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Energetic metabolism

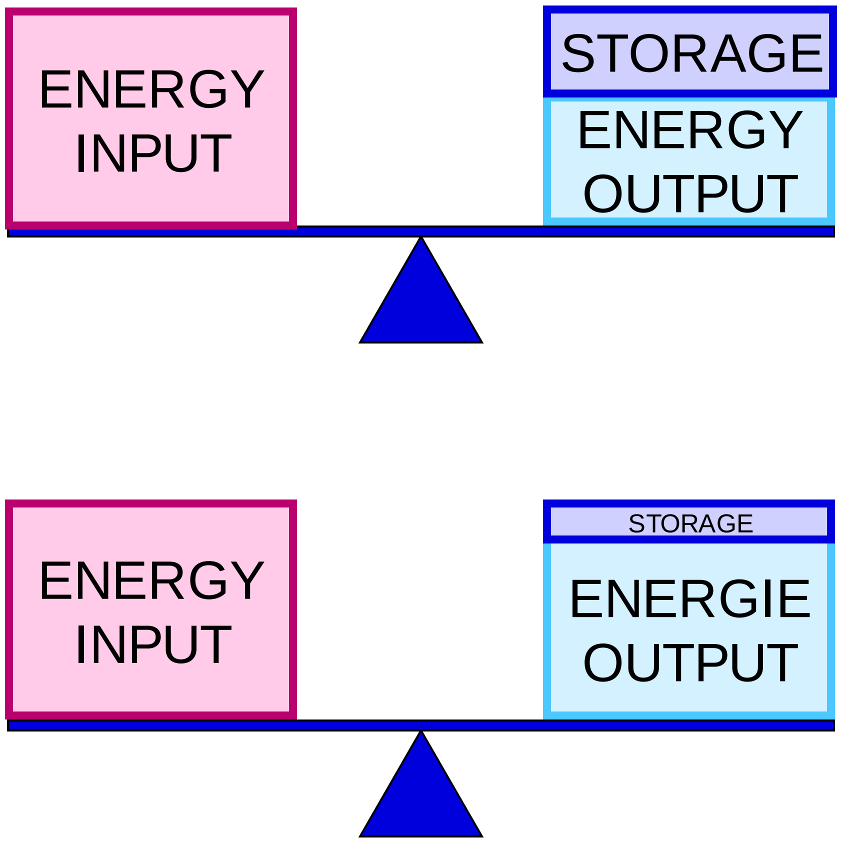
Physiology II lecture (aVLFY0422p)

Tibor Stračina

Energetic metabolism

- Energy input (external an internal sources)
- Energy output
- Energy stored

- **INPUT = OUTPUT + STORAGE**



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Energy input

- Basic substrates: **carbohydrates**, **fats** a **proteins**

- Energy is obtained by burning (oxidizing) substrates
  - carbohydrates 4,1 kcal/g
  - fats 9,3 kcal/g
  - proteins 5,3 kcal/g (in the body 4,1 kcal/g)

- Source of substrates: **food intake** or **mobilization of reserves**

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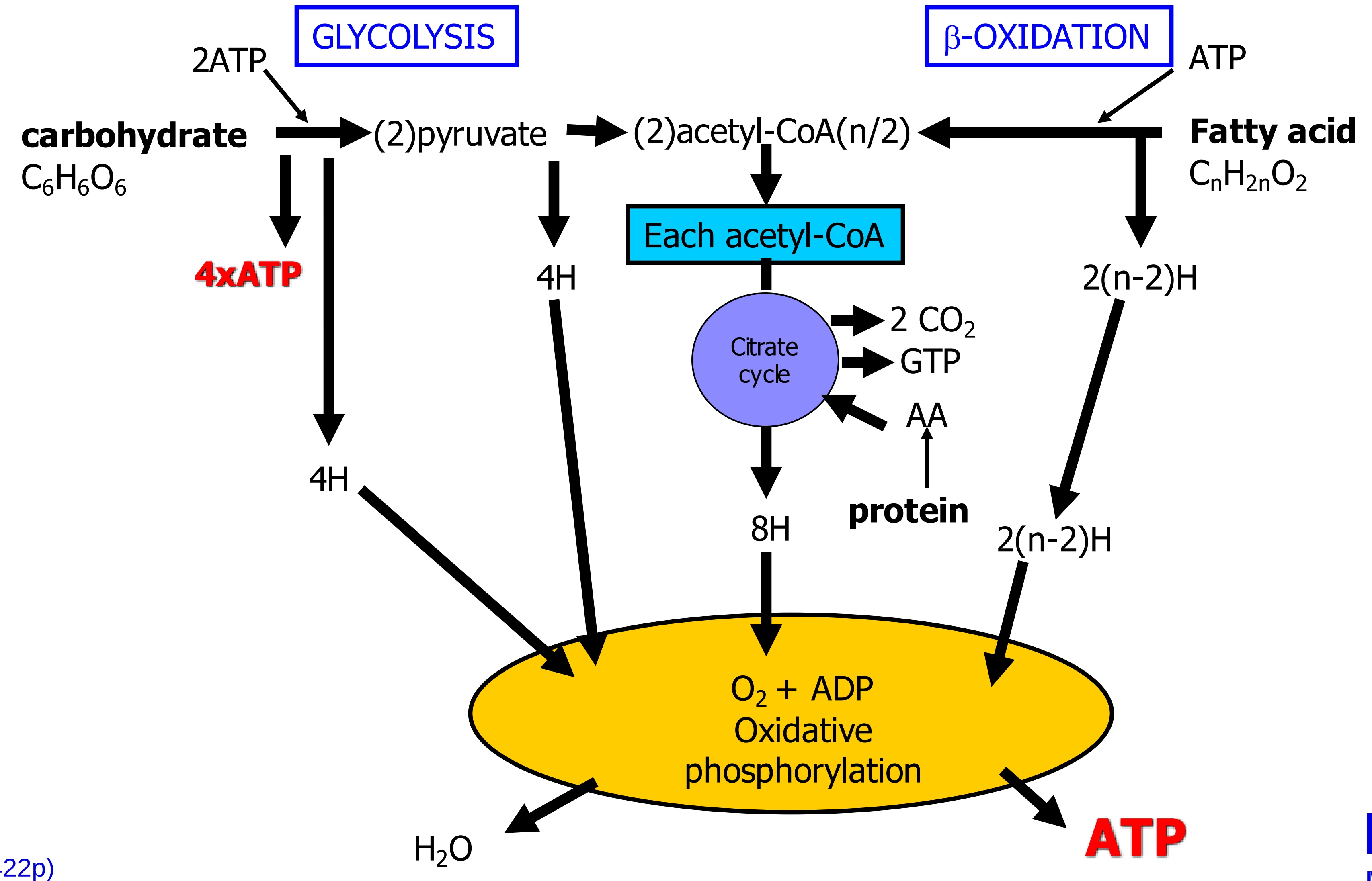
Nutrient burning



