Energetic metabolism

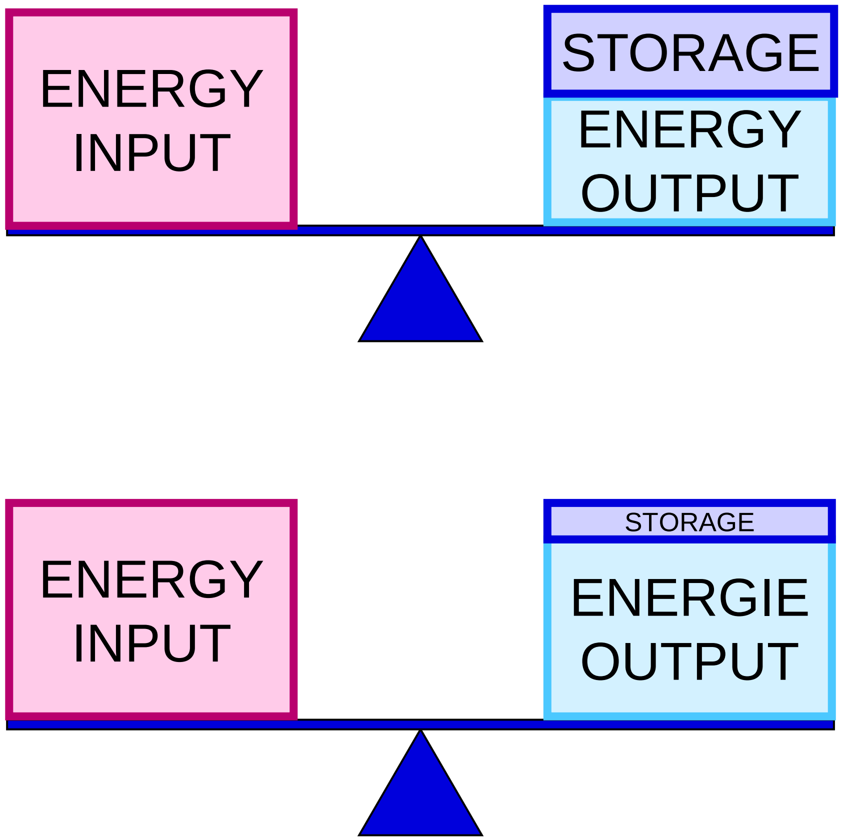
Physiology II lecture (aZLFY0422p)

Tibor Stračina

Energetic metabolism

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

- **INPUT = OUTPUT + STORAGE**



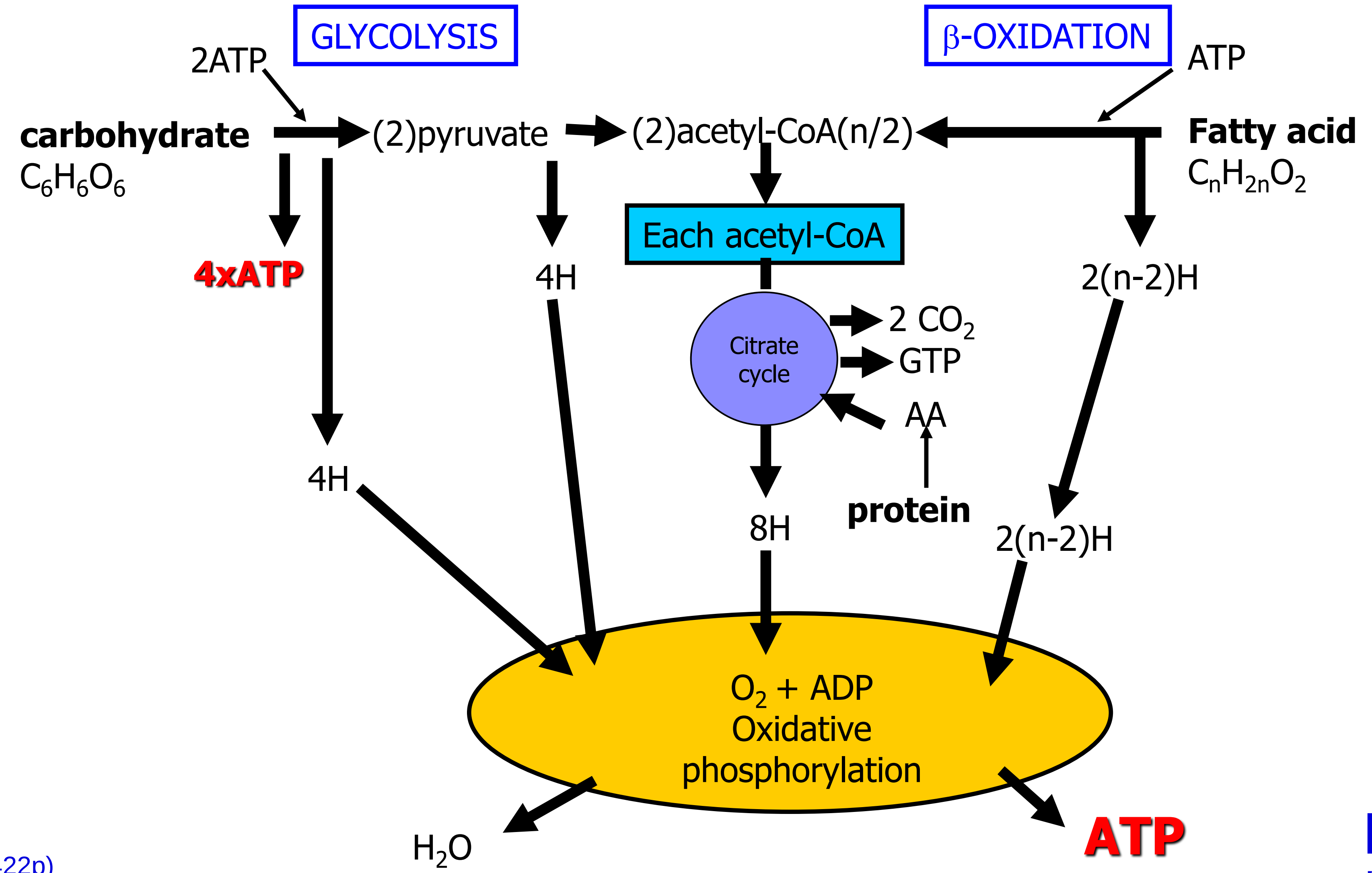
Energy input

- 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**

Nutrient burning



MUNI MED

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)**

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

MUNI
MED

Adenosine trisphophate (ATP)

- universal macroergic compound

Synthetis

- circa 63 kg/day (128 mol/day)
- oxidative phosphorylation
- glykolysis – for short-term production only, production of lactate

