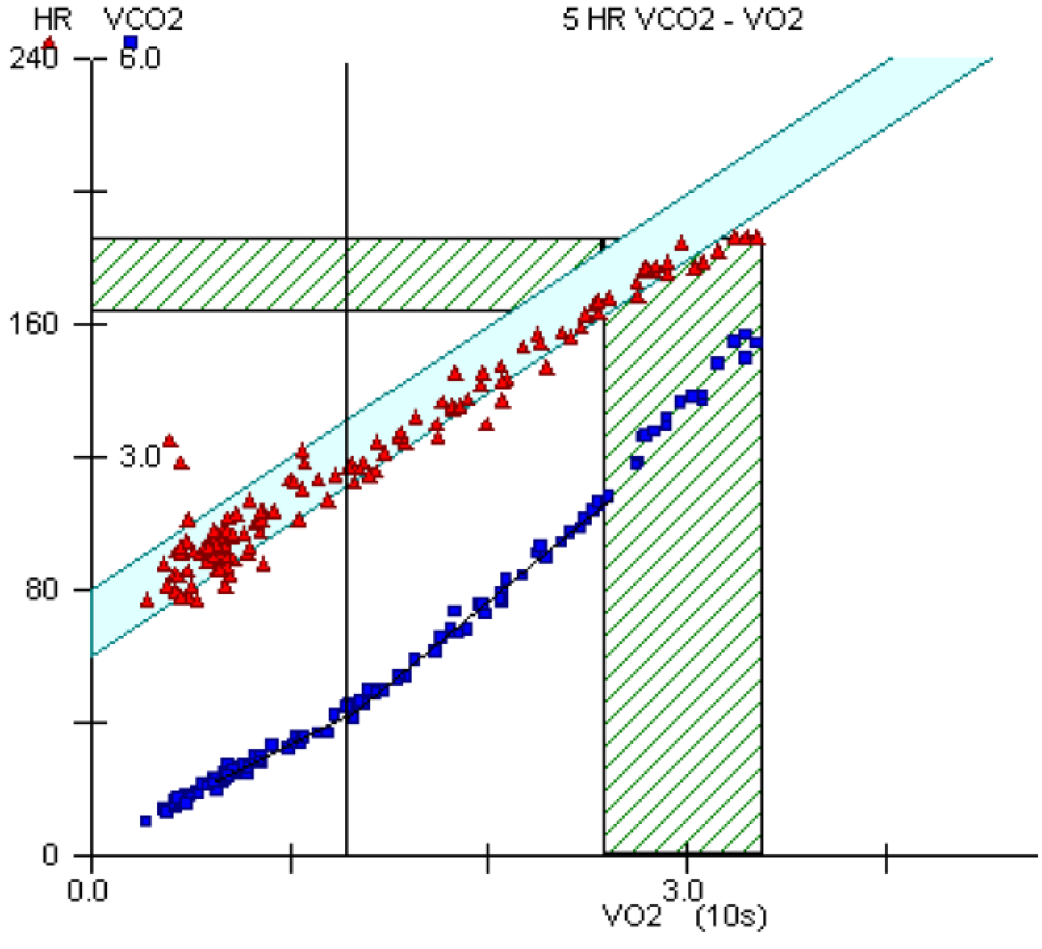



Wassermann, 4. Aufl. 2005

# Oxygen uptake



# Heart rate – $\dot{V}O_2$



# Oxygen Pulse

= oxygen uptake / heart rate

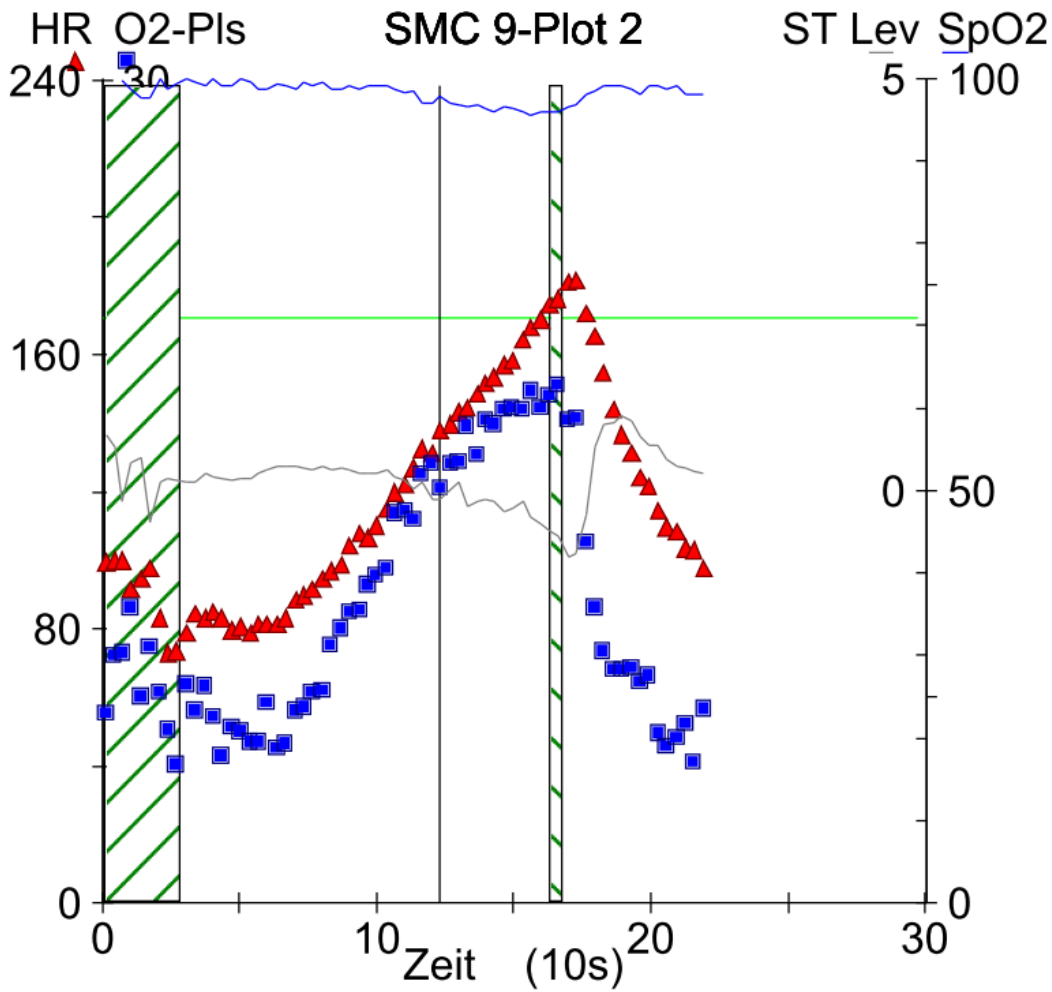
( = „ oxygen transport / heart beat “ )

$$= \not{HF} \cdot EF \cdot LVV_{ed} \cdot 0.0136 \cdot Hb \cdot (S_aO_2 - S_vO_2)$$

$$= \underbrace{EF \cdot LVV_{ed}}_{\text{stroke volume}} \cdot \underbrace{0.0136 \cdot Hb \cdot (S_aO_2 - S_vO_2)}_{\text{oxygen content change}}$$

