Energetic metabolism

Physiology of Exercise

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Energetic metabolism

= summary of all chemical (and physical) processes included in:

1. **Production of energy from internal and external sources**
2. **Synthesis** and **degradation** of structural and functional tissue components
3. Excretion of **waste products** and **toxins** from body

Metabolic speed: amount of energy released per unit of time

Calorie (cal) = amount of thermal energy, necessary for warming up 1g of water for 1°C, from 15°C to 16°C

SACCHARIDES

LIPIDS

PROTEINS

ENERGY INPUT = ENERGY CONSUMPTION

MECHANIC WORK	Muscle contraction Movement of cells, organelles, flagella
SYNTHESIS	Energetic stores production Tissue growth Essential molecules production
MEMBRANE TRANSPORT	Minerals Organic ions AA
PRODUCTION AND TRANSMISSION OF SIGNALS	Electrical Chemical Mechanical
HEAT PRODUCTION	Body temperature control Ineffective chemical reactions
DETOXICATION DEGRADATION	Urine production Conjugation Oxidation Reduction

I. thermodynamic law: At steady state, input of energy equals to its expenditure

Input ⟷ stores

Expenditure of energy = external work + energy stores + heat

Intermediate stages: various chemical, mechanical and thermal reactions

Energy intake (input)

Saccharides, lipids, proteins

Burning releases: 4.1kcal/g, 9.3kcal/g, 5.3kcal/g (4.1 in body) 1kcal=4184J

Conversion of proteins and saccharides to lipids – effective storage of the energy

Conversion of proteins to saccharides – need of „fast“ energy

BUT: there is no significant conversion of lipids to saccharides

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Energy output

1. **At rest:** basal metabolism; 8 000 kJ / day; 200-250 ml O_2/min; directly depends on body mass and surface; decreases with age; increases with ambient temperature; decreases by 10-15% during sleep; genetically determined **75%BM**
2. **After meal:** slight increase in energetic output – specific dynamic effect – e.g. for glycogen formation **7%BM**
3. **In sitting people:** spontaneous physical activity **18%BM**
4. **Facultative thermogenesis:** non-shivering

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5. **During exercising:** energetically most demanding; individual; changes according to season

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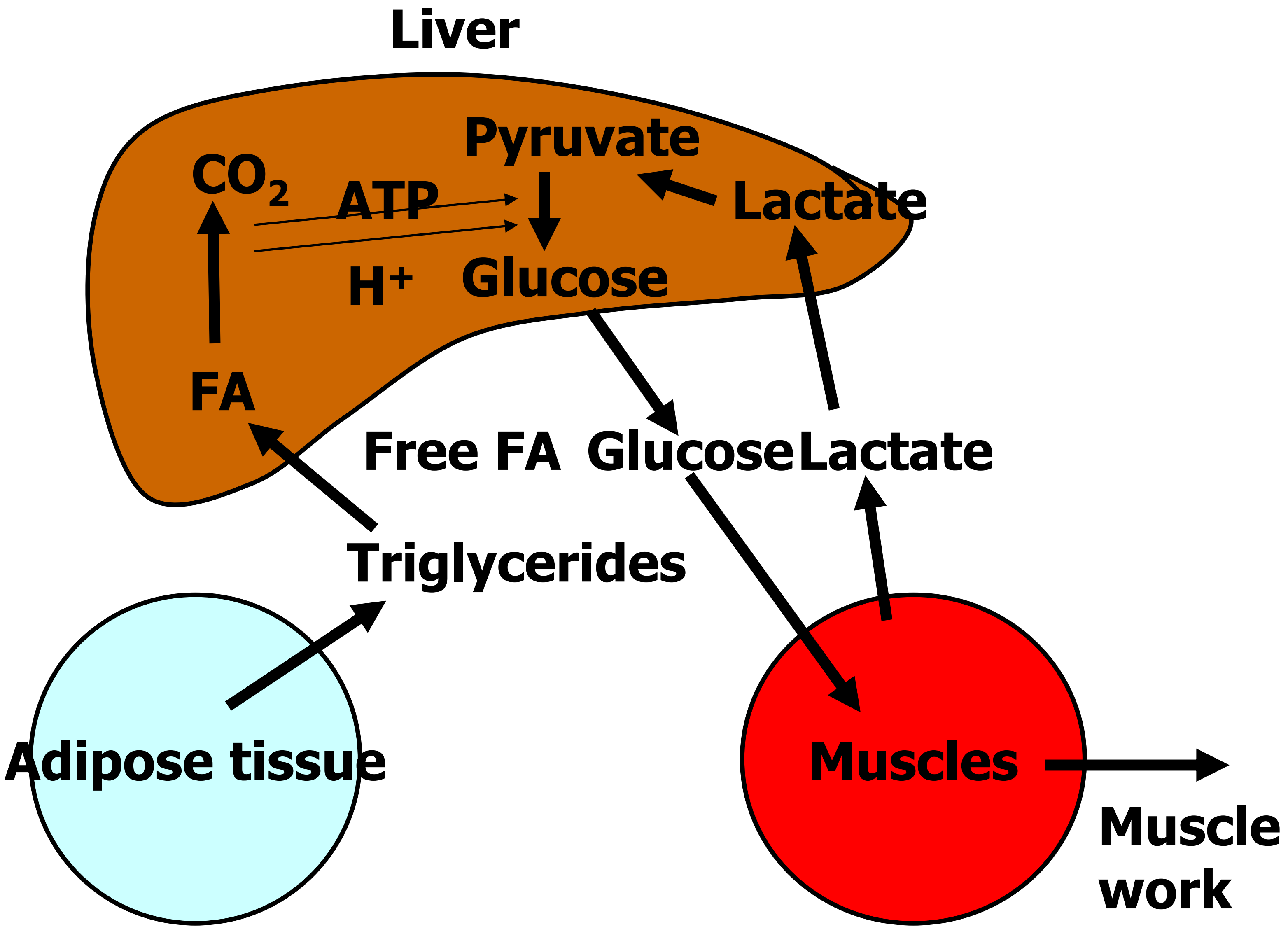
Transport of energy among organs



