MUNI
MED

Ergometry

Physiology II – practice
Spring, weeks 10th-12th

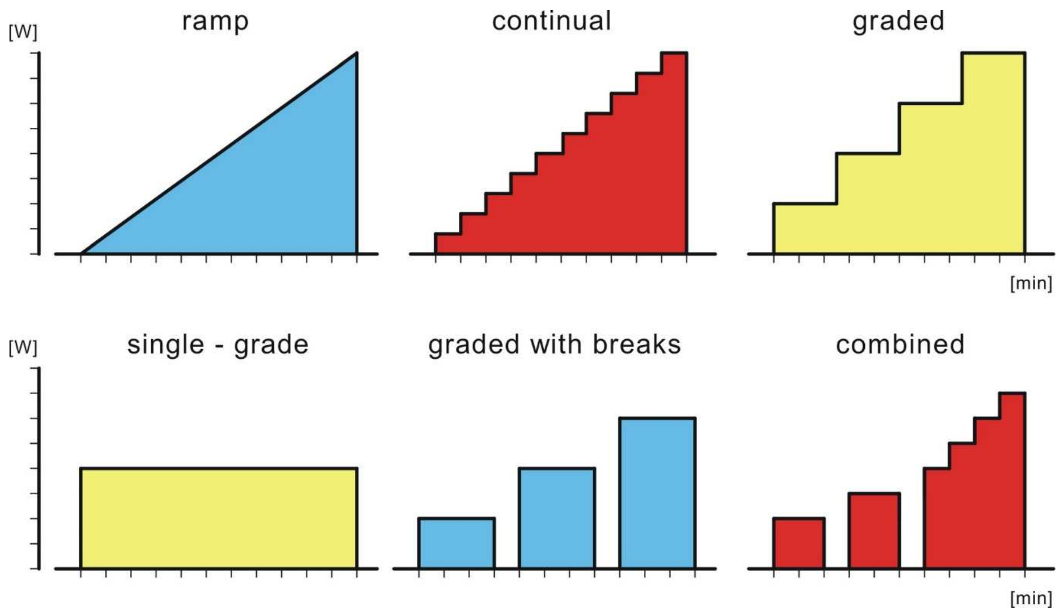
Ergometry (stress testing, exercise testing)

- Work load examination – measurement of ECG and other parameters during the increasing degree of exercise on the ergometer
- In addition to ECG, the following can be recorded:
  - O_2 consumption, CO_2 output, blood pressure, blood samples (mainly lactate)
- Types of ergometers
  - Bicycle ergometer – load mainly on the lower half of the body
  - Rowing machine – upper body load
  - Rump ergometer – exercise bike for hands, para/quadriplegia
  - Master´s step
  - Treadmill
- Can be used in:
  - Sports medicine
  - Rehabilitation medicine
  - Cardiology

MUNI MED

Basic types of protocols for ergometry

- Ramp
- Continual
- Graded
- Single-grade
- Graded with breaks
- Combined



MUNI MED

Myocardial metabolism

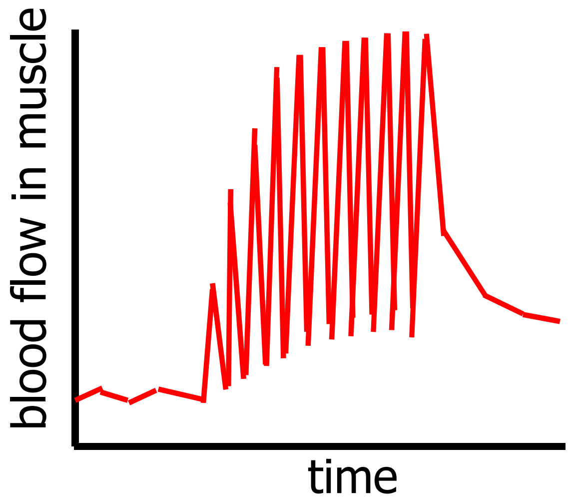
- It needs a high blood supply, rich capillarization
  - Blood supply occurs especially at the beginning of diastole because in systole the muscle is contracted and the vessels are closed. This is especially true for the left ventricle which exerts higher pressure – it is more vulnerable to hypoxia.
- The heart is an „omnivore“, it processes what it gets
  - 60% free fatty acids, triglycerides (60-90% acetyl-CoA from beta oxidation)
  - 35% carbohydrates
  - 5% ketones (starvation or untreated diabetes)
  - Under normal circumstances (outside ischemia and maximal performance) it metabolizes lactate
- High oxygen consumption
  - Physiologically only oxidative phosphorylation – maximization of ATP production, a high number of mitochondria
  - Even a small degree of ischemia is sufficient to disrupt myocardial metabolism

