MUNI
MED

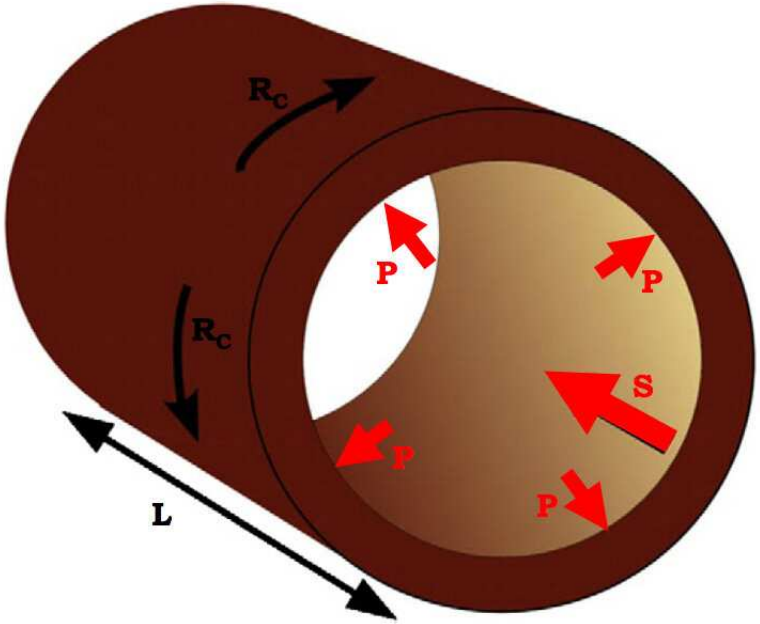
Blood pressure

Preclinical practice
13. 5. 2024

Department of Physiology, Faculty of Medicine, Masaryk University

Blood pressure

- **Blood pressure (BP): pressure of blood on the vessel wall**
  (arterial BP – part of the energy of systole converted into lateral pressure on the vascular wall)



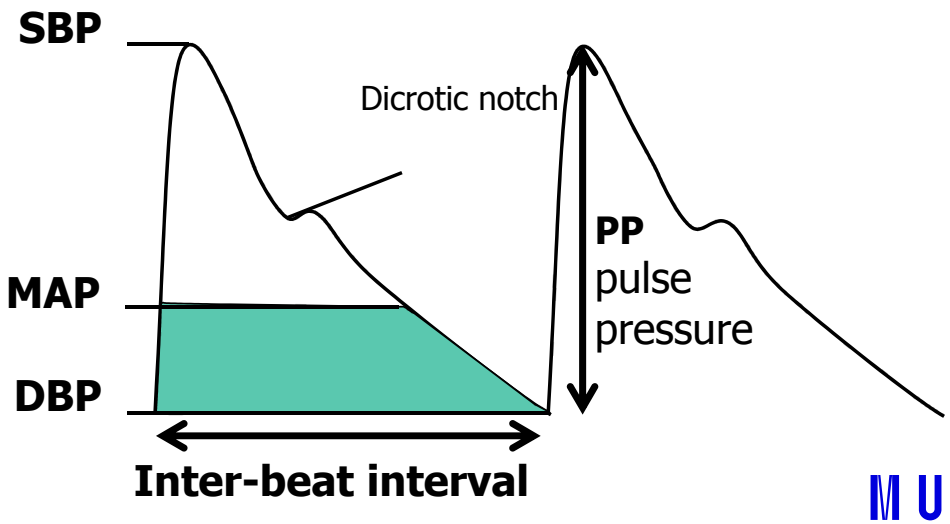
MUNI MED

Arterial blood pressure curve

- Pulse wave
  - arises when the blood is expelled from the left ventricle into the circulation during the systolic phase

- **Mean arterial pressure (MAP): mean value of blood pressure in the inter-beat interval** (IBI) – integral of the BP curve; **area above MAP = area below MAP**
  aproximation: MAP = DBP + 1/3 PP (PP = SBP – DBP)