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- Energy **stores**: ATP, creatinphosphate, GTP, CTP (cytosin), UTP (uridin), ITP (inosin)
- Macroergic bond – 12kcal/mol
- Efficiency is not 100% - 18kcal of substrate to 1 bond in ATP
- Daily: 63 kg of ATP (128 mol)
- Glycolysis: only short-lasting source of energy (2 pyruvates – only approx. 8% of glucose energy);

supply of glucose is limited, lactate

RESPIRATORY QUOTIENT

RQ = $V_{CO2} : V_{O2}$

(per unit of time, at steady state)

R – ratio of respiratory exchange (no steady state!)

Saccharides: RQ = 1
Lipids: RQ = 0.7
Proteins: RQ = 0.8

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Storage and transport of energy

- Both input and output of energy are irregular – necessity of storage
- **75%** of stores: triglycerides (9kcal/g) in adipose tissue (10-30% of body mass), lasts up to 2 months ; source – dietary FA and esterification with a-glycerolphosphate or synthesis from acetylCoA (from glycolysis) – saccharides are converted to more effective store of energy = lipids
- **25%** of stores: proteins (4kcal/g); conversion to saccharides (gluconeogenesis during stress); adverse effects on organism
- Less than **1%** of stores: saccharides (4kcal/g) as glycogen; important for CNS!!! and short-term enormous exercise; ¼ of glycogen stores in liver (75-100g), rest in muscles (300-400g); liver glycogen – glycogenolysis – release of glucose; muscle glycogen – used only in muscles (no glukoso-6-phosphatase)
- Gluconeogenesis: from pyruvate, lactate and glycerol and AA (except of leucin);NO from acetyl-CoA
- Storage and transport of energy requires input of other energy: 3% from original energy – lipids (triglycerides to adipose tissue), 7% - glucose (glycogen), 23% - conversion of saccharides to lipids, 23% - conversion of AA to proteins or glucose (glycogen).

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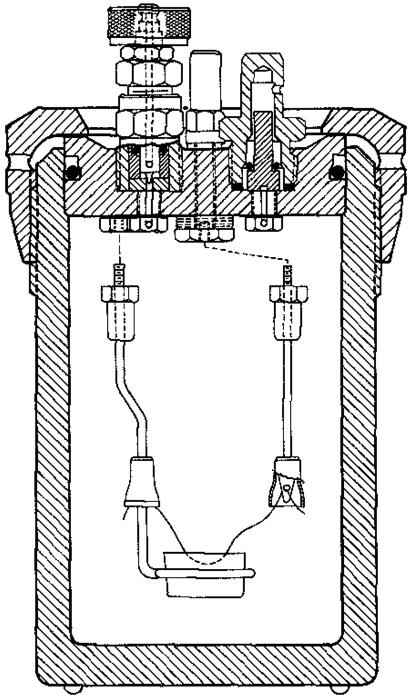
Direct calorimetry