    Pathologically, under anaerobic conditions (ischemia), pyruvate is reduced to lactate – anaerobic glycolysis – it leads to the loss of contractile function, arrhythmia, and cell death. Release of troponin from cytoplasm to blood – a marker of myocardial infarction

Skeletal muscle metabolism

- During physical exercise, the muscle vessels dilate (metabolic autoregulation) and the blood flow through the muscle increases
  - During an exercise, the blood supply to muscles occurs only after their relaxation
  - Rhythmic exercise leads to fluctuations in blood flow, but the blood flow still can be up to 20 times higher than at rest
- If blood supply is sufficient, O_2 supply meats demands – aerobic processes are the source of ATP
- If the load is too high then the demand for O_2 exceeds the supply – aerobic resynthesis of ATP is not sufficient
  - Some O_2 is initially released from myoglobin
  - Initially, ATP resynthesis occurs from phosphocreatine
  - Anaerobic glycolysis – less efficient, formation of lactate
  - Accumulation of lactate → acidosis, inhibition of enzymes and muscle work
  - Short-term significant increase in muscle performance

    100 m sprint – 85% energy from anaerobic glycolysis
    2.5 km race, 10 min – 20% anaerobic
    Run for more than an hour – 5% anaerobic



MUNI MED

Heart rate and exercise, W_{170}

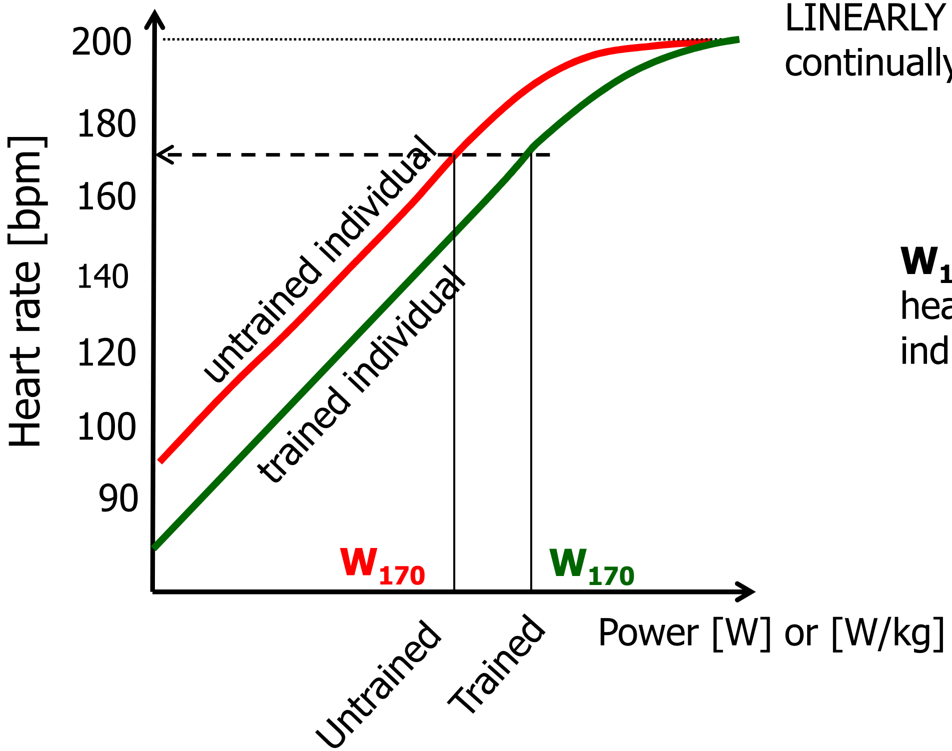
- With increasing work, heart rate (HR) increases linearly to reach maximal heart rate – depends on the age
  - Estimation of **max. heart rate = 220-age,** there are also other equations
  - Limitation is the length of the refractory phase in myocardiocyte and also the shortening of diastole when the filling of ventricles and the blood supply to the myocardium occurs.