Use

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

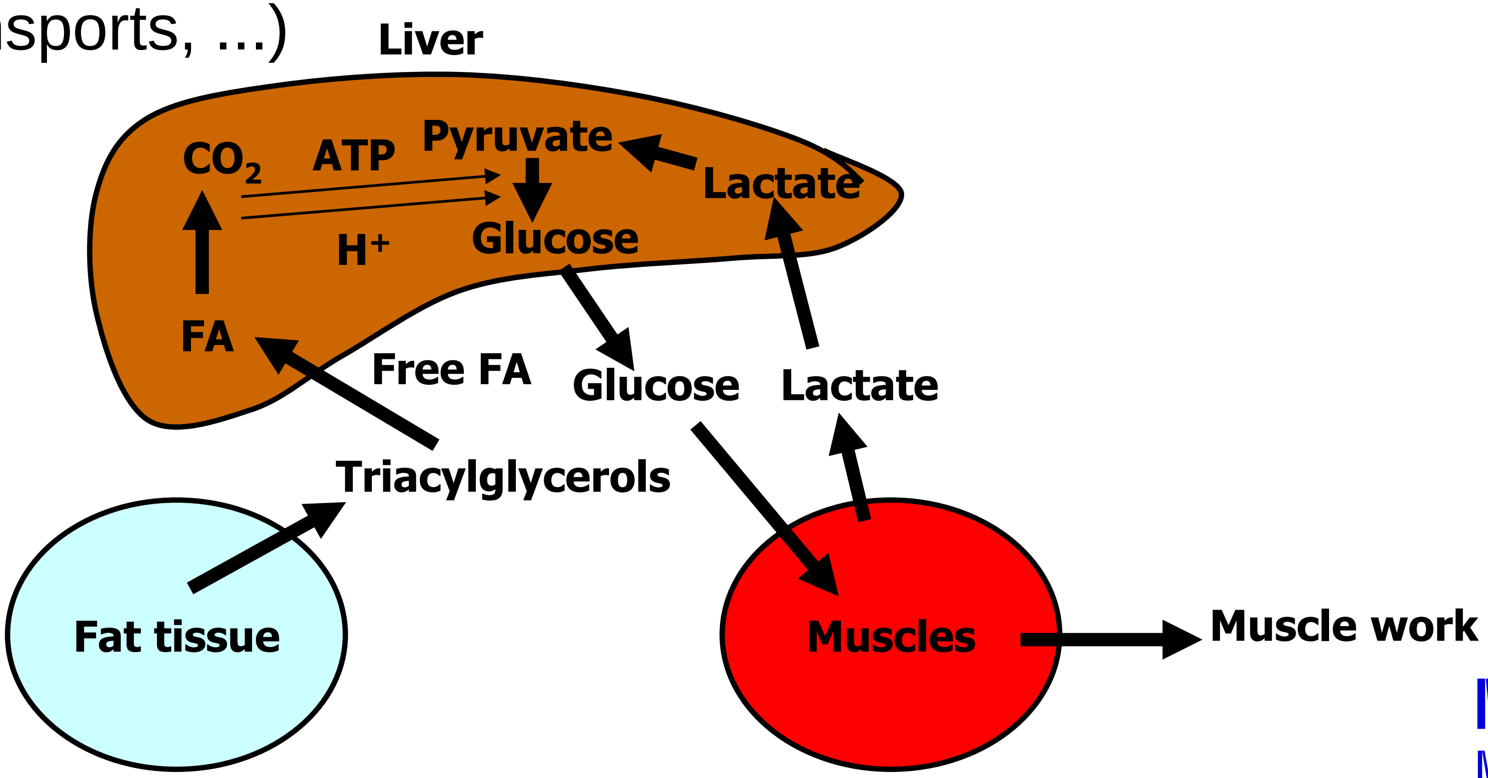
MUNI MED

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

- Direct calorimetry

- Indirect calorimetry (*PRACTICE!!!*)
  - Consumption of O_2 – **energetic equivalent of oxygen** (amount of energy released when consuming 1 liter of O_2)

    carbohydrate: 21,15 kJ/l

    fat: 19,6 kJ/l

    protein: 19,65 kJ/l

    mixed diet: 20,1 kJ/l

  - Consumption of O_2 + production of CO_2 – **respiratory quotient** ($RQ = V_{CO_2} / V_{O_2}$)

    carbohydrate: RQ = 1

    fat: RQ = 0,7

    protein: RQ = 0,8 – 0,9

Physiology of Exercise

Physiology II lecture (aZLFY0422p)

Tibor Stračina

Work (physical activity, exercise)

Source: www.freepik.com. Photos created by freepik and standret

Skeletal muscle

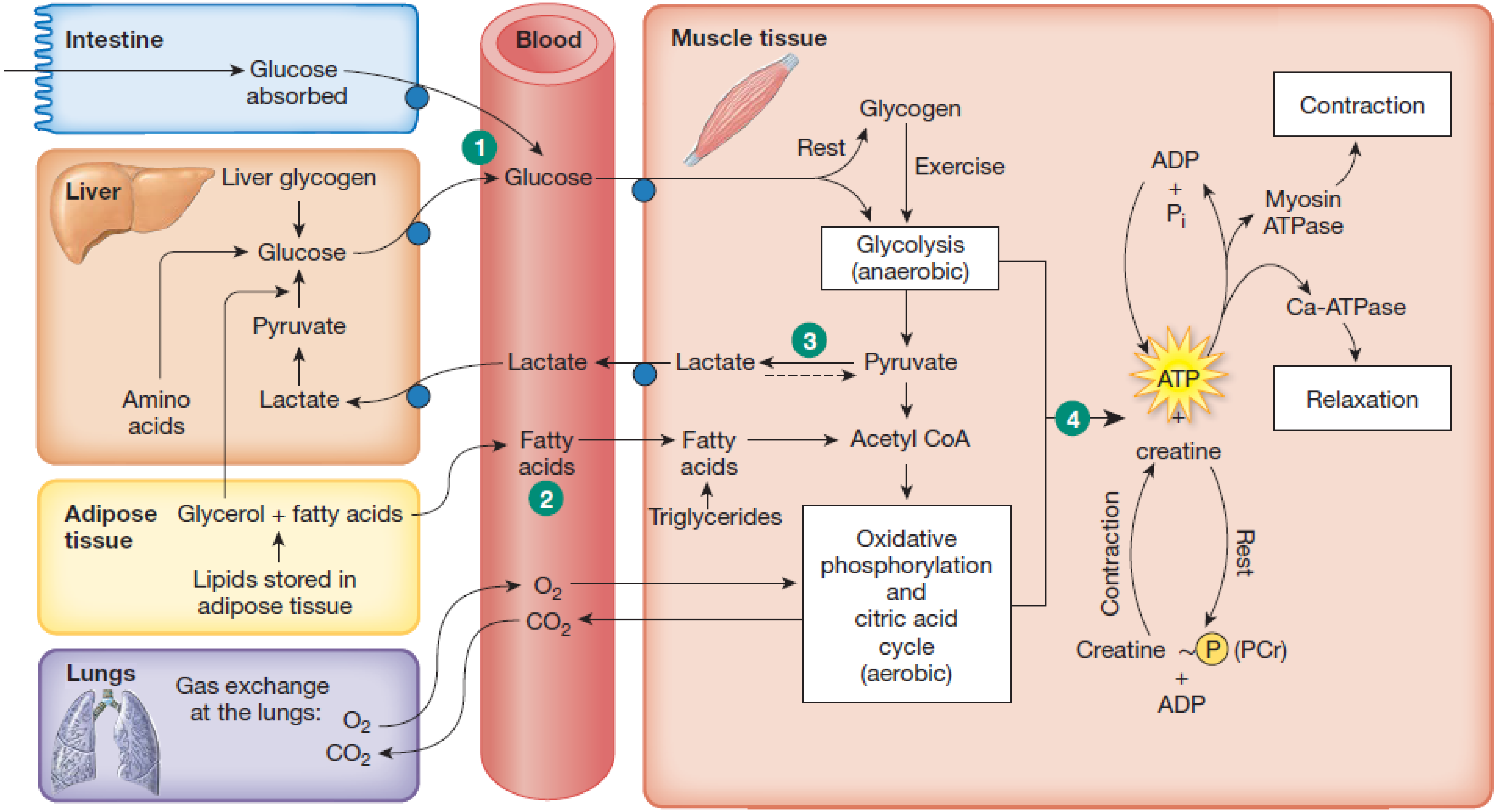
- Contraction: isometric (static work) vs. isotonic (dynamic work)

- 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)

MUNI MED

Reaction of the body to exercise

- Sympathetic NS (ergotropic system)

- Cardiovascular changes
- Respiratory changes
- Metabolic changes

- HOMEOSTASIS

MUNI MED

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
- Vasoconstriction in inactive skeletal muscles, the GIT, skin, (kidneys)
- Vasodilation in active muscles (metabolic autoregulation)
- Increased venous return
- Histamine release
- 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

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)

MUNI MED

Respiratory response to exercise

- Respiratory centre - ↑ ventilation
  - chemoreceptors: ↑ $pCO2$ + ↓ pH
  - proprioceptors in lungs

- Sympathetic stimulation (stress – anticipation)

MUNI MED

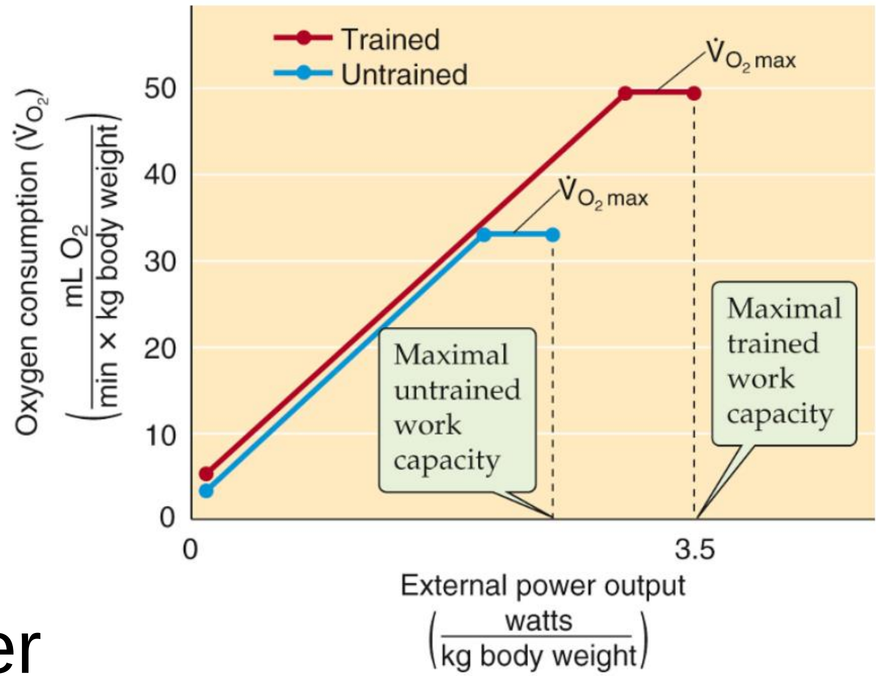
Respiratory response to exercise

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

MUNI MED

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)