= measurement of energy released by burning of diet out of body (oxidation of compounds in a **calorimeter**)

1. Caloric bomb
2. Whole-body calorimeter (for laboratory animals, for humans)



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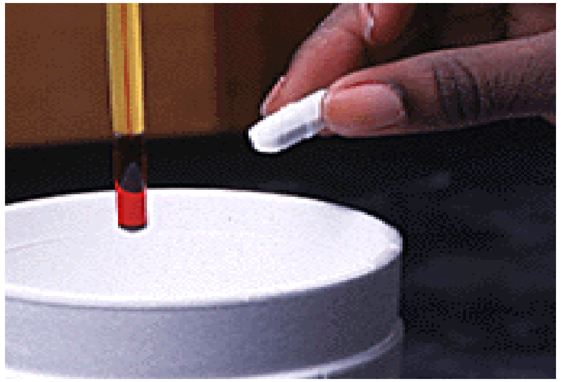



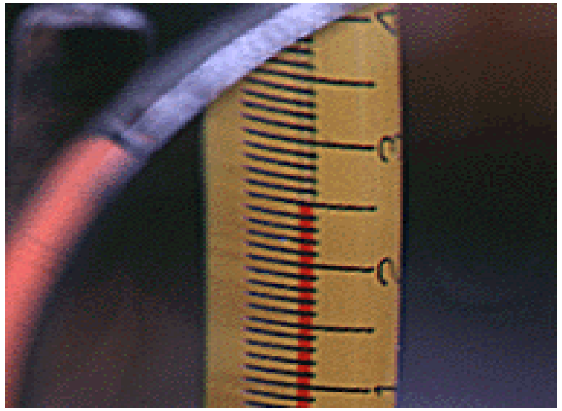

Indirect calorimetry

- Amount of consumed O_2.
- Amount of energy released for 1 mol of consumed O_2; differs according to type of oxidized compound (the effect of diet composition)

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Factors affecting basal metabolism

- Muscle work (before and/or during measurement)
- Food intake (before measurement)
- High or low ambient temperature (the dependence is expressed as a **U** curve)
- Height, weight, **body surface**
- Gender
- Age
- Emotional situation
- Body temperature
- Thyroidal status
- Plasmatic level of catecholamines

Work (physical activity, exercise)