Age (years)	< 30	31–40	41–50	51–60	61–70
Maximal heart rate (bpm)	195	185	182	170	162

- Resting heart rate – depends on training
  - In trained individuals it can be around 50 bpm at rest
- W_{170} index: working capacity at a heart rate 170 bpm
- Max HR in untrained person 180 bpm, in trained person up to 220 bpm

MUNI MED

Heart rate and exercise, W_{170}



Up to 180 bpm, heart rate increases LINEARLY (if a level of exercise increases continually)

W_{170}: Index describing work capacity at the heart rate of 170 bpm. It is higher in trained individuals.

MUNI MED

Respiratory quotient (RQ)

- Ratio: CO_2 produced / O_2 consumed
- Provides information about the utilized substrate
  - Saccharides: RQ = 1, lipids: RQ = 0,7; proteins: RQ = 0,8
- Provides information about metabolism
  - Exercise or metabolic acidosis RQ > 1
  - Voluntary hypoventilation or metabolic alkalosis RQ < 0.7
- It is affected by ventilation
  - Voluntary hyperventilation RQ > 1 – CO_2 is exhaled from the body
  - Voluntary hypoventilation RQ < 0,7
- Intense physical work: RQ up to 2, after exercise RQ = 0.5
  - Anaerobic glycolysis – lactate formation, more CO_2 is exhaled than O_2 consumed
  - Restoration of energy sources after exercise – lactate processing, synthesis of ATP, creatine phosphate and myoglobin oxygenation – higher consumption of O_2 than CO_2 production
  - **The change in the RQ curve depending on the intensity of exercise indicates the anaerobic threshold**