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Energy output

- **Basal metabolism** – energy expenditure to maintain homeostasis under basal conditions (vital function) – *~75% of AEE in a person sitting at rest*
- **Specific dynamic effect of food** – a small increase in energy expenditure after eating– *~7% of AEE in a person sitting at rest*
- **Thermoregulation**
- **Spontaneous motoric activity**– *~18% of AEE in a person sitting at rest*
- **Physical work (exercise)**

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Energy output: Basal metabolism

- The smallest amount of energy required to keep homeostasis (vital functions) under **the basal conditions**
  - Minimally 12 hours at rest (no physical activity, no stress)
  - No intense physical activity in the last 24 hours
  - Minimally 12 hours no food intake
  - Thermoneutral environment

- BEE (basal energy expenditure) / BMR (basal metabolic rate)

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Energy output:
Specific dynamic effect of food

- Energy required **to process food** and subsequently absorbed **nutrients**
- Depends on composition of diet
  - For proteins, 30% of energetic content
  - For carbohydrates, 6% of energetic content
  - For fat, only 4% of energetic content
- For mixt diet, ~ 8-10% of energy contained in the food

- Specific dynamic effect of the food = thermic effect of the food

Energy output: Thermoregulation

- All thermoregulatory mechanisms (effectors) **increase energy expenditure**

- Energy is needed to warm up the body – to decrease heat loss and to increase heat production
- Energy is needed to cool down the body – to increase heat loss (and to decrease heat production)

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Energy output: Spontaneous motoric activity and exercise

- Muscle work increases energy expenditure
  - AEE in supine position < AEE standing
- Such increase is proportional to intensity of the activity
  - Sleeping 1.1x BEE; studying 1.4x; fast walking 2.4x; running 8.5-10x BEE
- After high-intensity exercise, energy expenditure is **increased even after the end of the exercise** (tens of minutes to tens of hours)
  - Oxygen debt (lactate metabolism), rebuilding of substrates in muscle (glycogen), reparation of muscles

Energy output: Somatic diseases

- Any somatic "damage" increases energy expenditure
  - After surgery 1.1x BEE; sepsis 1.3x; multiple injuries 1.5x; burns 50-60% 1.8x BEE
- An increase in body temperature by 1°C increases energy expenditure by 10%
  - Core body temperature of 38°C 1.1x BEE; temperature of 40°C 1.3x BEE
- Some diseases – specific effect on energy expenditure
  - Hyperthyroidism, hypothyroidism, chronic inflammatory diseases, tumors

Energy storage and transfers

- Irregular energy intake and output – the need for energy storage

- Ready-to-use stock - macroergic compounds
  - ATP
  - creatin phosphate
  - GTP, CTP, UTP, ITP

- Long-term storage – stock substrates
  - Fat, proteins, glycogen

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Adenosine trisphophate (ATP)

– universal macroergic compound

Synthesis

– circa 63 kg/day (128 mol/day)
– oxidative phosphorylation
– glykolysis – for short-term production only, production of lactate
– conversion from other macroergic compounds (creatine phosphate)