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Skeletal muscle

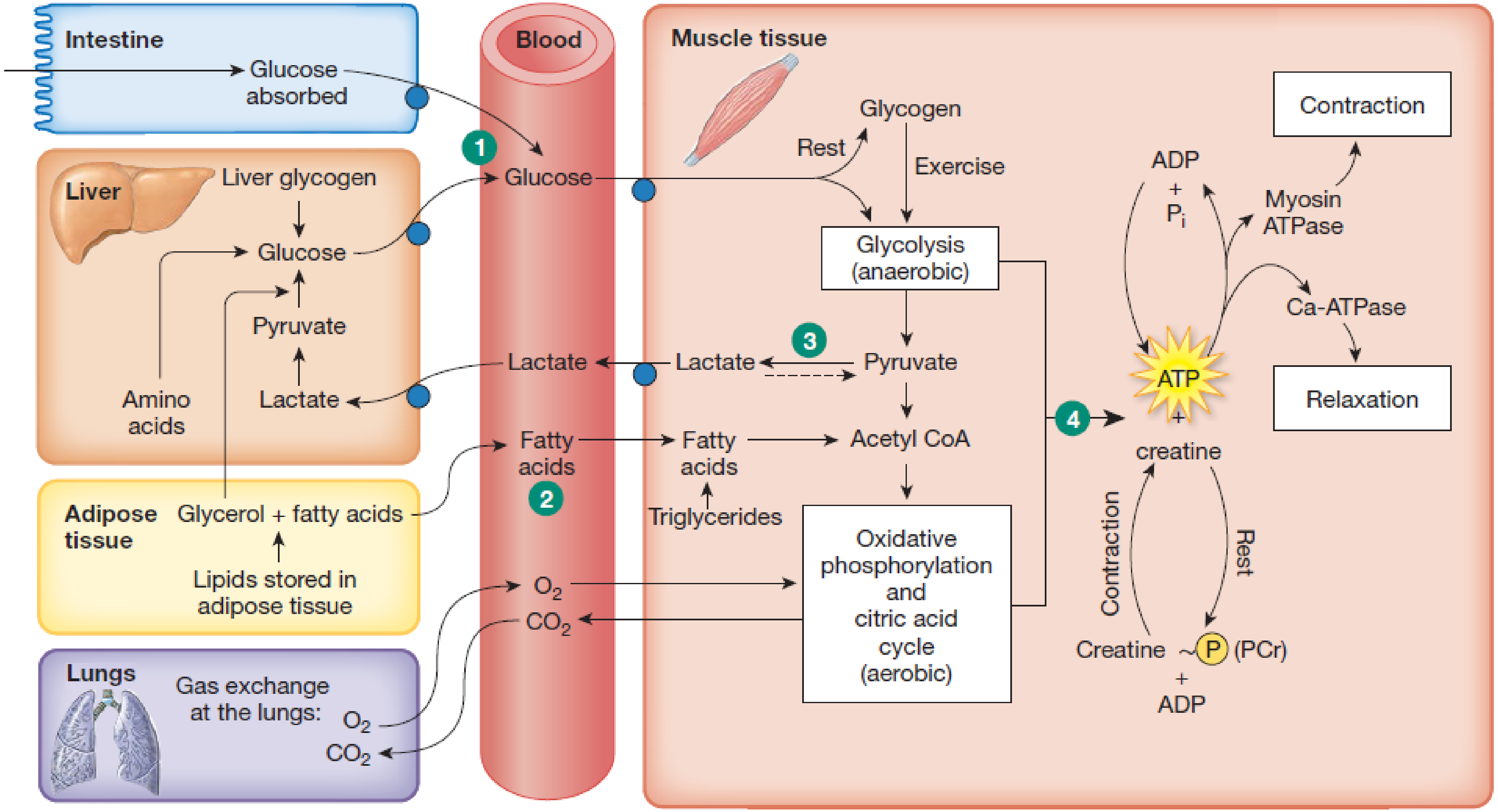
- Contraction: isometric (static work) *vs.* isotonic (dynamic work)

- 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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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)
- Prepares the body for the increased metabolic turnover in the exercising skeletal muscles

- Similar to 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

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Increase of cardiac output. Cardiac reserve

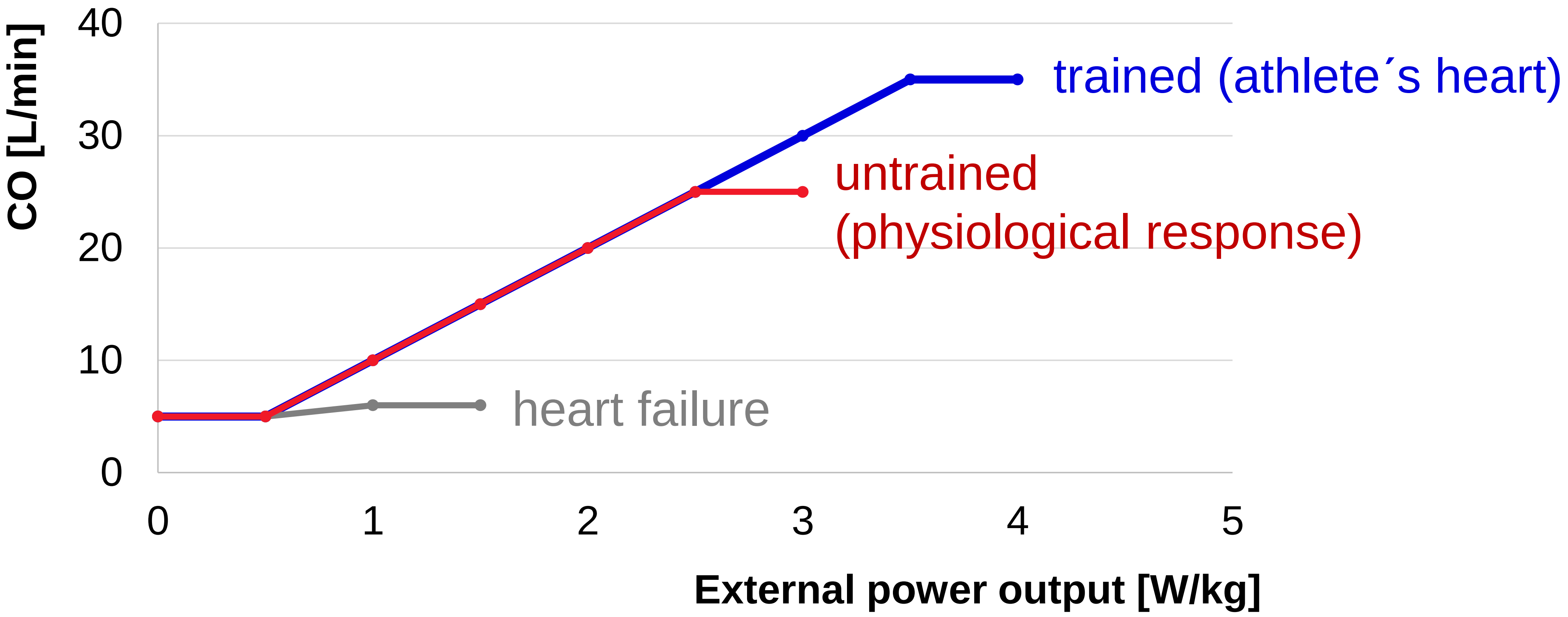
- CO = SV x HR (SNS: positive inotropic and chronotropic effects)