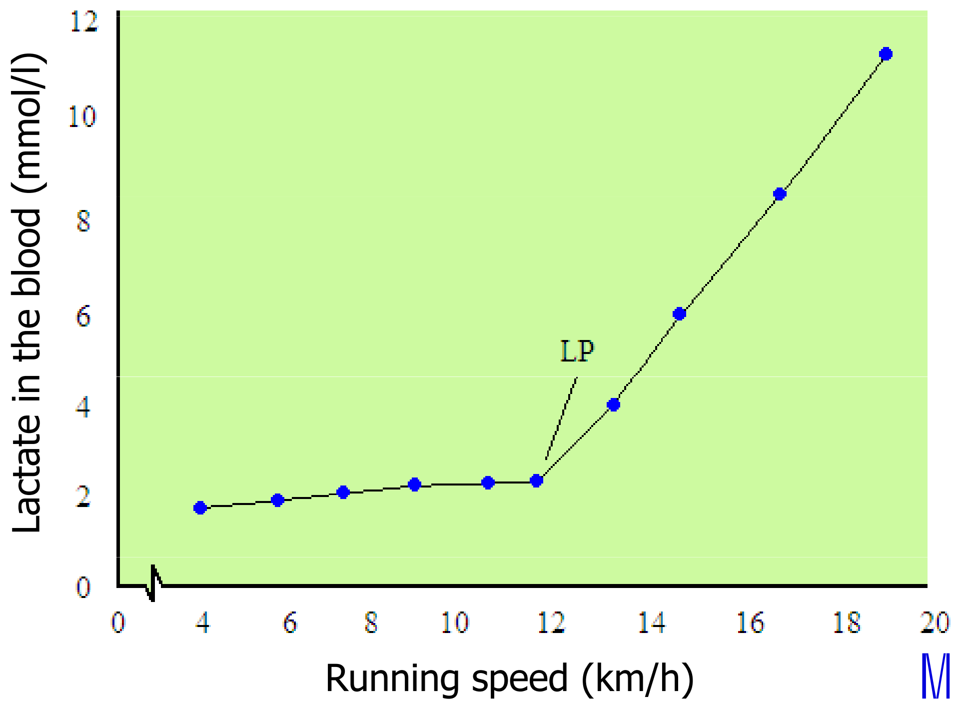
MUNI MED

Oxygen dept

- Energy for muscle work = aerobic resources + anaerobic resources
- If the demand for O_2 exceeds the supply, the muscle switches to anaerobic glycolysis (however, the lactate produced in a higher concentration inhibits enzymes and muscles)
- Blood circulation in the muscle increases slightly after the work initiation – already at that time the oxygen debt begins, but it stays constant at low power and increases in high power.
- Anaerobic sources: oxidized myoglobin, phosphocreatine, anaerobic glycolysis
- Oxygen debt: oxygen needed for the restoration of phosphocreatine, the breakdown of lactate and the oxidation of myoglobin
  - It is the oxygen consumption after the exercise that exceeds the resting oxygen consumption
  - It is measured after exercise until it stabilizes at the resting value – oxygen debt is the difference between O_2 consumption after exercise and resting O_2 consumption
- Oxygen debt can be up to 6 times higher than resting O_2 consumption – anaerobic glycolysis during exercise allows a significant increase in muscle performance

Threshold – anaerobic, lactate

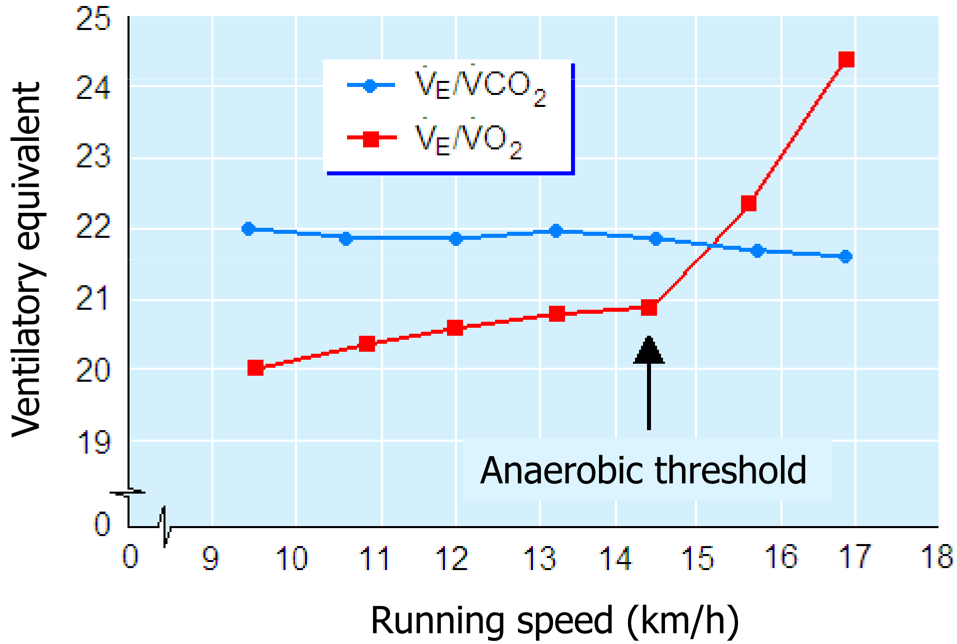
- Anaerobic threshold – the boundary between aerobic and anaerobic energy production – the level of exercise at which anaerobic glycolysis begins to dominate
  - It is determined according to the lactate, ventilatory or circulatory threshold and in the percentage of its maximal values
- Lactate threshold
  - During the increasing intensity of exercise, blood samples are taken and lactate levels are detected. A curve is obtained from the values and we determine the breakpoint when lactate begins to accumulate = lactate threshold