MUNI MED

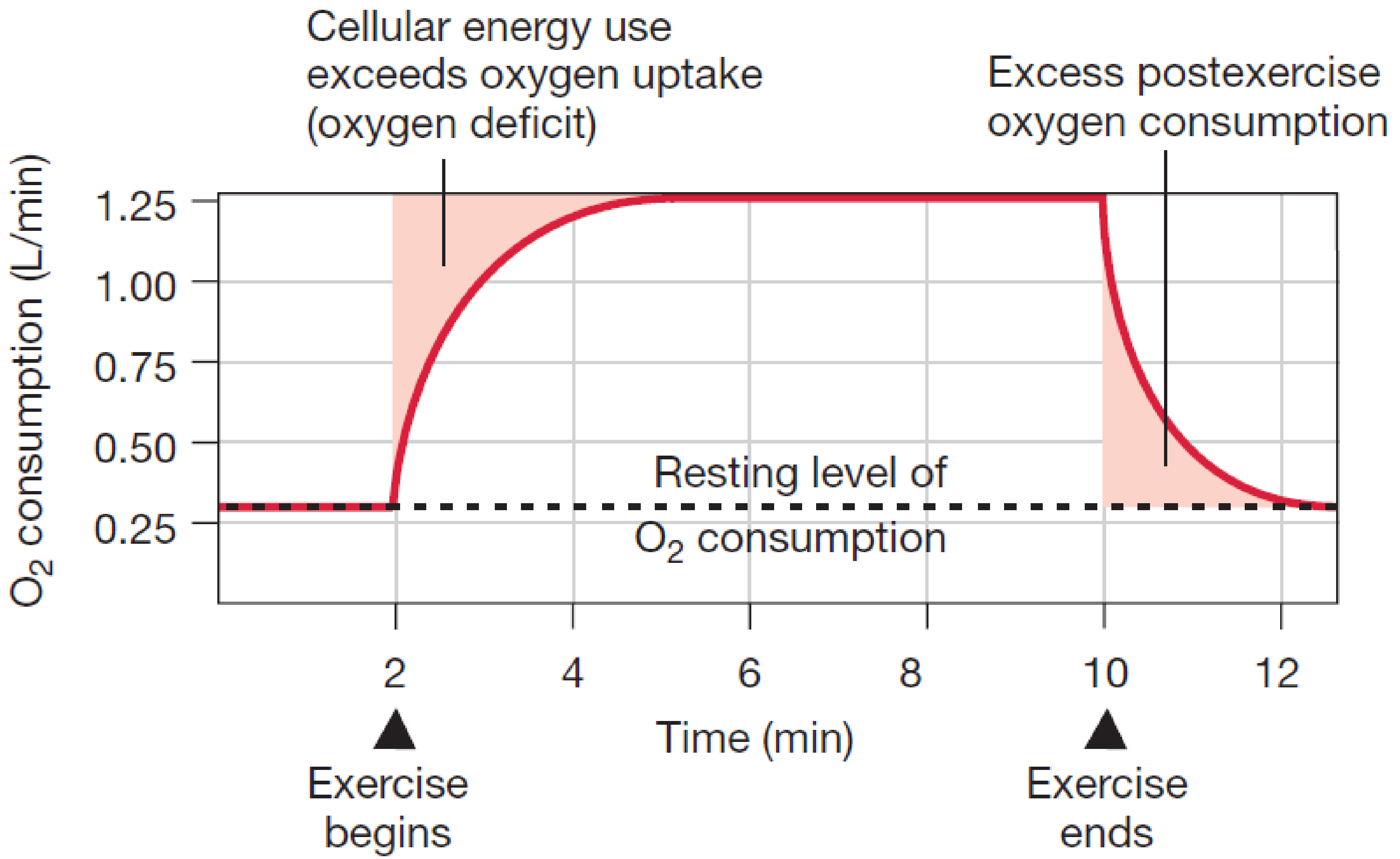
Determinants of $V_{O2\ max}$

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

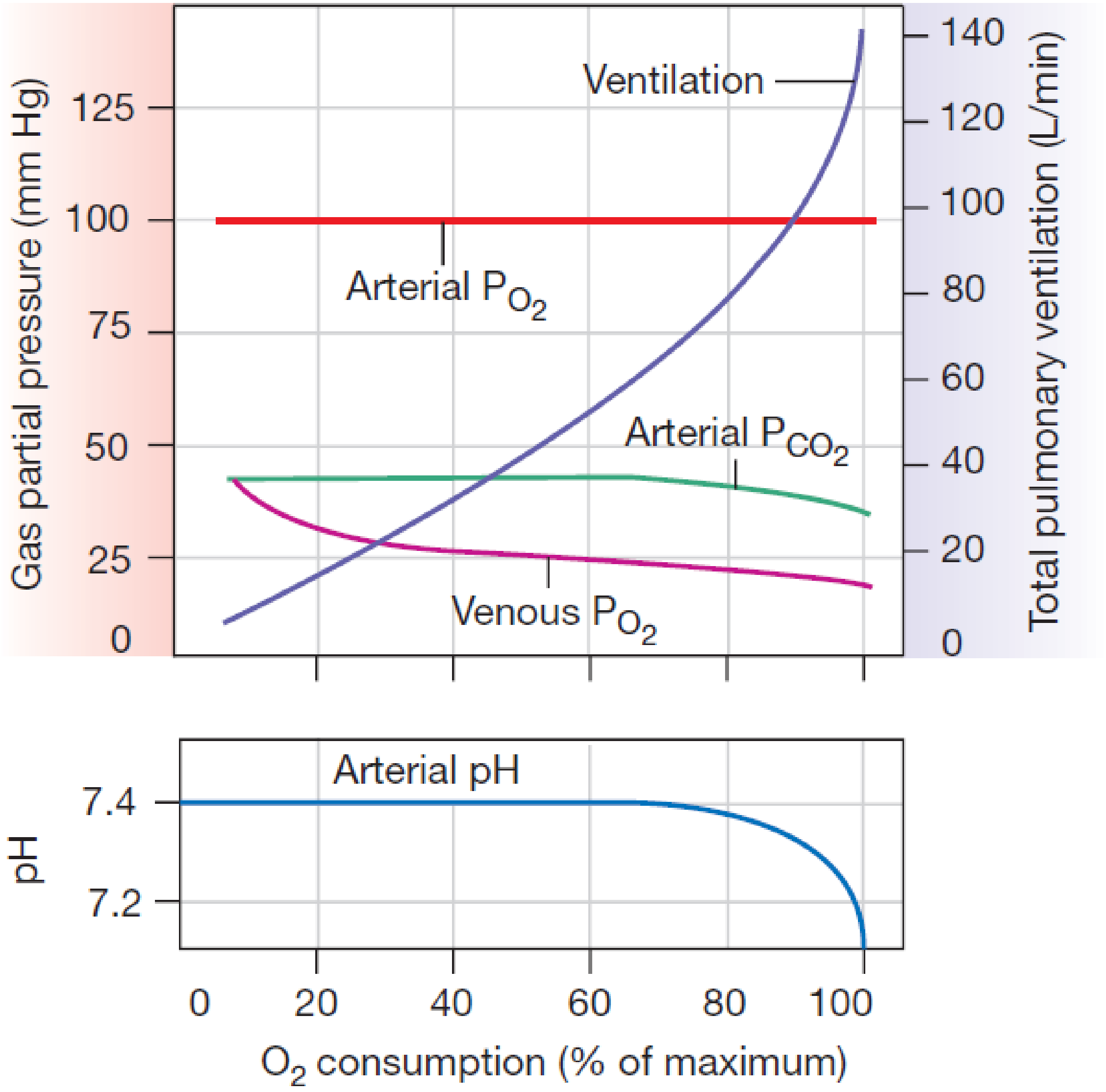
Oxygen consumption during exercise

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

- Oxygen debt



Blood gases during exercise

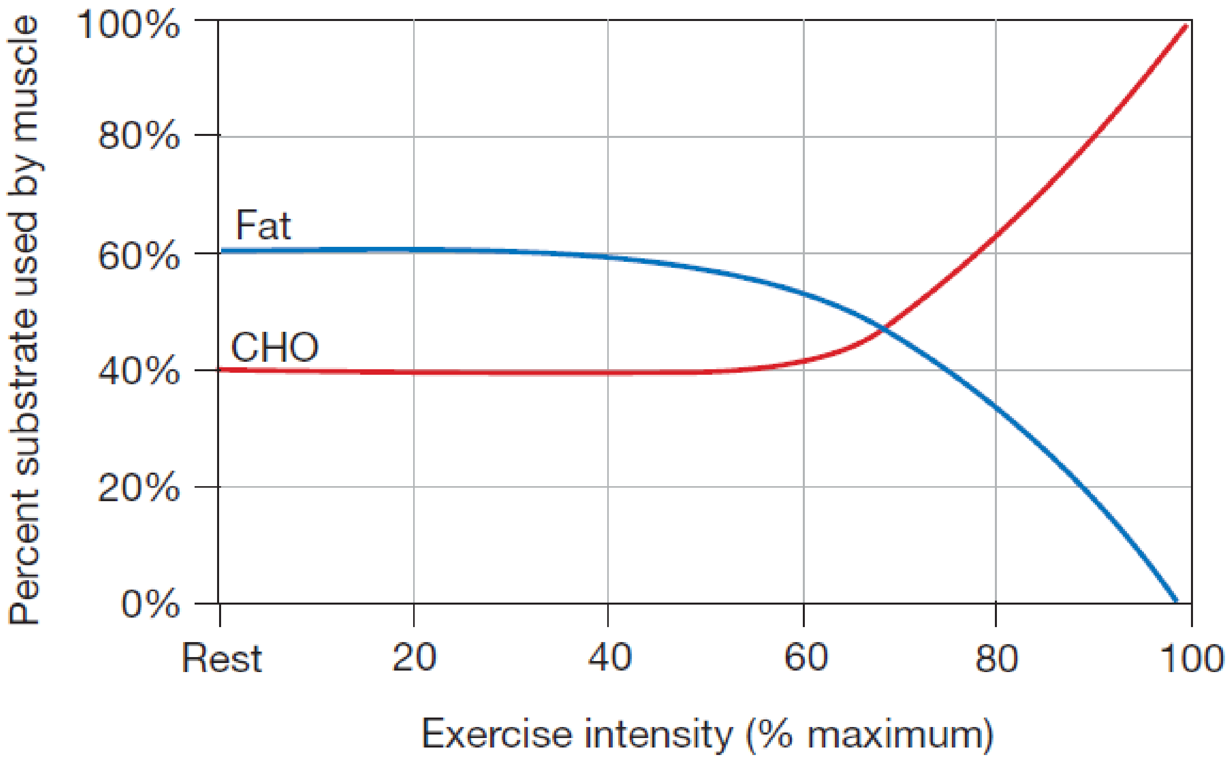


Adopted from: D.U.Silverthorn: Human Physiology (An Integrated Approach)

MUNI MED

Energy substrate used by skeletal muscle during exercise

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

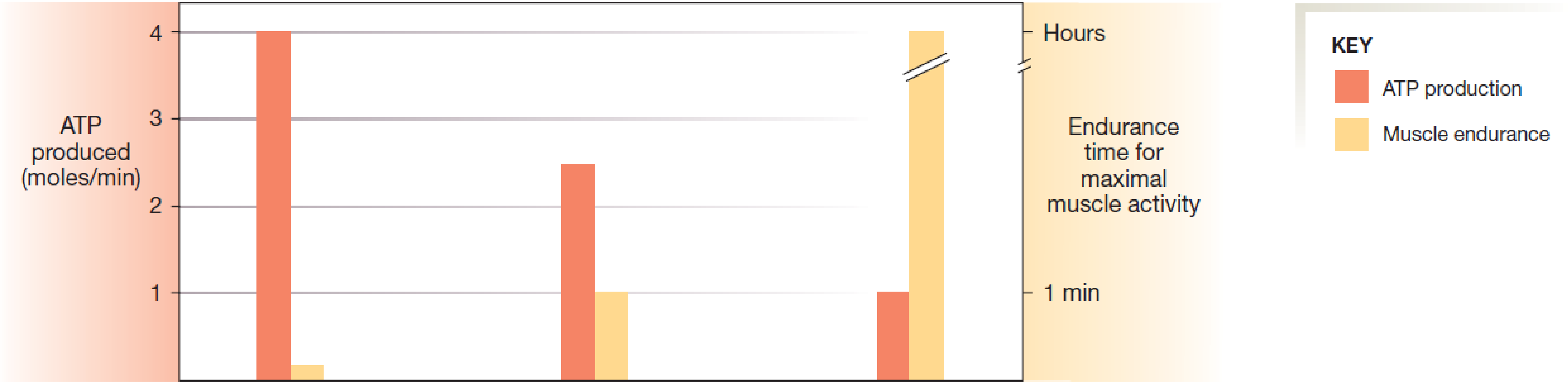


Data from G. A. Brooks and J. Mercier, *J App Physiol* 76: 2253–2261, 1994

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