- **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

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 perfusion [mL/min/100g]	2 – 4	60 – 120 (180) *static vs. dynamic work*	30 (10% CO_{max})

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Respiratory response to exercise

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

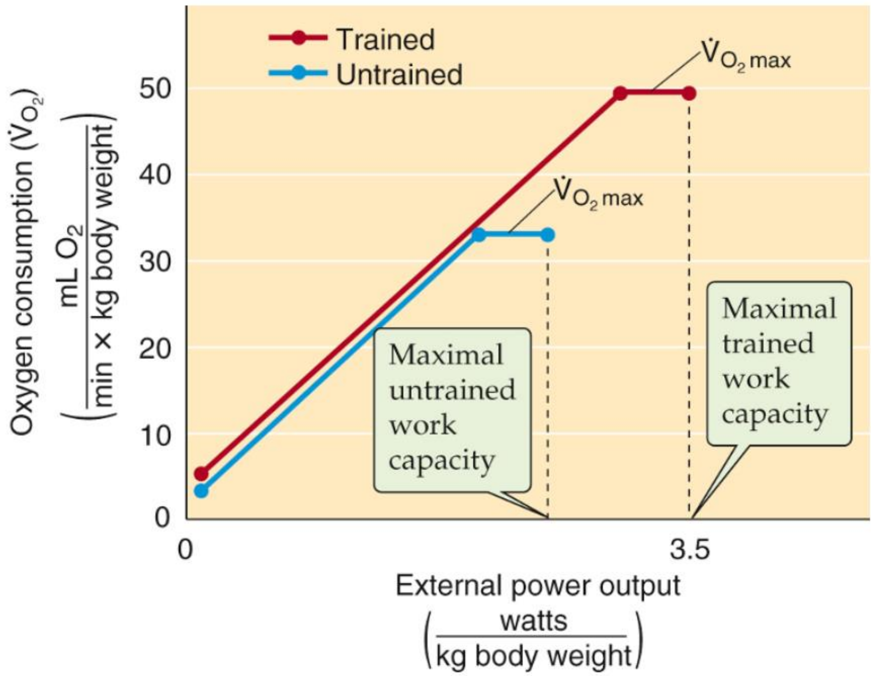
- Sympathetic stimulation (stress – anticipation)