Use

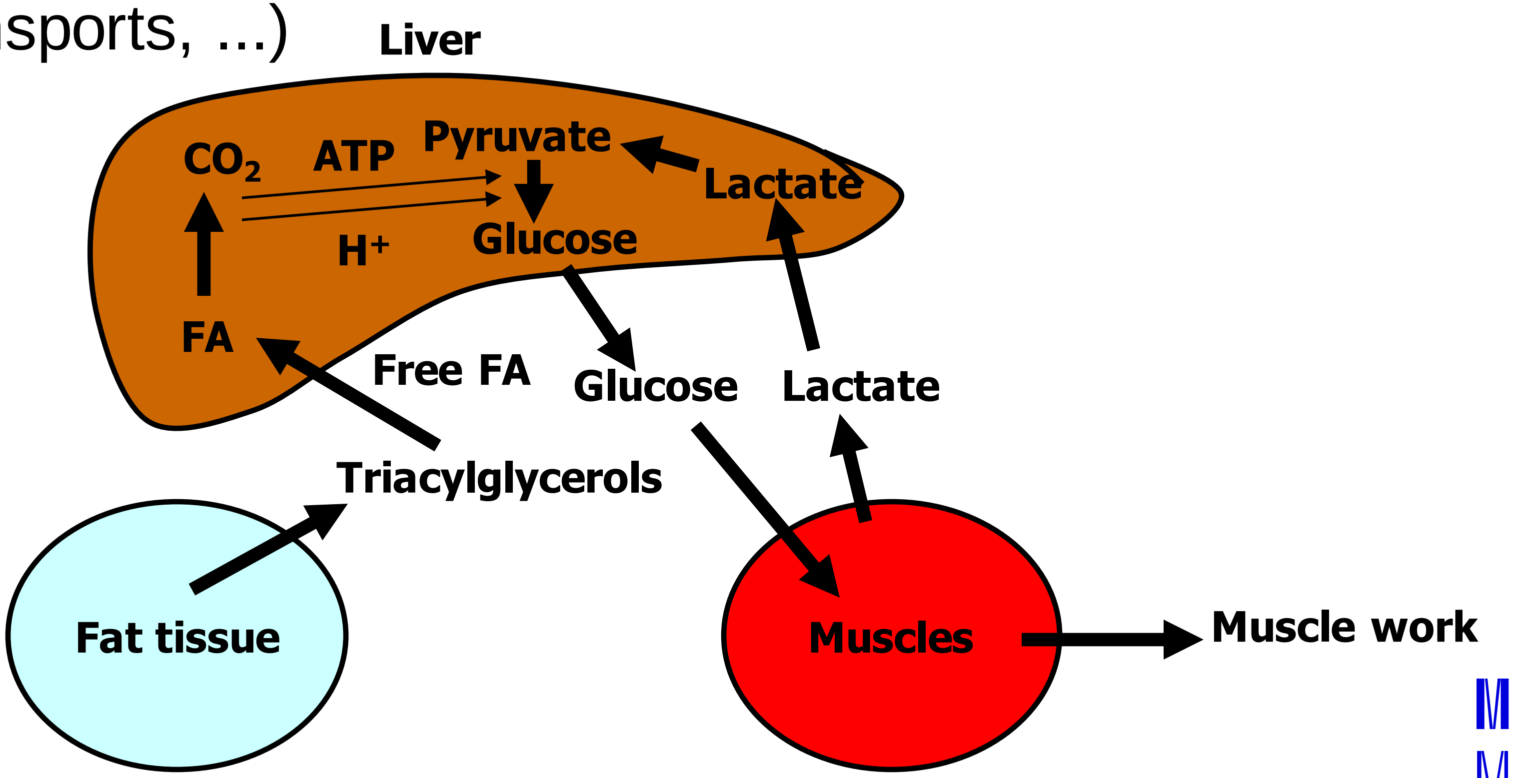
– macroergic bond splitting – efficiency is not 100%, **heat release**

Storage substrates

- Triacylglycerols in fat tissue (75% of stores) – up to 2 months
  - Source: FA from food and esterification with α-glycerol phosphate or synthesis of FA from acetyl-CoA from glycolysis (conversion of sugars into a more efficient energy store = fat)
- Proteins in skeletal muscles and blood plasma (25% of stores)
  - Possible conversion to sugars (glukoneogenesis; stimulated by glucocorticoids)
  - Blood plasma proteins – quickly usable; leads to hypoproteinemia, drop of specific immunity
  - Mobilization of muscle proteins leads to sarcopenia
- Carbohydrates in form of glycogen (less than 1% of stores)
  - Important for the CNS and covering energy demands during short-term physical work
  - Glycogen stored in the liver (about 25%) and in the muscles (about 75%)
  - Liver glycogen - glycogenolysis - release of Glc into the blood
  - Muscle glycogen - use only in muscles (glucose-6-phosphatase is missing)

Energy transfers between organs

- Only in the form of substrates (glucose, FA, AA, lactate, ketons, ...)
- Any transfer of substrates consumes some energy (synthesis and splitting of stock substrates, transports, ...)