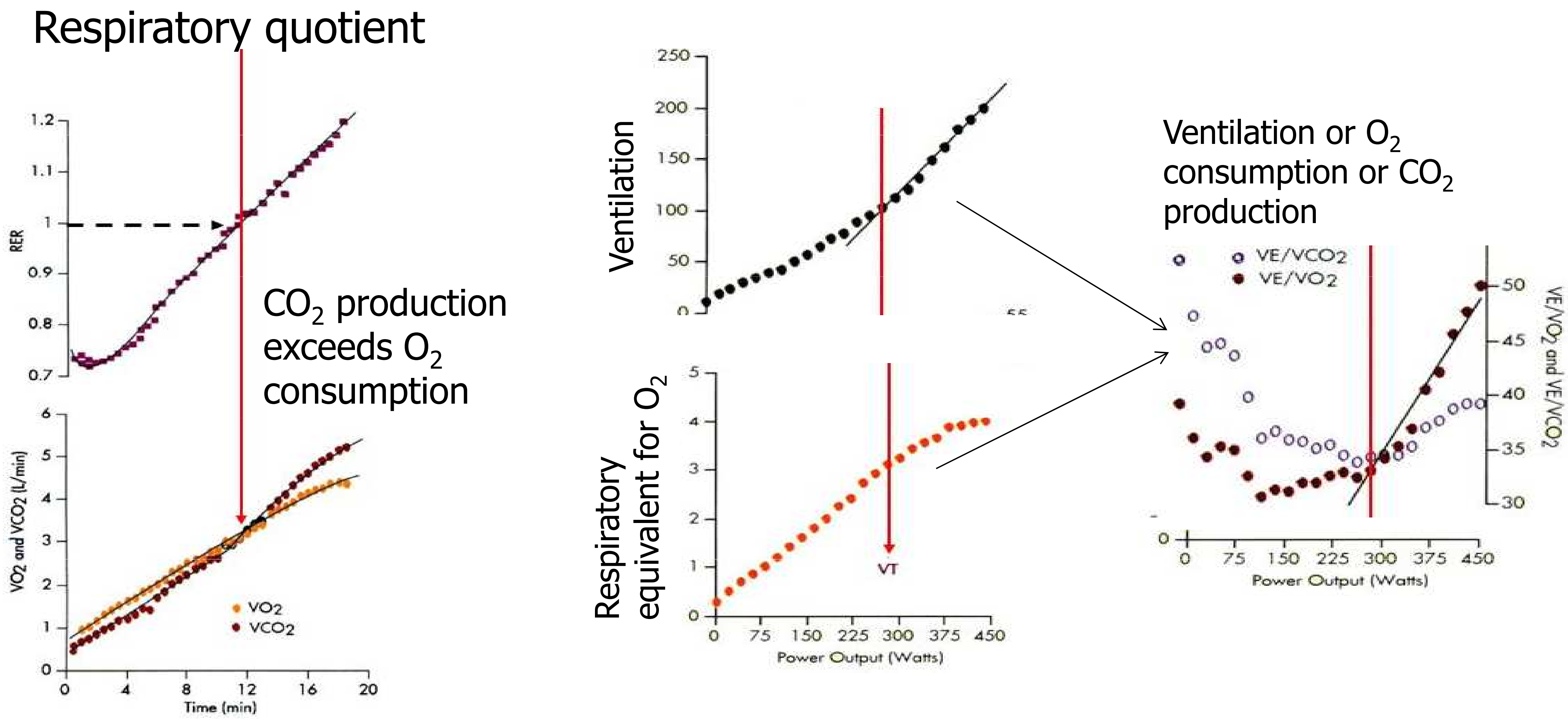
UNI MED

Threshold – ventilatory, circulatory

- Ventilatory threshold
  - The curve of ventilation, consumption of O_2, respiratory quotient or ventilatory equivalent for oxygen depends on the level of exercise. Looking for the breakpoint (trend reversal)
  - (Ventilatory equivalent for oxygen: the amount of oxygen obtained from 1 litre of air)
- Circulatory threshold
  - It is determined by the point where the increasing heart rate starts to slow down on the record of heart rate during exercise
- In general, the ability to achieve maximum performance is limited by several factors: cardiovascular system, respiratory system, musculoskeletal system