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

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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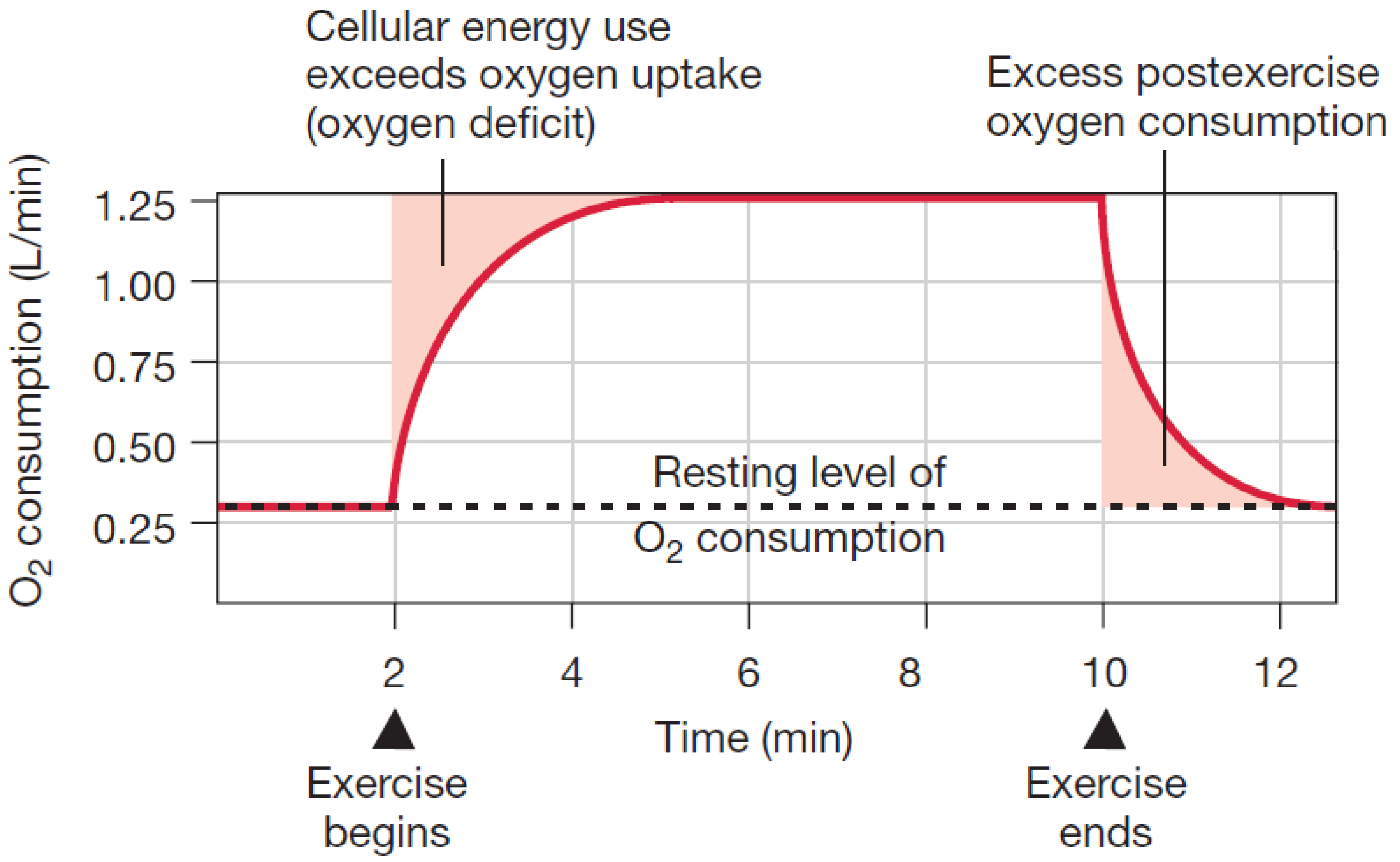
Determinants of $V_{O2\ max}$