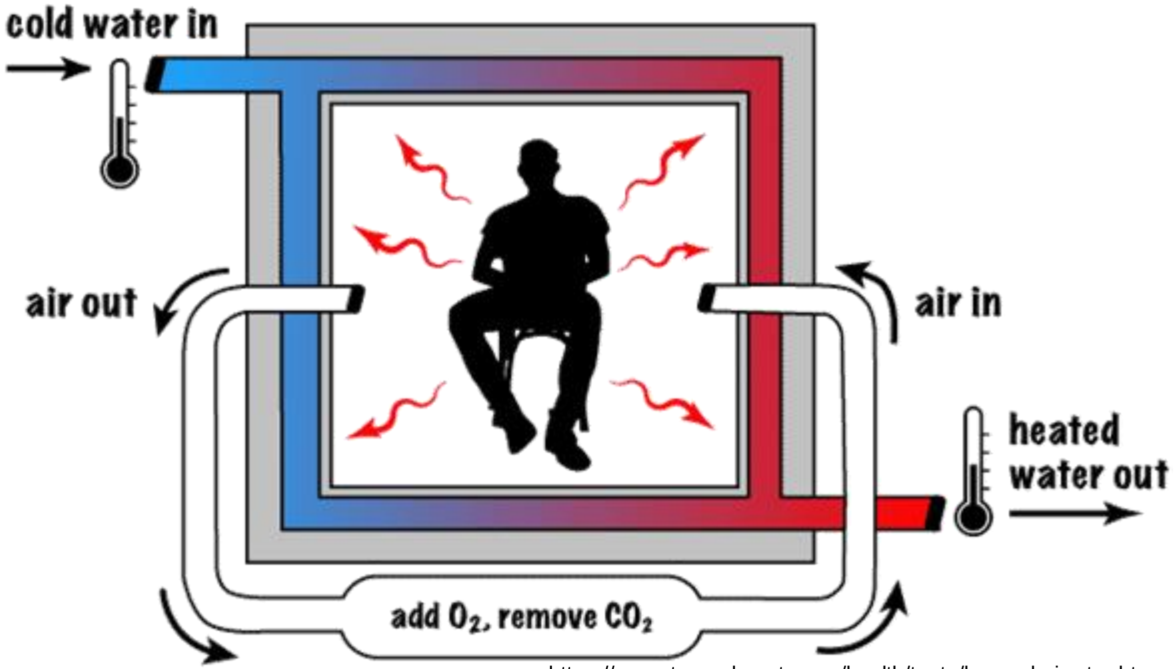
Measurement of energy expenditure

- Precise measurement – **direct** or **indirect calorimetry**
- Calculation based on anthropometric parameters (diverse formulas)
- Estimation based on the level of physical activity

Direct calorimentry

- **Assumption**: when ATP molecule is split, some heat is released
- Heat production ≈ energy expenditure

- **Heat production** is measured directly
- Technically demanding



https://www.topendsports.com/health/tests/bmr-calorimeter.htm

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Indirect calorimentry

- Assumption 1: the amount of ATP consumed is the same as the amount of ATP produced
- Assumption 2: each ATP is produced by consuming O_2 and producing CO_2
- O_2 consumption and/or CO_2 production is measured

- Open vs. closed system (Krogh respirometer - practical exercises)

- Energy equivalent of O_2: the amount of energy released when consuming 1 liter of O_2
  - Sugars: 21.15 kJ/L
  - Fats: 19.6 kJ/L
  - Proteins: 19.65 kJ/L
  - Mixed diet: 20.1 kJ/L

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Respiratory quotient

- The ratio of the volume of CO_2 produced and O_2 consumed

- **RQ = V_{CO_2} / V_{O_2}**

- It provides information about the composition of the substrates that the organism metabolizes
  - Sugars (glucose) RQ = 1
  - Fats RQ = 0.7
  - Mixed sources RQ ≈ 0.85
  - After intensive exercise, RQ > 1 (paying the oxygen debt)

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Calculation of basal energy expenditure (BEE)

- BEE from anthropometric parameters
  - Harris-Benedict formulas:

$$\text{Men: BEE [kcal/day]} = 66{,}5 + (13{,}75 \times \text{m}) + (5{,}003 \times \text{h}) - (6{,}755 \times \text{a})$$

$$\text{Women: BEE [kcal/day]} = 665{,}1 + (9{,}563 \times \text{m}) + (1{,}850 \times \text{h}) - (4{,}676 \times \text{a})$$

  - Mifflina and St. Jeora formulas:

$$\text{Men: BEE [kcal/day]} = (10 \times \text{m}) + (6{,}25 \times \text{h}) - (5 \times \text{a}) + 5$$

$$\text{Women: BEE [kcal/day]} = (10 \times \text{m}) + (6{,}25 \times \text{h}) - (5 \times \text{a}) - 161$$

m – body mass [kg]; h – high [cm]; a – age [years]

- Resting energy expenditure (REE) from body composition
  - Katch-McArdle formula: $\text{REE [kcal/day]} = 370 + 21{,}6 \times \text{FFM}$, *FFM – fat-free mass*

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Physiology of Exercise

Physiology II lecture (aVLFY0422p)

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Work (physical activity, exercise)