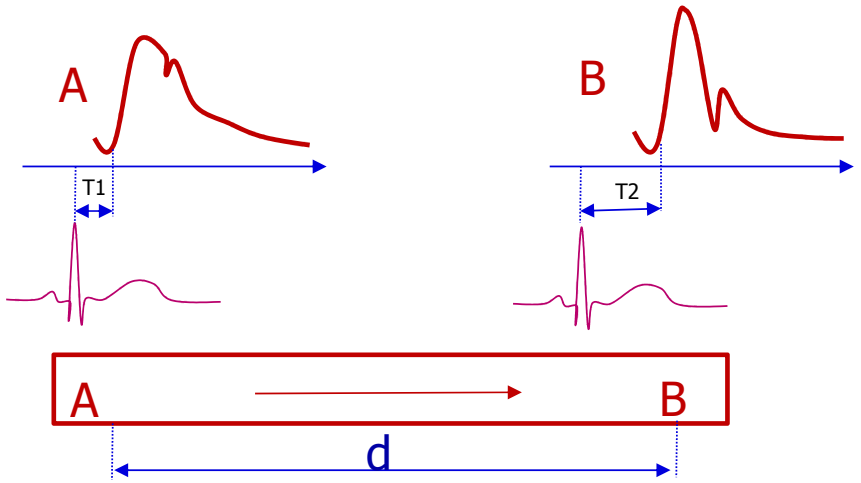
- **Definition:**
  - **SBP (systolic BP)**
    maximum of BP in the inter-beat interval
  - **DBP (diastolic BP)**
    minimum of BP in the inter-beat interval



MUNI MED

Pulse wave velocity (PWV)

- The pulse wave propagation rate (PWV) is measurable, around 4 m/s in the aorta.
  - Beware, the actual speed of blood flow is significantly lower, it is around 80-100 cm/s in the aorta
- The peripheral pulse wave velocity is 10-20 m/s (depending on the site of measurement)
- Measureable by inderect method: Sphygmography with ECG



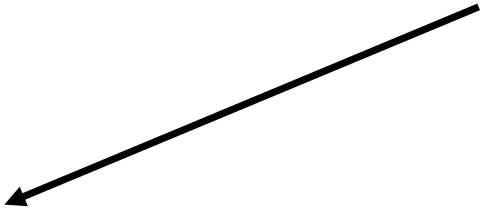
PWV= d/ (T2-T1)

MUNI MED

Blood pressure

- a function of cardiac output (CO) and total peripheral resistance
  - SBP is determined mainly by CO
  - DBP is determined mainly by TPR

Blood pressure = Cardiac output (CO) * Total peripheral resistence (TPR)

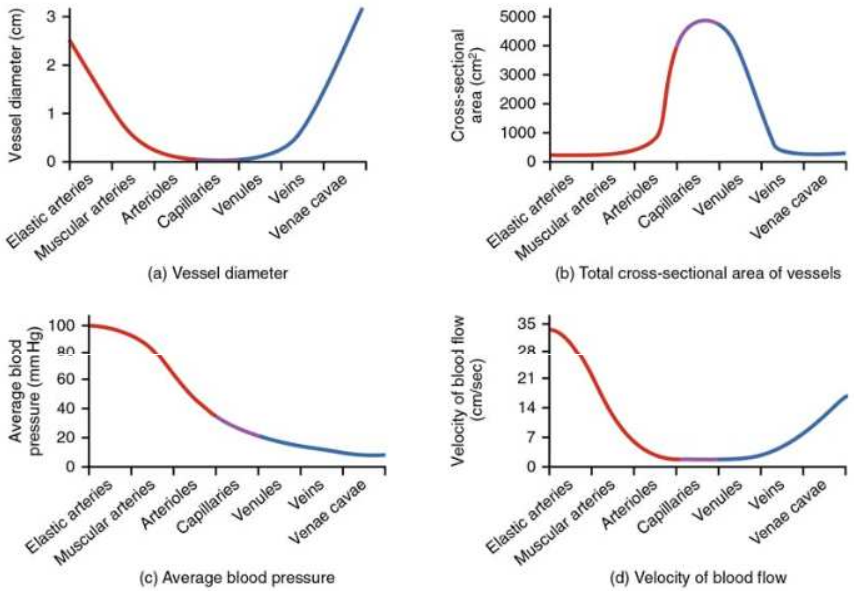


CO = Heart rate (HR) * Stroke volume (SV)