1. Uptake of O_2 by the lungs
   – pulmonary ventilation
2. O_2 delivery to the muscles
   – blood flow (pressure gradient – cardiac output x resistance)
   – hemoglobin 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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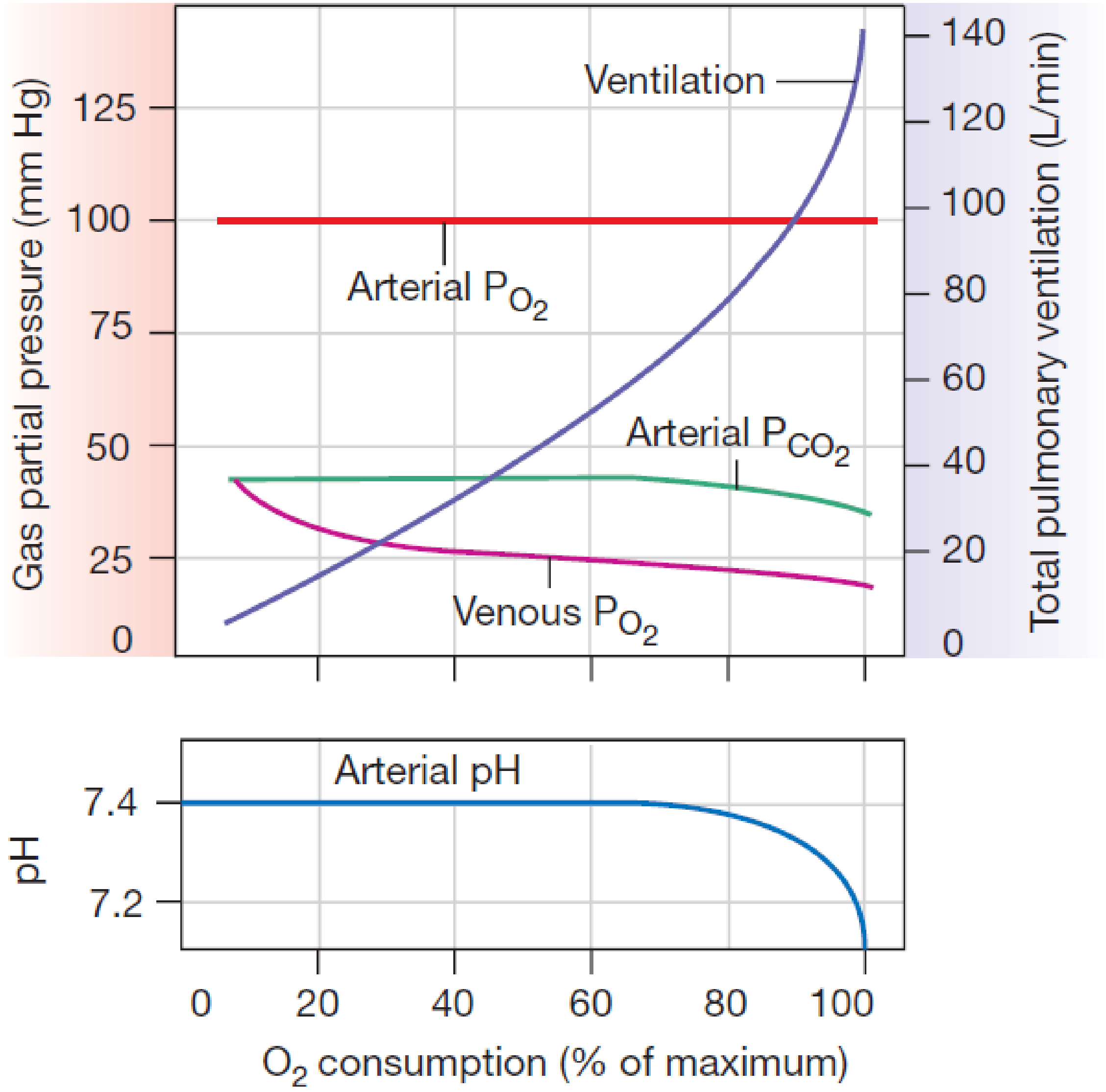
Blood gases during exercise