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Skeletal muscle

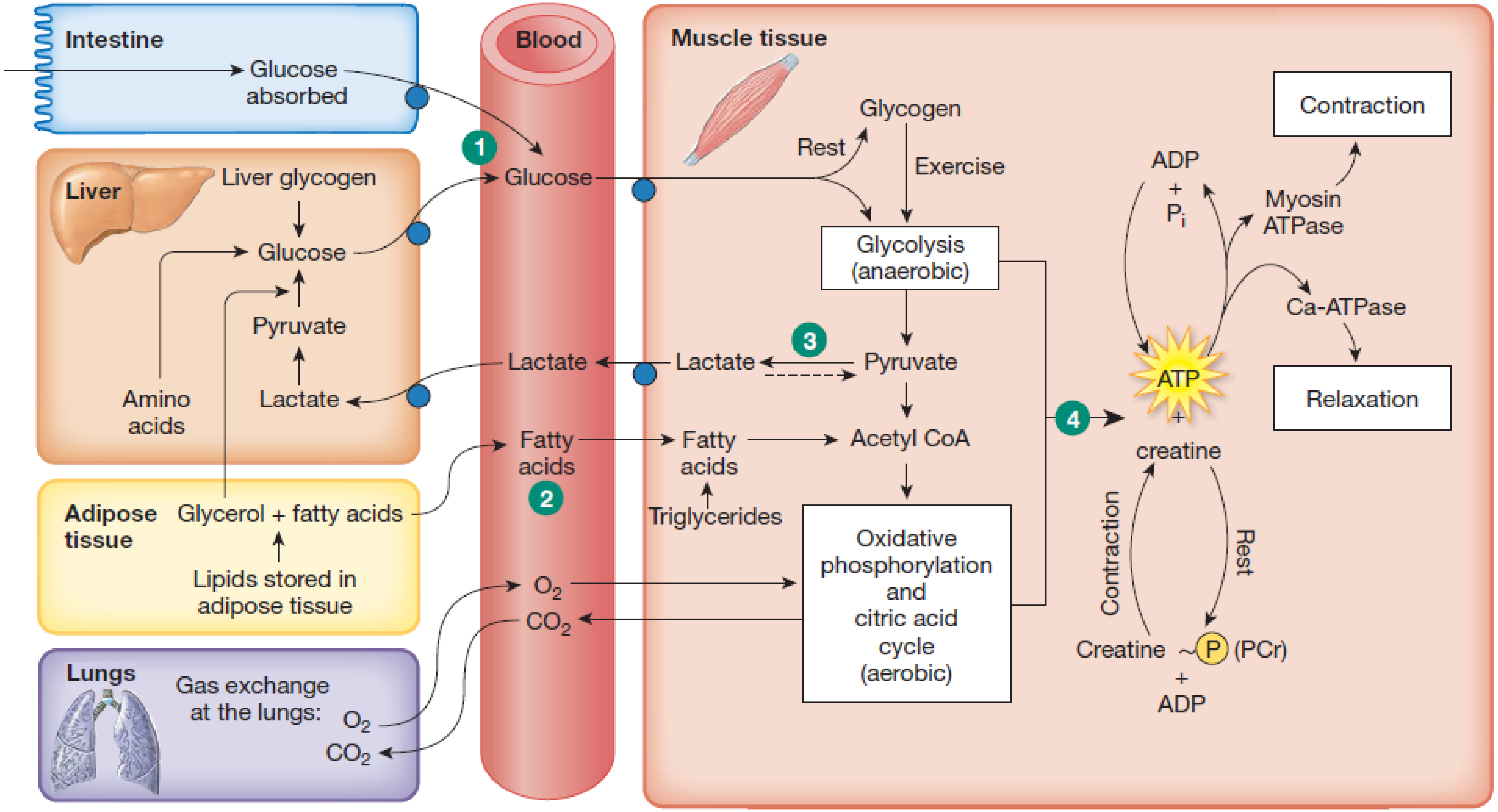
- Contraction: isometric (static work) vs. isotonic (dynamic work)

- Blood flow depends on muscle tension
- Metabolic autoregulation: ↓pO_2; ↑pCO_2; ↓pH; ↑K^+; ↑local temperature

- Metabolism: aerobic vs. anaerobic

- Muscle spindles – muscle tension – afferentation of exercise pressor reflex

Skeletal muscle metabolism



Adopted from: D.U.Silverthorn: Human Physiology (An Integrated Approach)

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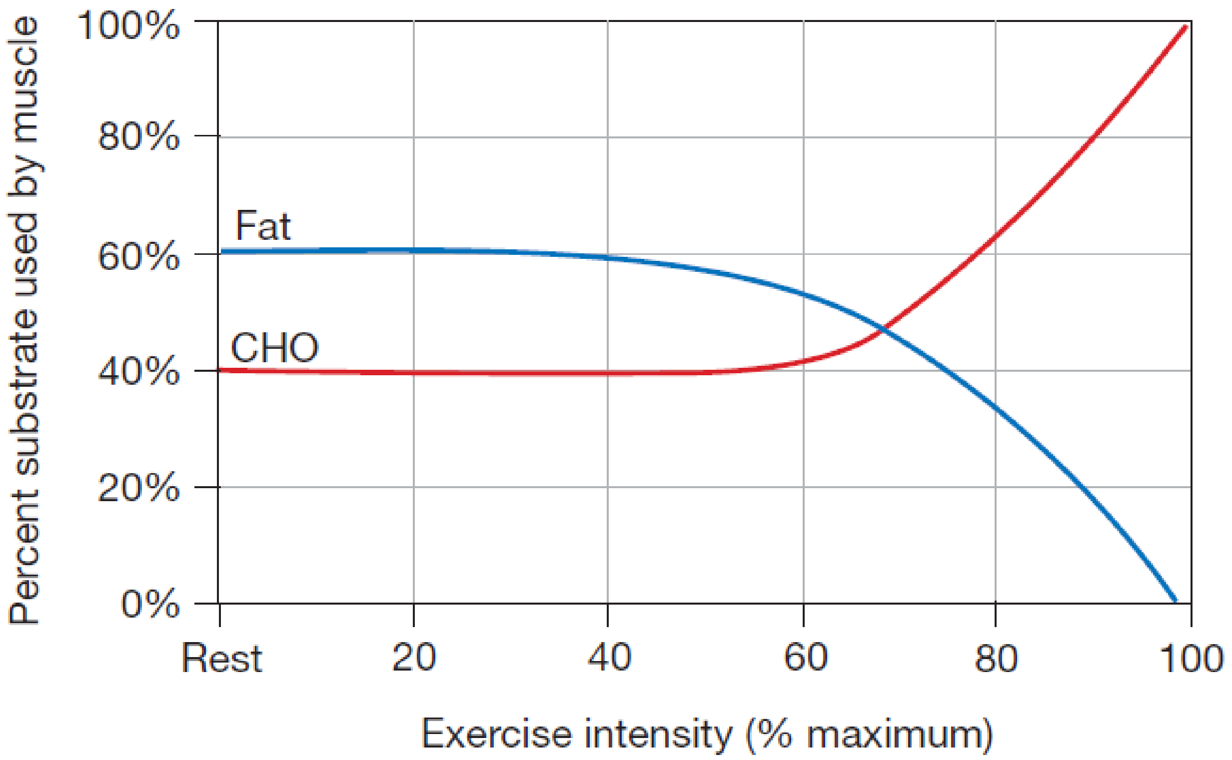
Energy substrate used by skeletal muscle during exercise