= stroke volume · oxygen content change

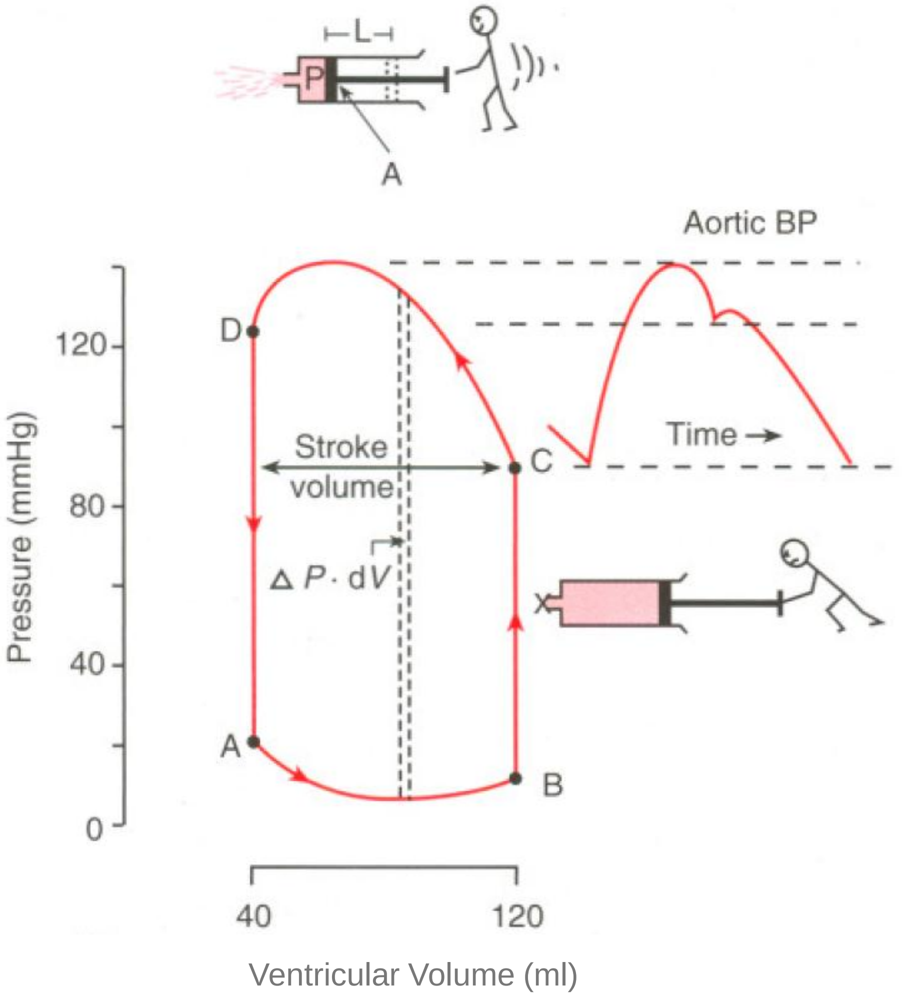
# Oxygen Pulse



# Cardiac Work

Energy = P · V

Work = dP · dV



# Cardiac Work

=

stroke volume ·

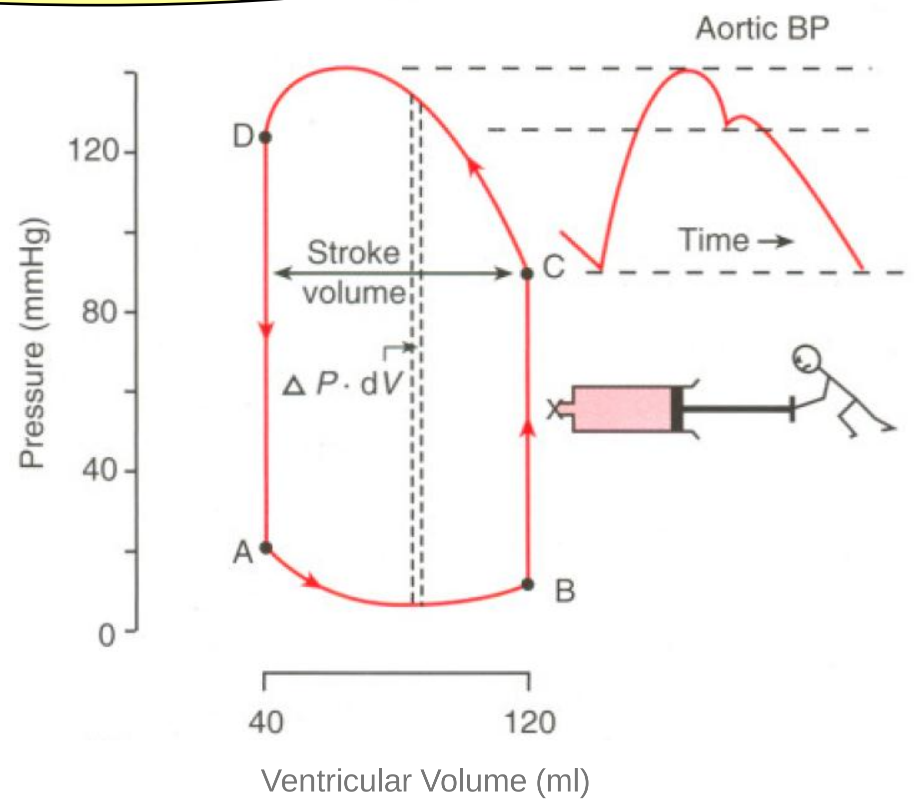
(“mean SBP” – “mean diastolic left ventricular pressure”)

≈

stroke volume · SBP

Energy = P · V

Work = dP · dV



# Cardiac Power

$= \text{work} / \text{time} \quad (= \dot{W})$

$= \text{heart rate} \cdot \text{cardiac work}$

$\approx \text{heart rate} \cdot \text{stroke volume} \cdot \text{SBP}$

$= \text{cardiac output} \cdot \text{SBP}$

$\dot{V}O_2 = \text{cardiac volume} \cdot \text{oxygen content change}$

# Circulatory Power

= cardiac output · oxygen content change · SBP

(= oxygen uptake · SBP)

(= cardiac power · oxygen content change)

$= HF \cdot EF \cdot LVV_{ed} \cdot 0.0136 \cdot Hb \cdot (S_aO_2 - S_vO_2) \cdot RR$