MUNI MED

Energy substrate use – aerobic vs. anaerobic



Phosphocreatine can sustain only 10 seconds of maximal exercise.

Anaerobic metabolism produces ATP 2.5 times faster than aerobic metabolism but can support only 1 minute of maximal exercise.

Aerobic metabolism supports exercise for hours.

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

MUNI MED

Testing of fitness

- Spiroergometry
- 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]
- $V_{O2\ max}$ [mL O_2 / (min x kg)]
- Aerobic / anaerobic threshold

- Fatigue
- Training
- Adaptation to exercise

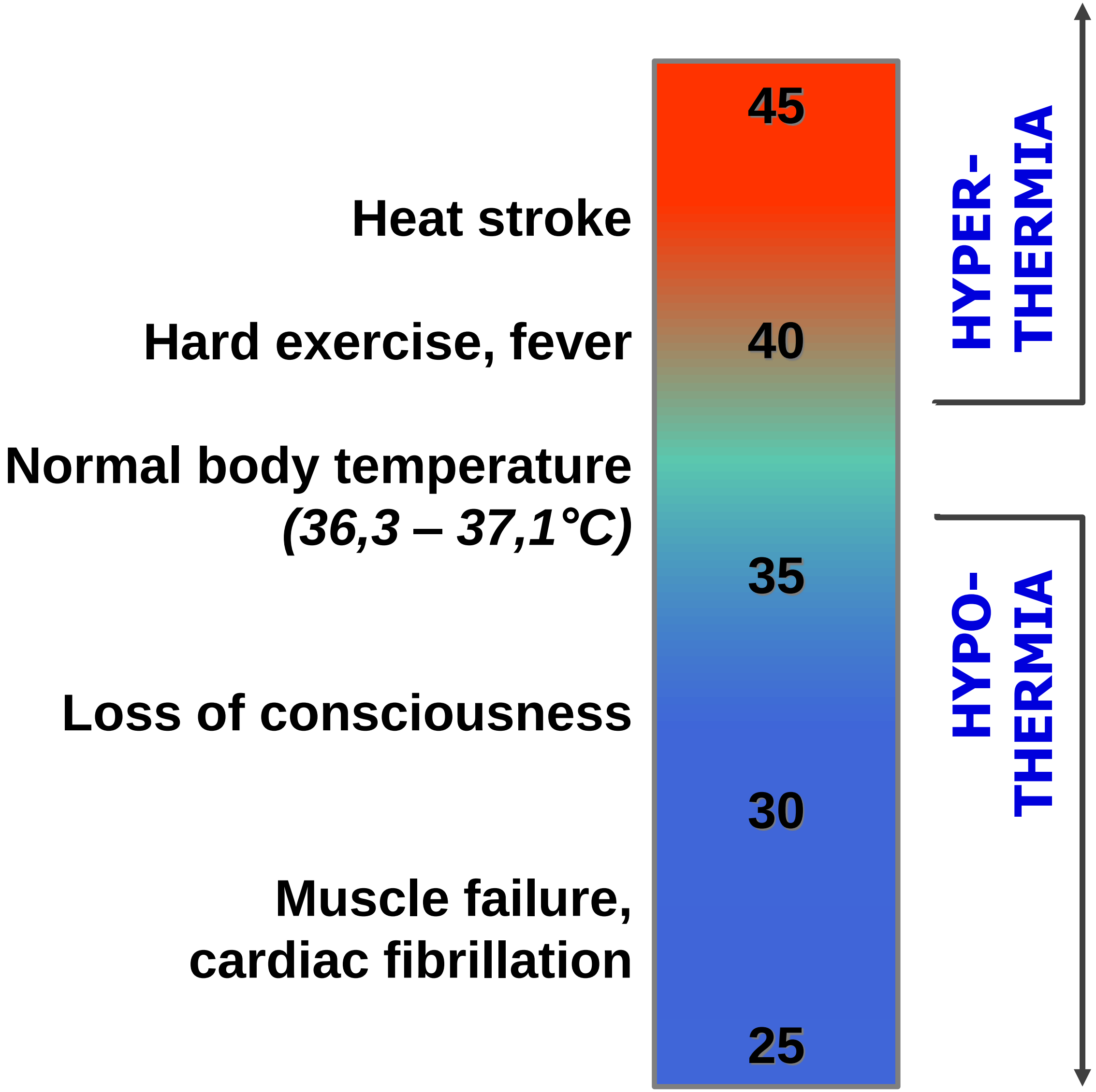
MUNI MED

Thermoregulation

Physiology II lecture (aZLFY0422p)