- Low-intensity e.: fats
- High-intensity e.: glucose



Data from G. A. Brooks and J. Mercier, *J App Physiol* 76: 2253–2261, 1994

Adopted from: D.U.Silverthorn: Human Physiology (An Integrated Approach)

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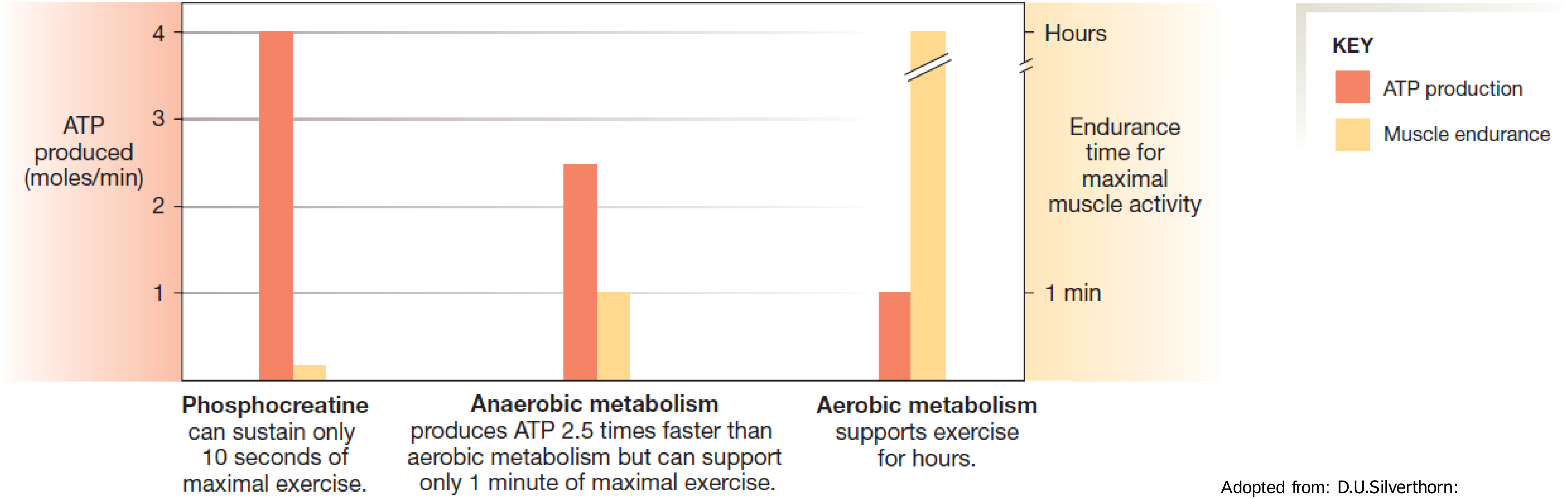
Energy substrate use – aerobic vs. anaerobic



Adopted from: D.U.Silverthorn: Human Physiology (An Integrated Approach)

Reaction of the body to exercise

- Sympathetic NS (ergotropic system)

- Cardiovascular changes
- Respiratory changes
- Metabolic changes

- HOMEOSTASIS

Anticipation of exercise

- Reaction of the body (cardiovascular system)
- Prepare the body for the increased metabolism of the exercising skeletal muscles

- Same as the early response to exercise
- Resembling fight-or-flight reaction

Cardiovascular response to exercise

- Increased cardiac output
- Increased venous return
- Vasoconstriction in inactive skeletal muscles, the GIT, skin, (kidneys)
- Vasodilation in active muscles (metabolic autoregulation)
- Epinephrine release (adrenal medulla)

- Thermoregulation

Increase of cardiac output. Cardiac reserve

- CO = SV x HR (SNS: positive inotropic and chronotropic effect)

- **Cardiac reserve = maximal CO / resting CO (4 – 7)**

- Coronary reserve = maximal CF / resting CF (~3.5)
- Chronotropic reserve = maximal HR / resting HR (3 – 5)
- Volume reserve = maximal SV / resting SV (~1.5)