# Circulatory Power

European Heart Journal (2009) **30**, 3000–3006
doi:10.1093/eurheartj/ehp138

EUROPEAN SOCIETY OF CARDIOLOGY®

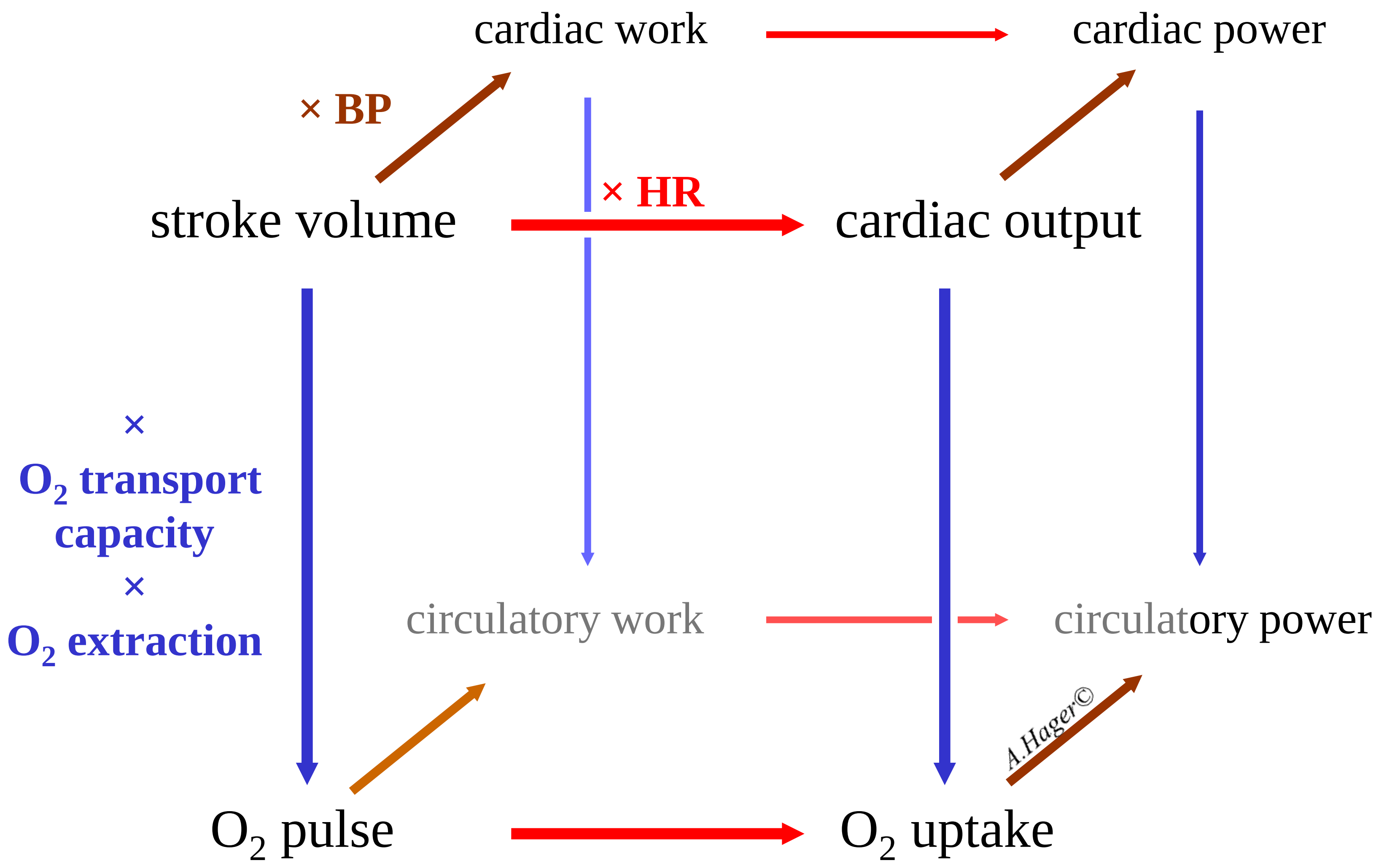
**CLINICAL RESEARCH**
*Heart failure*

## Exercise haemodynamic variables rather than ventilatory efficiency indexes contribute to risk assessment in chronic heart failure patients treated with carvedilol

**Ugo Corrà[1*], Alessandro Mezzani[1], Andrea Giordano[2], Enzo Bosimini[3], and Pantaleo Giannuzzi[1]**

peakSBP, Circulatory Power and oscillatory breathing are the best predictors

# CPET Cube


cardiac work
cardiac power
× BP
× HR
stroke volume
cardiac output
×
$O_2$ transport capacity
×
$O_2$ extraction
circulatory work
circulatory power
A.Hager©
$O_2$ pulse
$O_2$ uptake

# Limitations of the Model

- Mitral / aortic valve regurgitation:
  stroke volume ≠ effective aortic stroke volume
- Cardiac work with only SBP (without volume pressure loops) ?
- Cardiac work without right ventricular work ?
- In congenital heart defects with shunts there is not a single cardiac output: $\dot{Q}_P$, $\dot{Q}_S$
- What is the physical background of „circulatory power / work“ (gas flow · BP) ?

# Limitations of the Model

- Mitral / aortic valve regurgitation:
  stroke volume ≠ effective aortic stroke volume
- Cardiac work with only SBP (without volume pressure loops) ?
- Cardiac work without right ventricular work ?
- In congenital heart defects with shunts there is not a single cardiac output: $\dot{Q}_P$, $\dot{Q}_S$

only oxygen pulse and oxygen uptake
are reliable for all patients