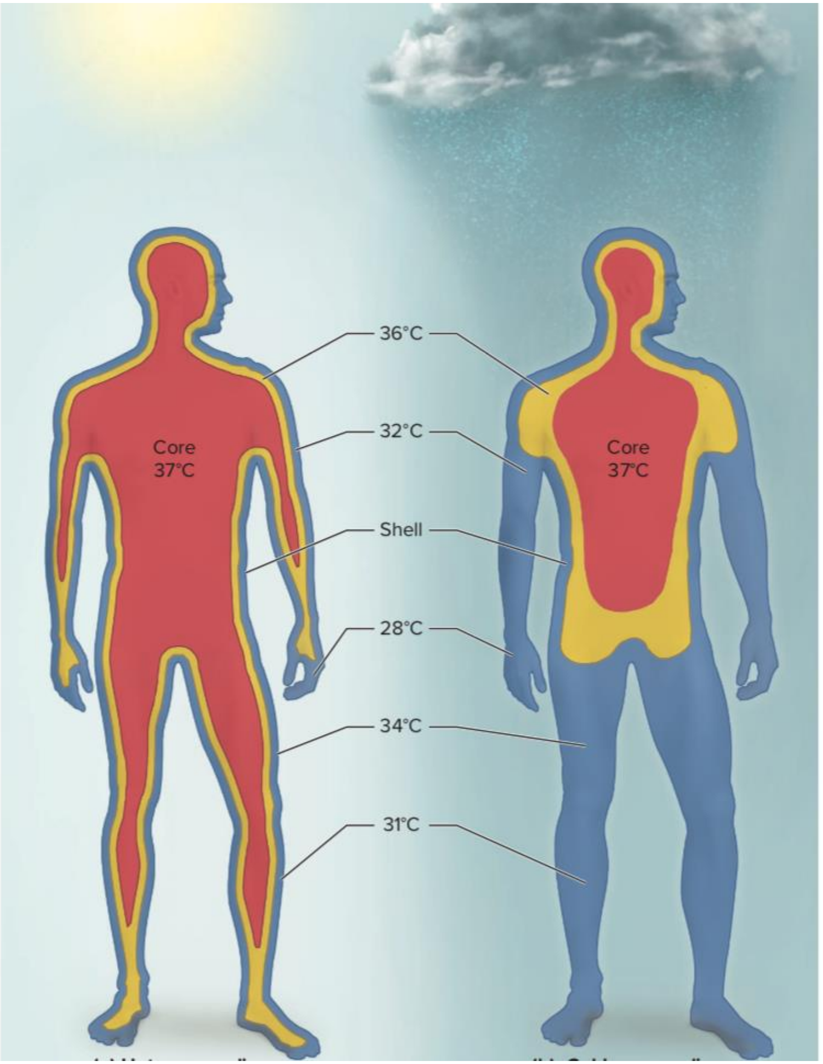
Tibor Stračina

Body temperature – homeostatic parameter



Body core vs. shell

- homeotherms vs. poikilotherms
- Body core temperature – regulated within certain (narrow) range
- Skin temperature (shell) – more variable (ambient t., core body t.)

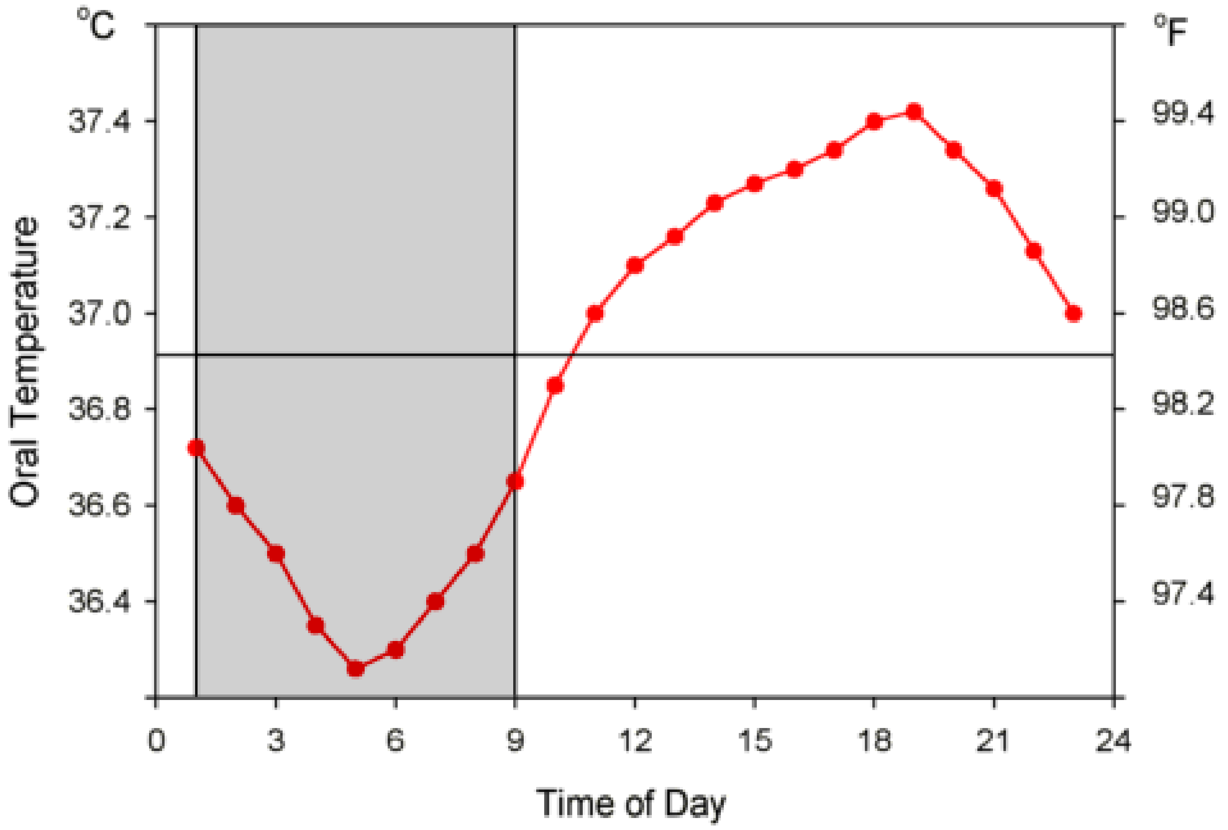


Adopted from: K.S. Saladin, *Anatomy & Physiology—The Unity of Form and Function*, 8th ed. (McGraw-Hill, 2018)