Ventilatory threshold



MUNI MED

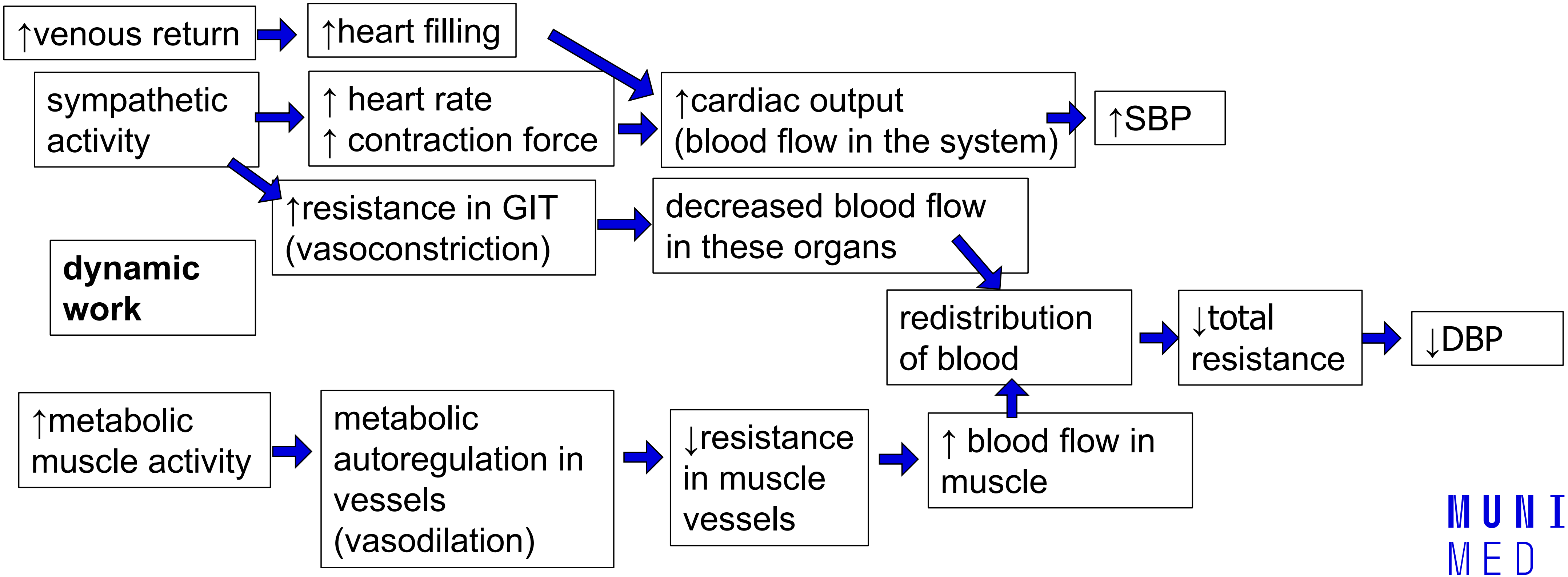
Termoregulation during physical exercise

- Energy formed by muscles ≈ executed work + ATP production + heat
- Muscle efficiency
  - Isotonic work – efficiency is about 50% (50% of energy is converted into kinetic, 50% into heat)
  - Isometric work – efficiency is almost 0%
- Increased heat production in the muscle persists up to 30 minutes after exercise – metabolic processes in the muscle recovery
- Excess heat needs to be released
  - The mechanisms involved in thermoregulation depend on the temperature of the core and the surroundings
  - Sweating and evaporation, conduction, convection, radiation
  - The blood supply in the superficial venous plexuses – initially, blood flow through the skin is restricted due to blood redistribution during exercise, until thermoregulatory mechanisms prevail
- The heat production by the muscle is used to warm up the body during hypothermia – tremor thermogenesis

MUNI
MED

Physiological changes during exercise

– The aim of cardiovascular changes during exercise is to increase blood flow and redistribution towards the working muscle. Therefore, the changes will depend on the intensity and type of exercise (dynamic or static).



MUNI MED

Physiological changes during exercise

- Blood pressure values strongly depend on the intensity and type of exercise.
  - Dynamic exercise involving more muscles leads to an increase in systolic blood pressure (due to an increase in cardiac output) and a decrease in diastolic (due to a decrease in total peripheral resistance) – for example running, swimming
  - Blood flow in muscles increases up to 20 times, cardiac output increases (muscle can take up to 90% of cardiac output)
  - In isometric work, during muscles contraction both systolic and diastolic pressure increase – for example, in weightlifting (blood vessels in the muscle are closed during muscle contraction)
  - After the exercise, peripheral resistance is still low (blood vessels in the muscles and skin are still dilated), but venous return decreases (muscle no longer contracts) and cardiac activity decreases → hypotension → fainting (so-called "bleeding out into the muscle")
- pH: lactate accumulation during heavy exercise causes metabolic acidosis, light exercise does not change pH
- Respiratory system
  - The initial increase in activity is induced by the stimulation of proprioceptors in the muscles
  - With growing power and consumption of O_2, ventilation increases linearly. During heavy exercise, ventilation exceeds the consumption of O_2 – metabolic acidosis caused by lactate stimulates ventilation.
  - VO_{2max}: the maximum amount of oxygen that the body can use in 1 min – depends on age, constitution, health status, and training – it is limited by both the musculoskeletal system and the cardiovascular system
  - O_2 and CO_2 concentration values in arterial blood do not change during aerobic exercise – ventilation covers consumption. In heavy exercise, CO_2 levels in arterial blood decrease due to acidosis and hyperventilation.