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

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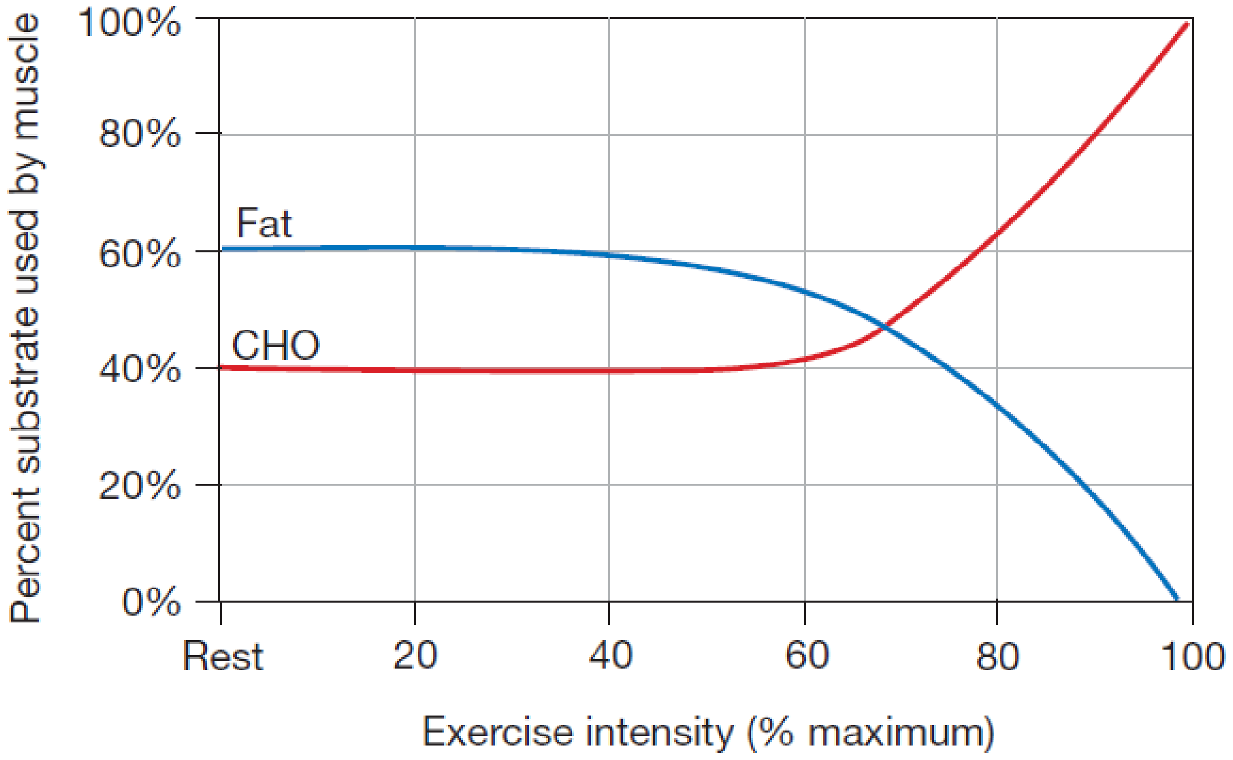
Energy substrate used by skeletal muscle during exercise

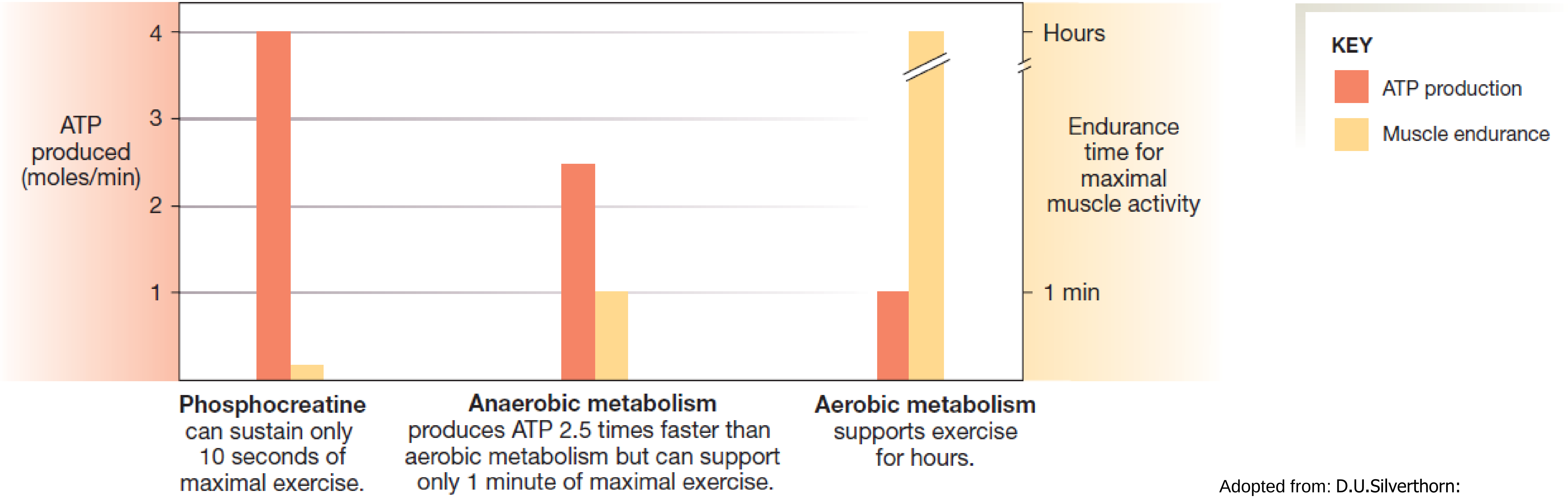
- Low-intensity e.: fats
- High-intensity e.: glucose



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)

Energy substrate use – aerobic *vs.* anaerobic



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Testing of fitness

- Spiroergometry
- Standardised workload
  - exact: 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