MUNI
MED

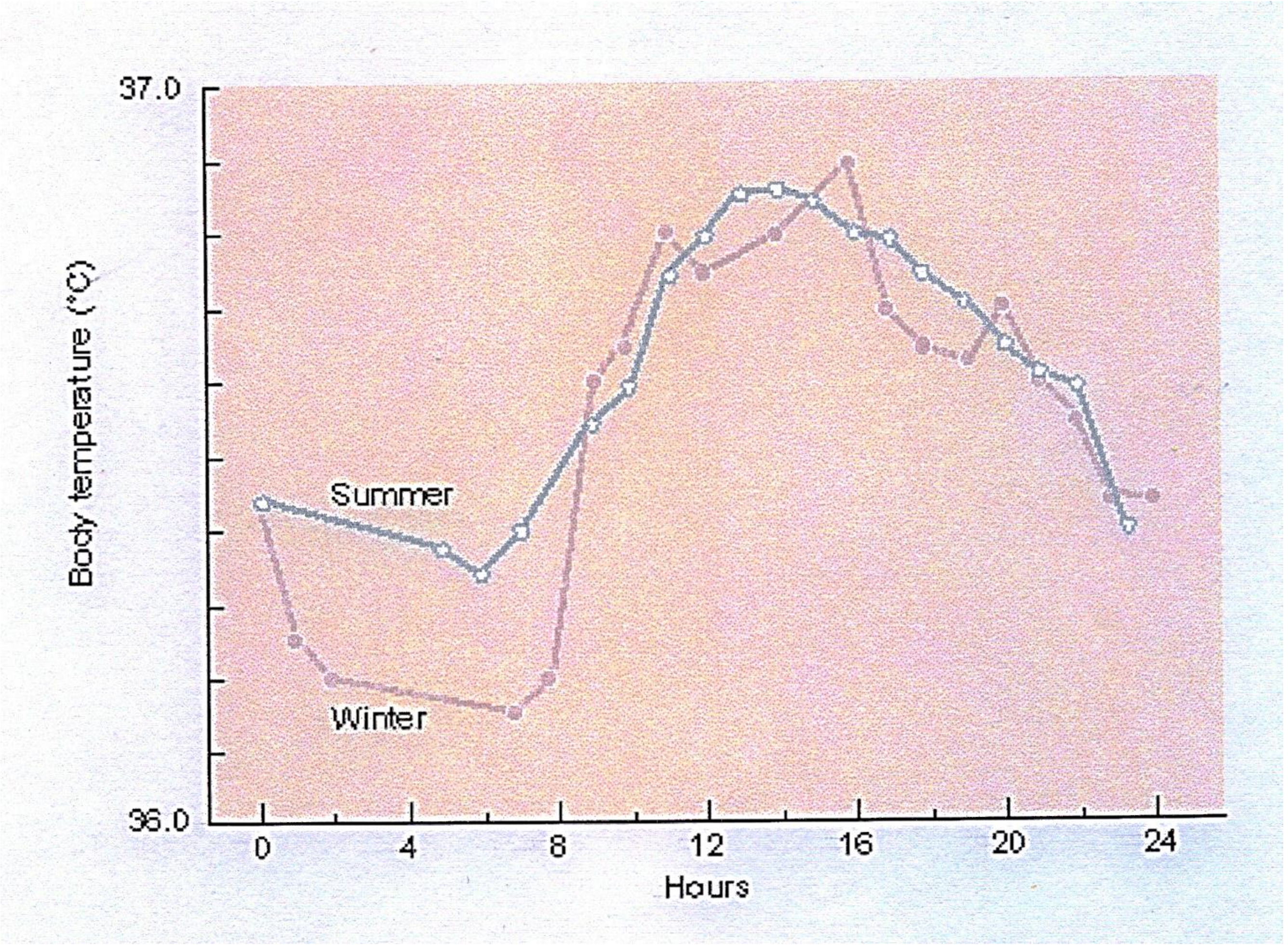
Variations of body core temperature

– Circadian rhythm
– Circamensal rhythm (women between puberty and menopause)
– Seasonal variations (circannul rhythm)
– Ageing



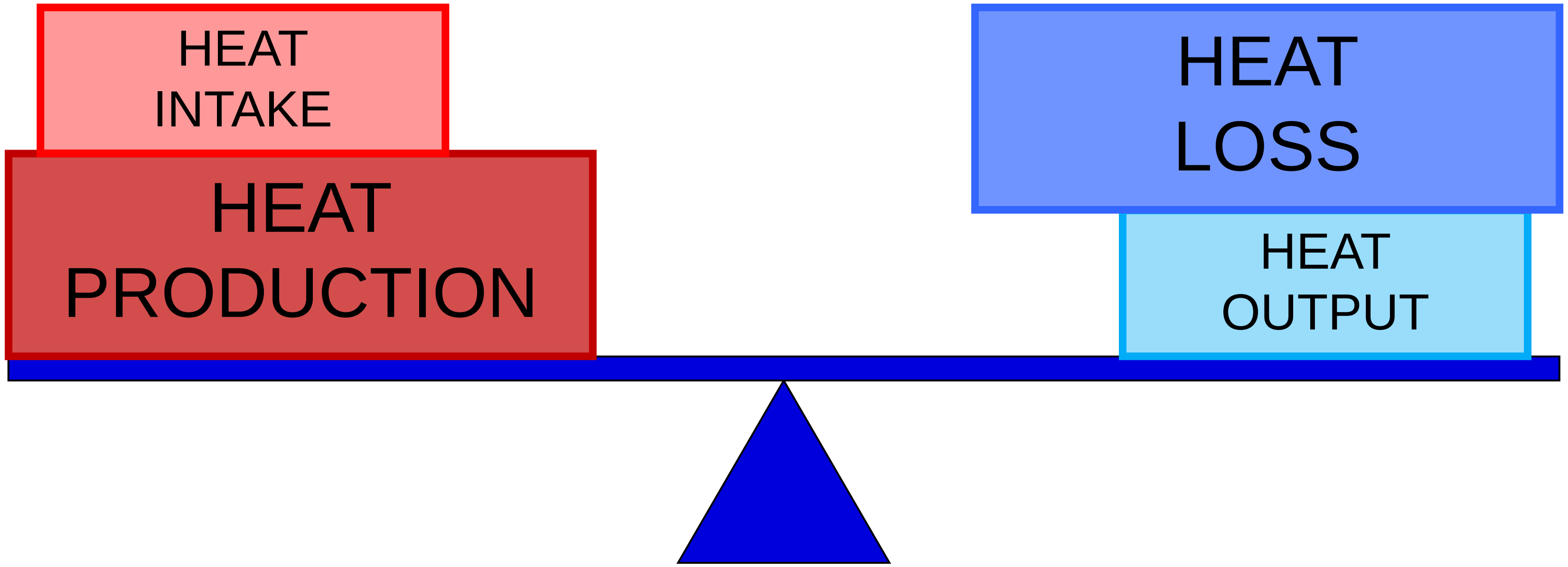
MUNI MED

Variations of body core temperature



MUNI MED

A fine balance of body core temperature



Heat vs. temperature

- **Heat [J]** – energy transfered to or from the system; measure of the internal energy state

- **Temperature [K, °C, °F]** – a measure of heat content; mean kinetic energy of the particles (molecules, ions)

MUNI MED

Transfer of heat within the body

- primarily by **CONVECTION**
- medium = blood

- minor amount by **CONDUCTION**
- direct contact of organs/tissues

MUNI MED

Heat production

- Metabolism: metabolic rate ≈ heat production
- Physical activity (active muscle contraction) – rest vs. exercise

- Postprandial thermogenesis (food intake)

- Shivering thermogenesis
- Non-shivering thermogenesis (brown adipose tissue)

Heat intake and loss

– passive processes

– RADIATION
– CONVECTION
– CONDUCTION

– skin-environment temperature gradient

Heat output (active loss)

- EVAPORATION
- sensible perspiration = sweat production (1 L of evaporated s. = 2 428 kJ)
- Insensible perspiration = diffusion of water through skin and mucosae

- from the skin to the environment
- (RADIATION)
- (CONDUCTION)
- (CONVECTION)