Total peripheral resistence

- consist of resistence from all vessels
- the narrower tube (↓ diameter) → the ↑ pressure needs to be exerted to maintain the flow
- determined by **the Hagen-Poiseuille law** for tube resistance

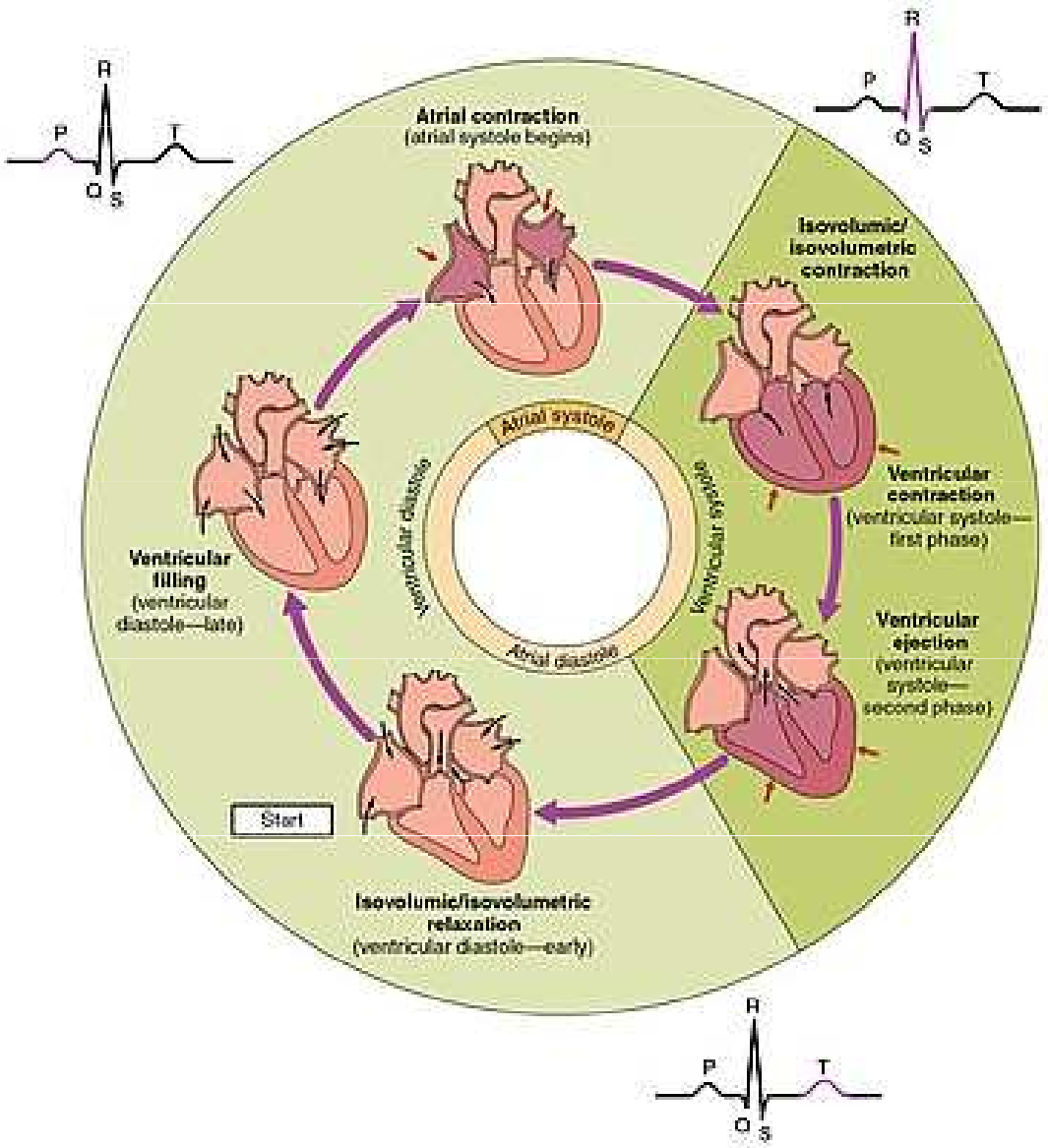
$$R = \frac{8 \cdot \eta \cdot L}{\pi \cdot r^4}$$