CO – cardiac output; CF – coronary flow; HR – heart rate; SV – stroke volume

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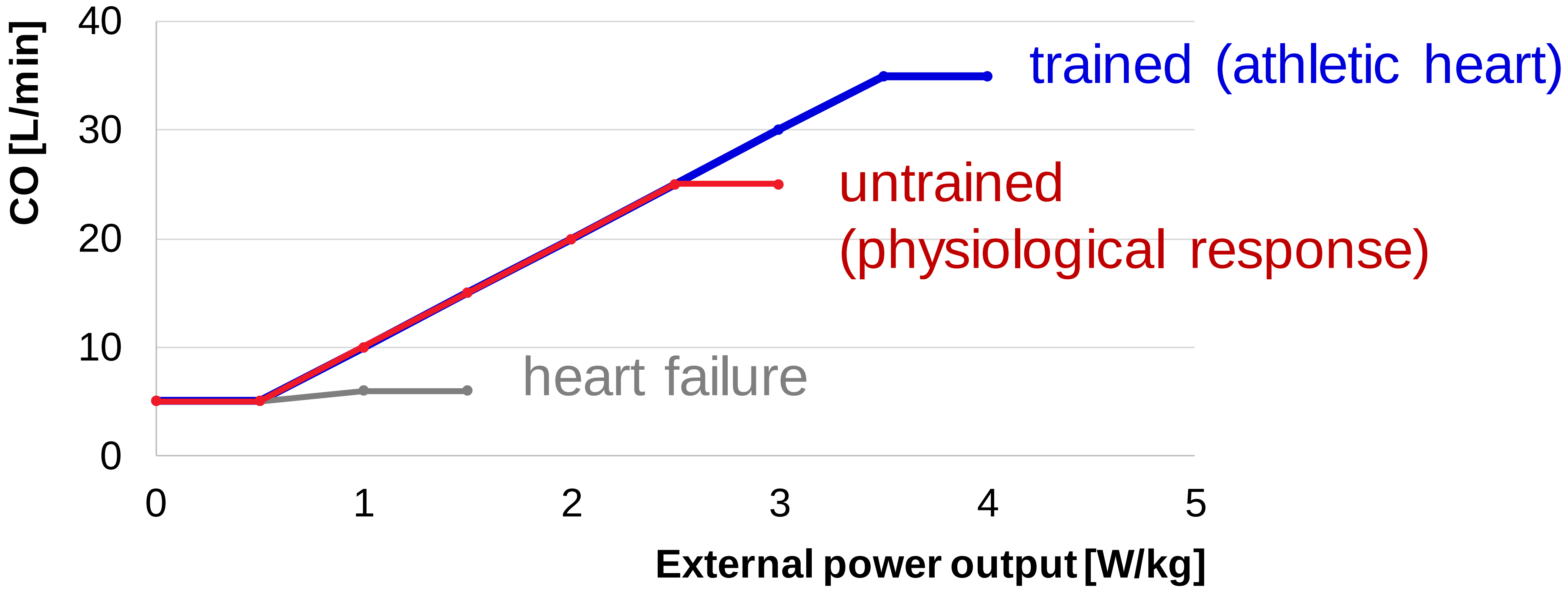
Cardiac reserve in healthy and failing heart



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Changes of arterial blood pressure

PARAMETER	AT REST	DURING EXERCISE	INCREASE (x)
Cardiac output [L/min]	5 – 6	25 (35)	4 – 5 (7) *cardiac reserve*
Heart rate [1/min]	(45) 60-90	190 – 200 (220) *age-dependent*	3 – 5 *chronotropic reserve*
Stroke volume [mL]	75	115	~1.5 *volume reserve*
Systolic BP [mmHg]	120	*static work* ↑ *dynamic work* ↑↑	
Diastolic BP [mmHg]	70	*static work* ↑↑↑ *dynamic work* — / ↓	
Mean arterial P (MAP) [mmHg]	~90	*static work* ↑ *dynamic work* — / ↑	
Muscle persufion [mL/min/100g]	2 – 4	60 – 120 (180) *static vs. dynamic work*	30 (10% COmax)

Respiratory response to exercise

- Respiratory centre - ↑ ventilation
  - chemoreceptors: ↑ pCO_2 + ↓ pH
  - proprioceptors in lungs

- Sympathetic stimulation (stress – anticipation)

Respiratory response to exercise

PARAMETER	AT REST	DURING EXERCISE	INCREASE (x)
Ventilation [L/min]	6 – 12	90 – 120	15 – 20 *respiratory reserve*
Breathing frequency [1/min]	12 – 16	40 – 60	4 – 5
Tidal volume (V_T) [mL]	0.5 – 0.75	~2	3 – 4
Pulmonary artery blood flow [mL/min]	5 – 6	25 – 35	4 – 6
O_2 uptake (V_{O2}) [mL/min)]	250 – 300	~3000	10 – 12 (25)
CO_2 production [mL/min]	~200	~8000	~40

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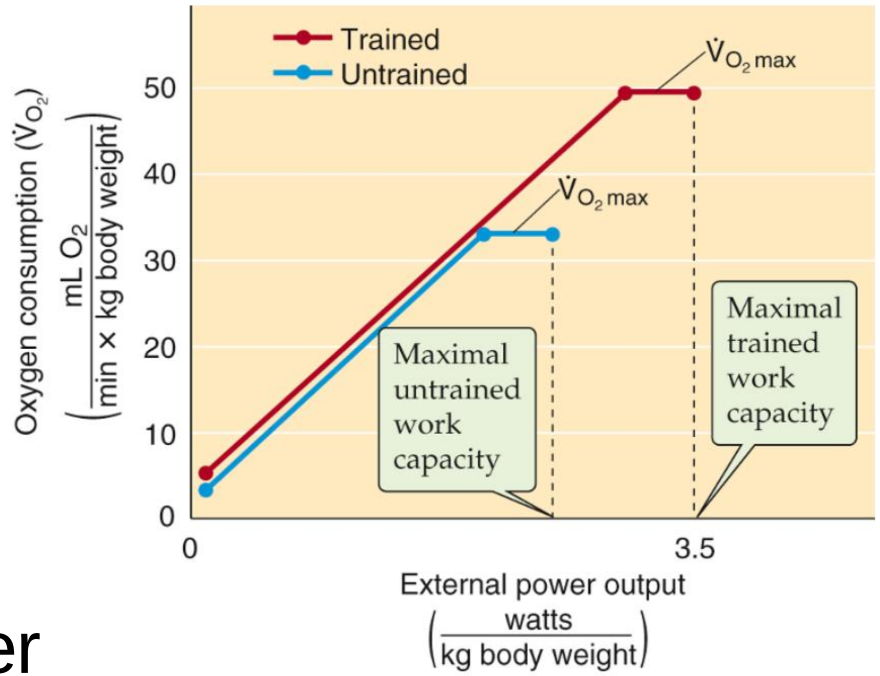
Adopted from: https://studentconsult.inkling.com/read/boron-medical-physiology-3e/chapter-60/figure-60-6