MUNI MED

Thermoregulation

- All processes involved in keeping the body core temperature within the range

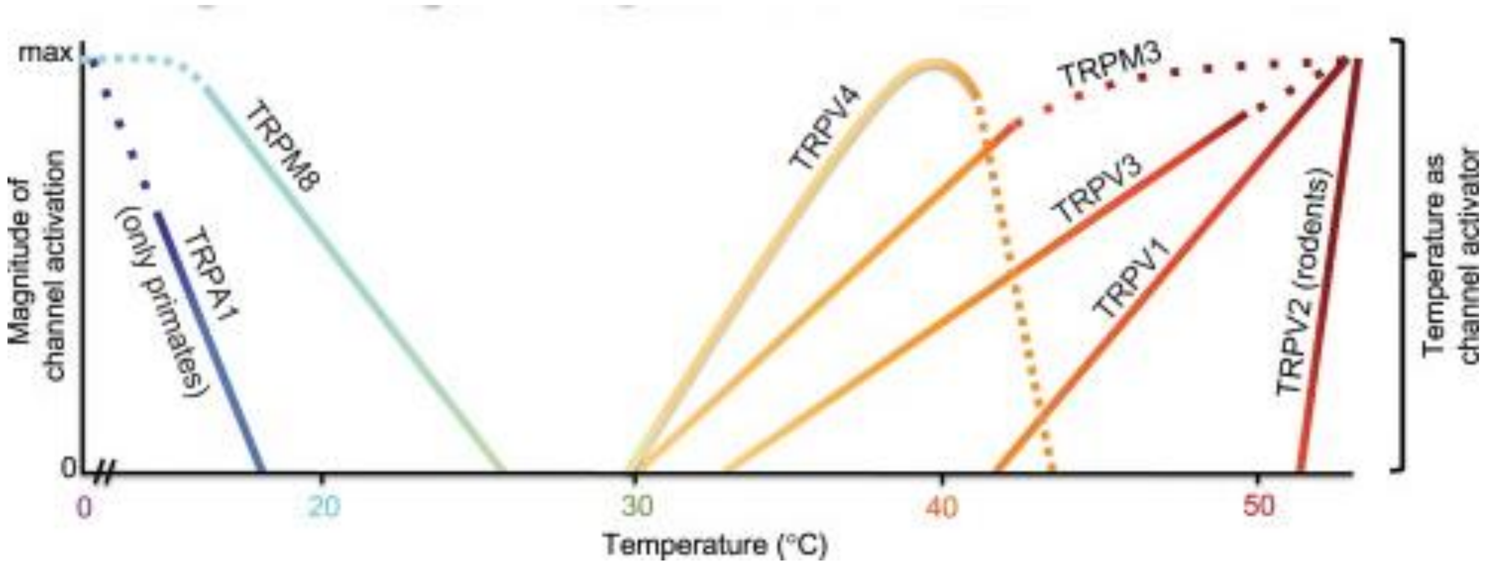
- Thermoregulatory behaviour

- Social thermoregulation

Afferentation

- Central thermoreceptors – deep brain temperature
- temperature-sensitive neurons in anterior preoptic hypothalamus

- Peripheral thermoreceptors – skin temperature
- TRP channels



Adopted from:: https://doi.org/10.1016/bs.pmbts.2015.01.002

MUNI MED

Thermoregulatory centre

– anterior preoptic HYPOTHALAMUS

– integration of afferent information
– modifying the efferent pathways (vegetative, somatic) to the thermal effectors

– „set-point“ vs. threshold temperature for the effector(s)

Thermal effectors

- Behaviour
- Cutaneous circulation
- Sweat glands
- Skeletal muscles (shivering)
- Horripilation
- Brown adipose tissue (nonshivering thermogenesis)

Cold-induced thermoregulatory mechanisms

- Decrease of heat loss
  - Behaviour: Decrease of body surface, taking warm clothes
  - Vasoconstriction in the skin. Horripilation
  - Inhibition of sweating
- Increase of heat production
  - Skeletal muscles: Intentional movements (behaviour). Shivering
  - Nonshivering thermogenesis (brown adipose tissue, NA, β3R, UCP1)
  - Hunger (increas of food intake)

MUNI
MED

Warm-induced thermoregulatory mechanisms

- Increase of heat loss/output
  - Skin vasodilatation
  - Increase of sweating (evaporation)
  - Increase of ventilation
- Decrease of heat production/intake
  - Behaviour: Moving out of the sun, taking light clothes. Inactiveness (decrease of intentional movements), apathy
  - Loss of appetite

Adaptation

Physiology II lecture (aZLFY0422p)

Tibor Stračina

Adaptation

- Long-term functional and/or structural change as a response to long-term or repeated change (on certain level) of the environment

- Leads to decrease of energetic demand for keeping homeostasis in changed conditions

- Evolution (fixed adaptation)

MUNI
MED

Adaptation: starting up

Stimulus

- Suprathreshold change of external and/or internal environment

- It works long-term or repeatedly

Adaptation to exercise: Strength vs. Endurance training

Source: www.freepik.com - photo created by gpointstudio

Source: www.freepik.com - photo created by alexeyzhilkin

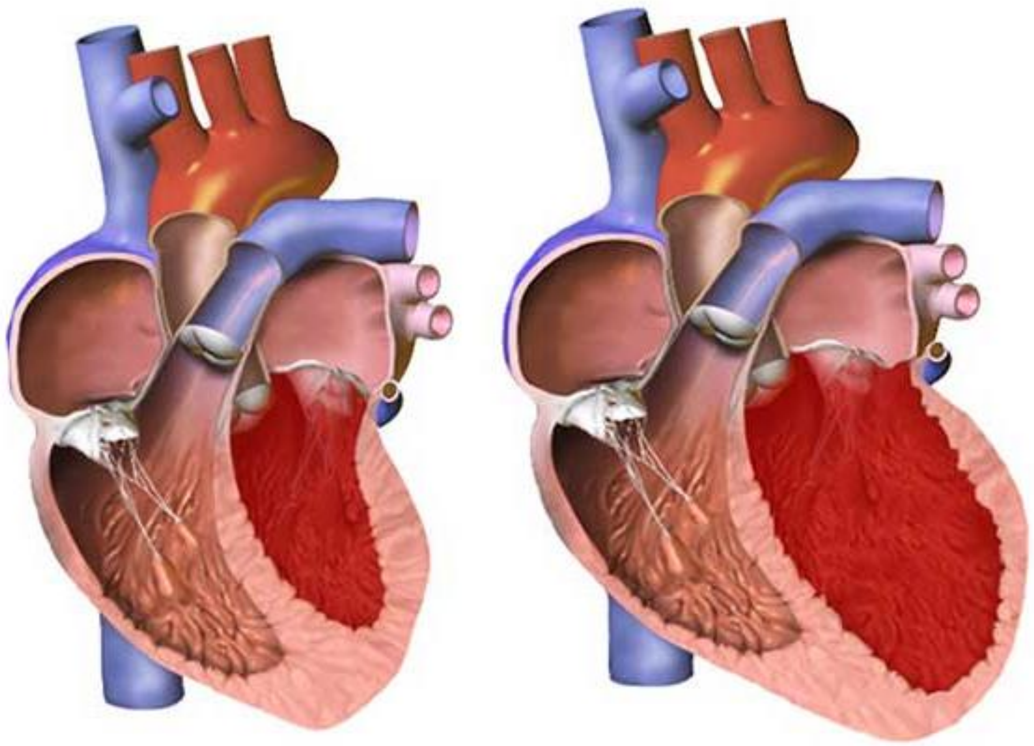
MUNI MED

Adaptation to exercise

- Skeletal muscles
  - Hypertrophy, vascularization
- Cardiovascular system
  - Heart adaptation (concentric hypertrophy vs. athletic heart)
  - Increase in RBC and heamoglobin concentration
- Respiratory system
  - Increase in VC (if possible), increase in maximal respiartion (increase in respiratory reserve), more effective diffusion on alveolo-capillar membrane
- Metabolism

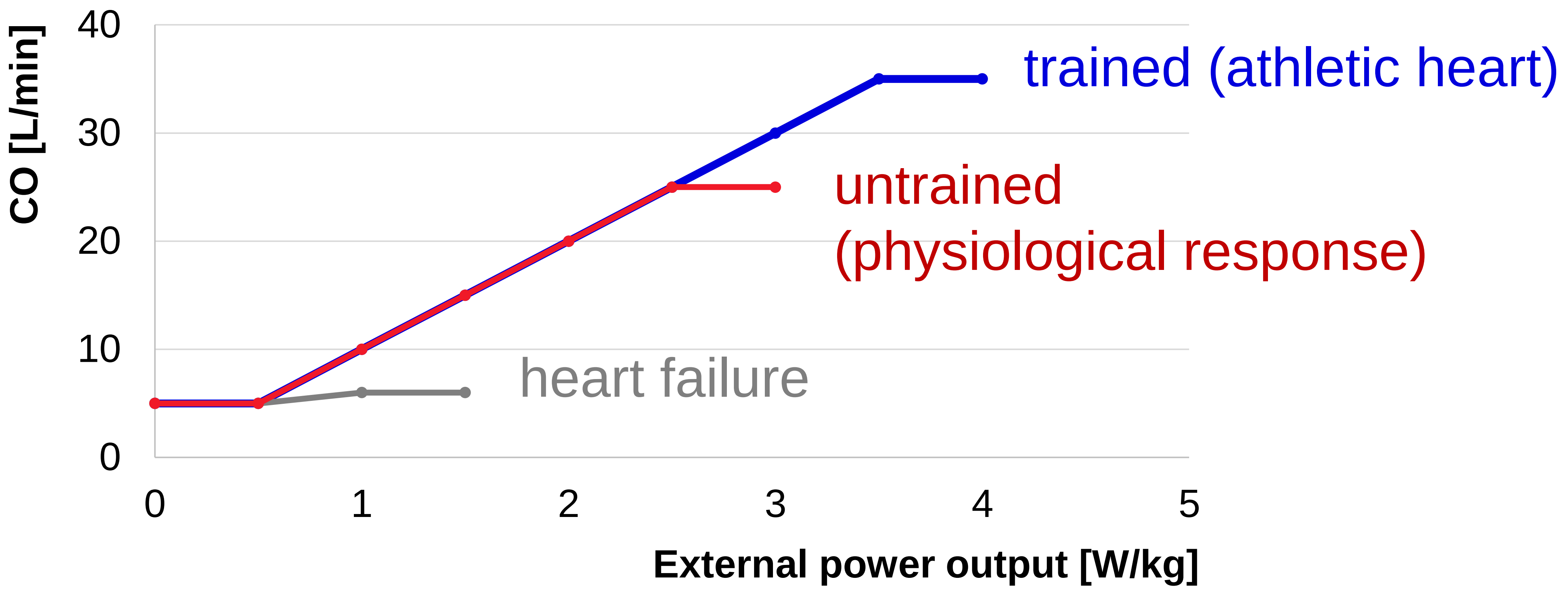
Athletic heart

- Adaptation to endurance training
- ↑ LVEDV - ↑ SV - (baroreflex) ↓ HR
- ~ CO
- ↑ chronotropic reserve = ↑ cardiac reserve