MUNI
MED

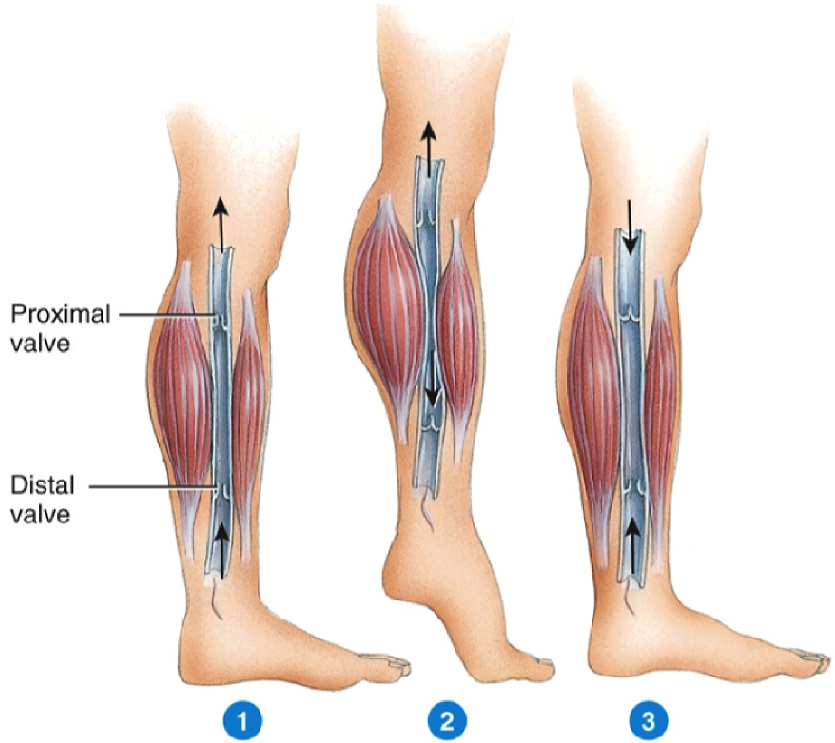
Adaptation to exercise – heart

- Higher parasympathetic influence on the heart, lower sympathetic effect
- Athlet's heart – physiological enlargement of the heart
  - muscle hypertrophy (without an increase in the fibre numbers) – in speed and power sports
  - dilatation of cavities (especially of the left ventricle) – in endurance sports
- Bradycardia in athletes – decrease in resting heart rate below 60 bpm
- Reserves:
  - Chronotropic reserve = HR max/HR at rest (3–5)
    Untrained: at rest 80 bpm, max 180 bpm
    Trained: at rest 40 bpm, max 180 bpm
  - Systolic volume reserve = SV max/ SV at rest (1.5)
    Untrained: rest 70 mL, max 100 mL
    Trained: rest 140 mL, max 190 mL
  - Cardiac reserve = max cardiac output/resting cardiac output
    Untrained (3): rest 5,6 L/min, max 18 L/min
    Trained (6): rest 5,6 L/min, max 35 L/min
  - Coronary reserve (3.5)

MUNI MED

Venous return and its mechanism

- Venous return is the return of blood to the right heart
- Mechanisms:
  - Venous valves and muscle pump
  - Negative pressure in the chest during inhalation (and overpressure in the abdominal cavity)
  - Suction force of systole – systole of the ventricles changes the shape of the right atrium (pulling the tricuspidal valve into the ventricle), the atrium increases its volume and sucks in blood
  - Power from the behind (*vis a tergo*): remaining pressure from the MAP



MUNI MED