Oxygen uptake by lungs



- Spiroergometry
- Resting V_{O2}: **~3.6** mL O_2 / (min x kg)
- **$V_{O2\ max}$** – objective index for aerobic power
  - untrained middle age person: **30 – 40** mL O_2 / (min x kg)
  - elite endurance athletes: **80 – 90** mL O_2 / (min x kg)
  - HF / COPD patients: **10 – 20** mL O_2 / (min x kg)

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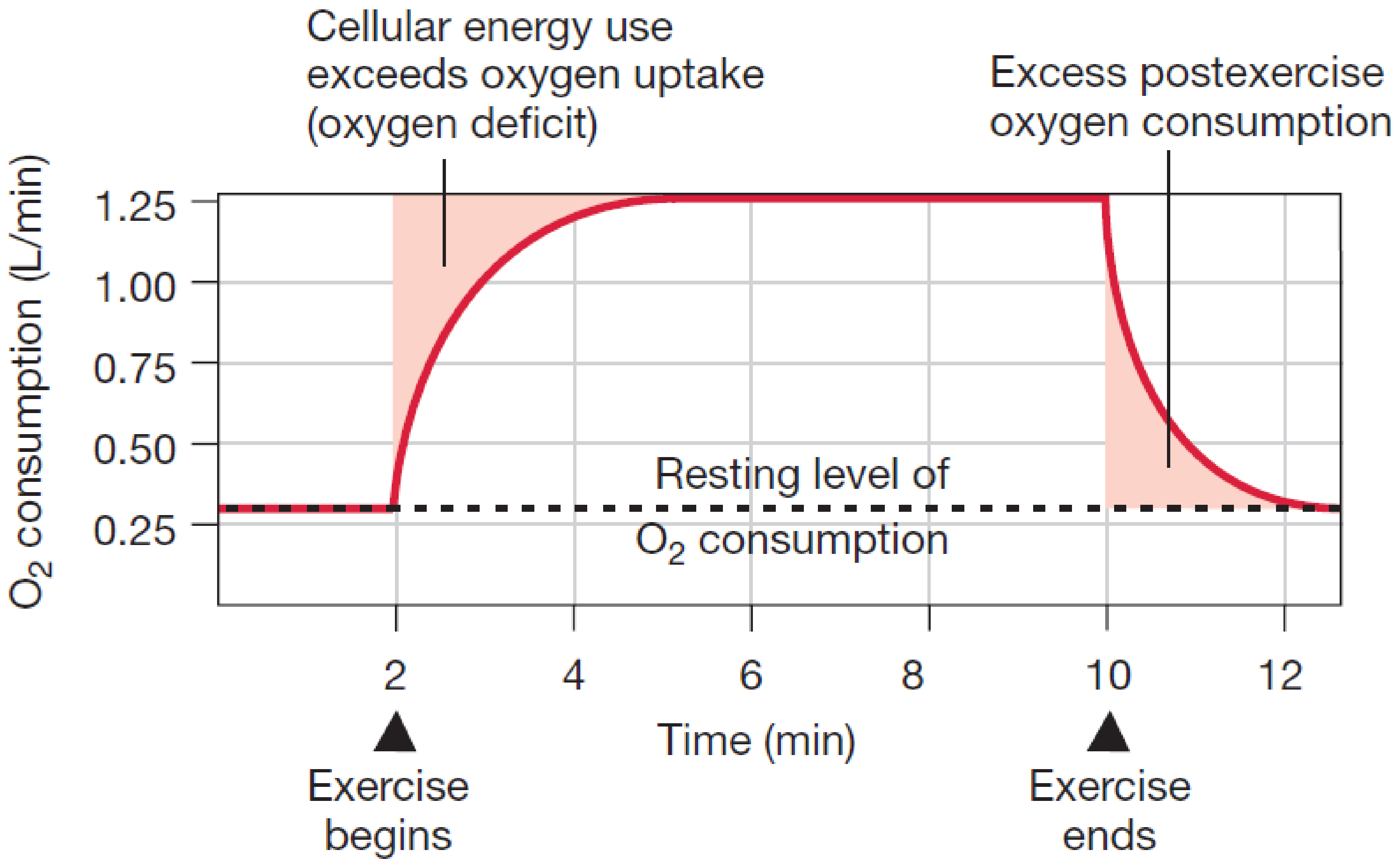
Determinants of $V_{O_2\,max}$

1. Uptake of O_2 by the lungs
   – pulmonary ventilation
2. O_2 delivery to the muscles
   – blood flow (pressure gradient – cardiac output x resistence)
   – haemoglobin concentration
3. Extraction of O_2 from blood by muscle
   – pO_2 gradient: blood-mitochondria

Oxygen consumption during exercise

Adopted from: D.U.Silverthorn: Human Physiology (An Integrated Approach)

– Oxygen debt



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Testing of fitness

- (Spiro)ergometry
- Standardised workload
  - accurate: in W/kg
  - comparative (simple, inaccurate): in MET
    - metabolic equivalent (actual MR / resting MR)
    - 1 MET = uptake of 3.5 ml O_2/kg.min ≈ 4.31 kJ/kg.h
    - sleeping ≈ 0.9 MET; slow walking ≈ 3-4 MET; fast running ≈ 16 MET

Indexes of fitness

- W_{170} [W/kg]
- $V_{O_2 max}$ [mL O_2 / (min x kg)]
- Aerobic / anaerobic threshold

- Fatigue
- Training
- Adaptation to exercise