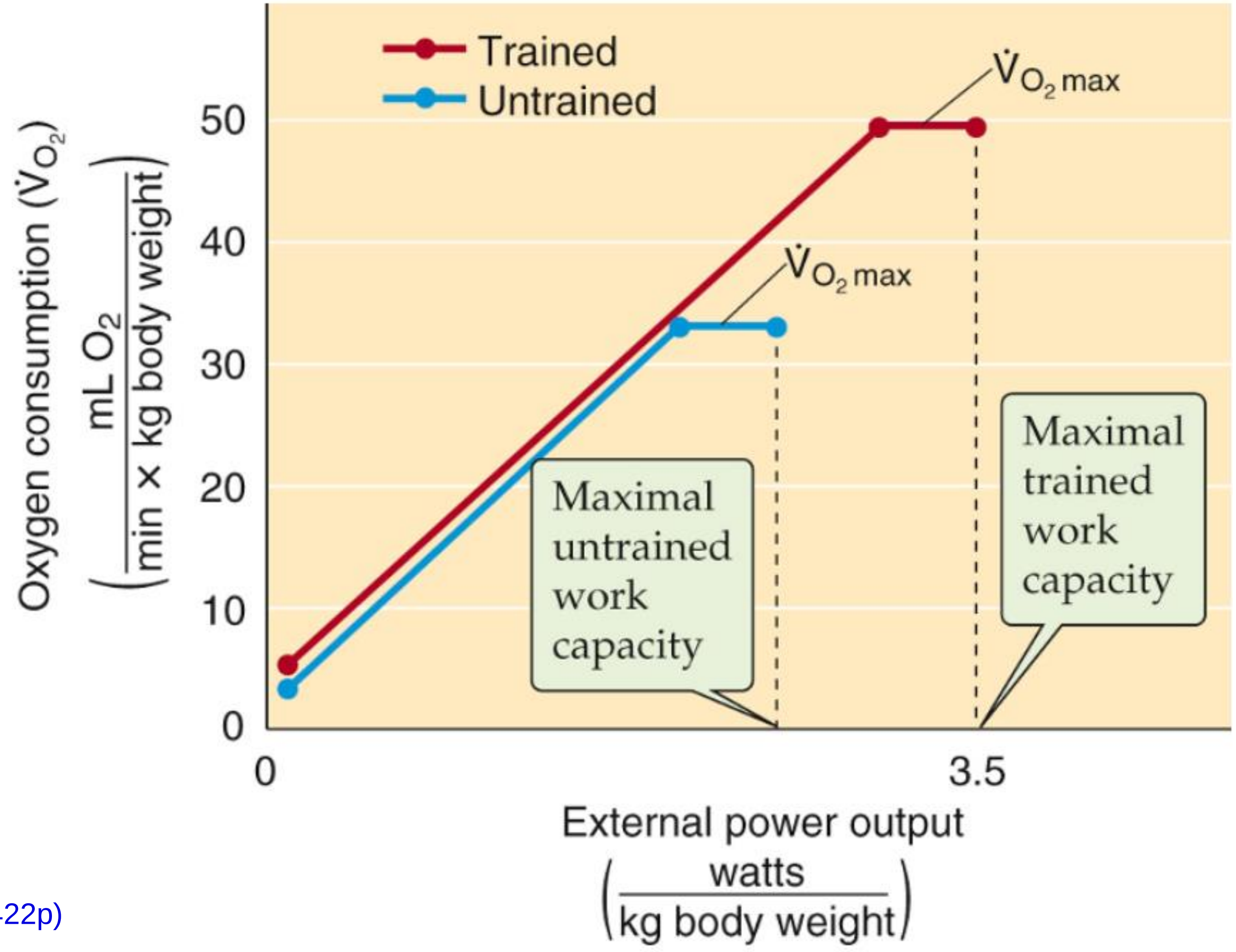


Source: https://assets.beta.meta.org/discover/thematic-feed/83-athletic-heart-syndrome.jpg

Cardiac reserve in trained and untrained



Oxygen uptake in trained and untrained



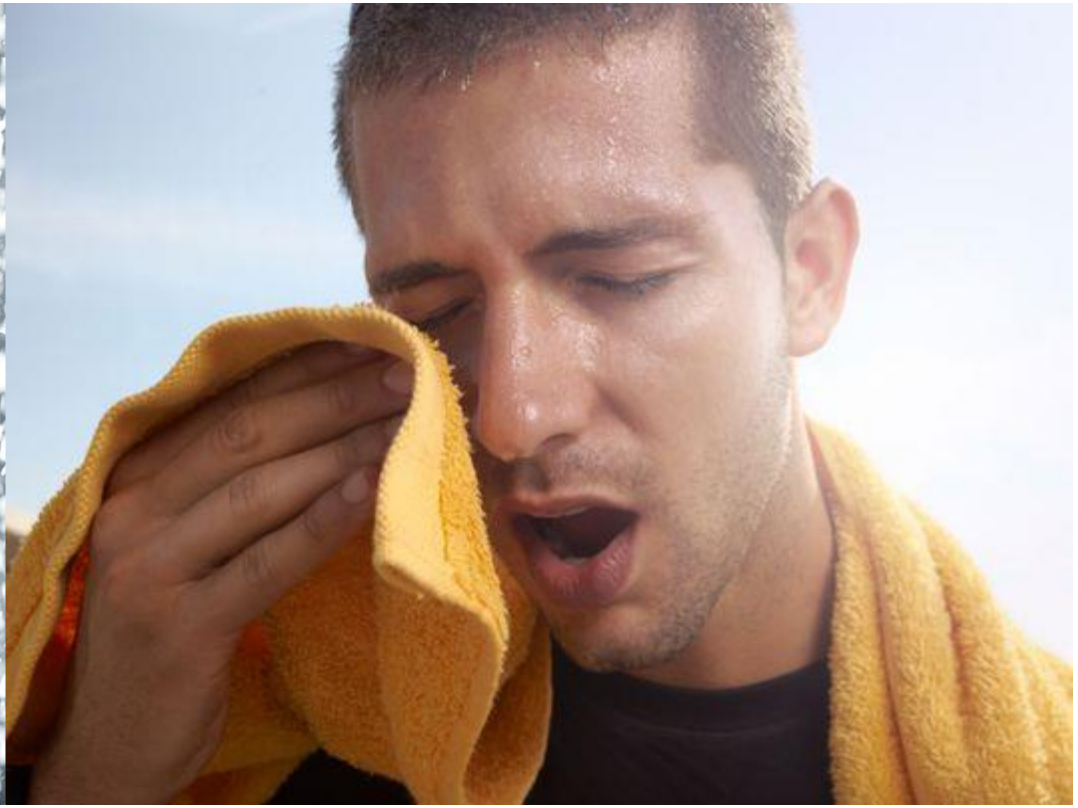
Source: https://studentconsult.inkling.com/read/boron-medical-physiology-3e/chapter-60/figure-60-6

Determinants of $V_{O2\ max}$

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

MUNI MED

Adaptation to extreme temperatures



Source: www.freepik.com

MUNI
MED

Adaptation to cold environment

- Strategy: reduction of heat loss (+ increase of heat production)

- Increase in appetite
- An increase in the subcutaneous fat layer
- Re-set of the thermoregulation center
  - Lowering the temperature to activate shivering thermogenesis

Adaptation to hot environment

- Strategy: increase heat loss + decrease heat production

- Decreased appetite (appetite)
- Adaptation of sweating
  - Dependent on environmental humidity; reduction of sweat production, reduction of ion concentration
- Re-set of the thermoregulation center
  - Increase in temperature to activate sweating

MUNI MED