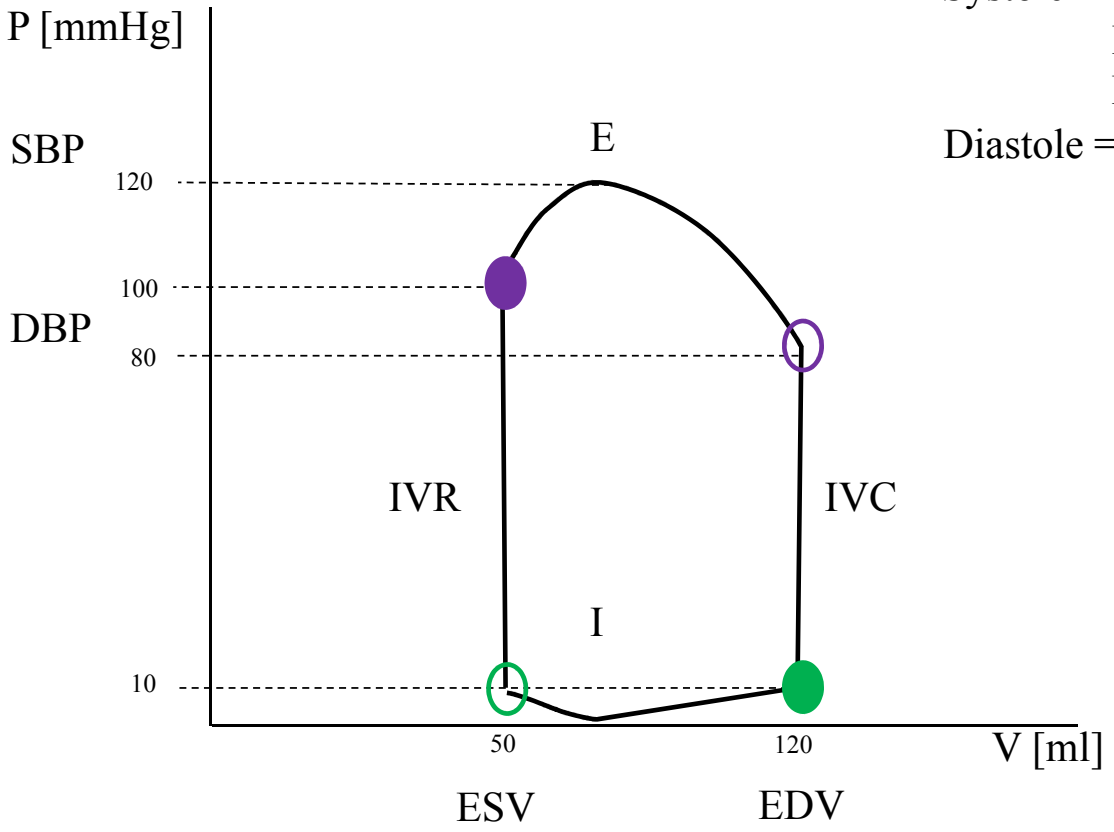
MUNI MED

Cardiac cycle

- Isovolumic contraction (IVC):
  - Contraction of ventricular myocardium leads to an increase in intraventricular pressure
- Ejection (E):
  - Intraventricular pressure overcomes diastolic pressure in big arteries, semilunar valves open, and blood flows to the arteries
- Isovolumic relaxation (IVR):
  - Semilunar valves close, rapid decrease in intraventricular pressure even below pressure values in atria, AV valves open
- Inflow (I):
  - Inflow phase (ventricular diastole), atrial systole



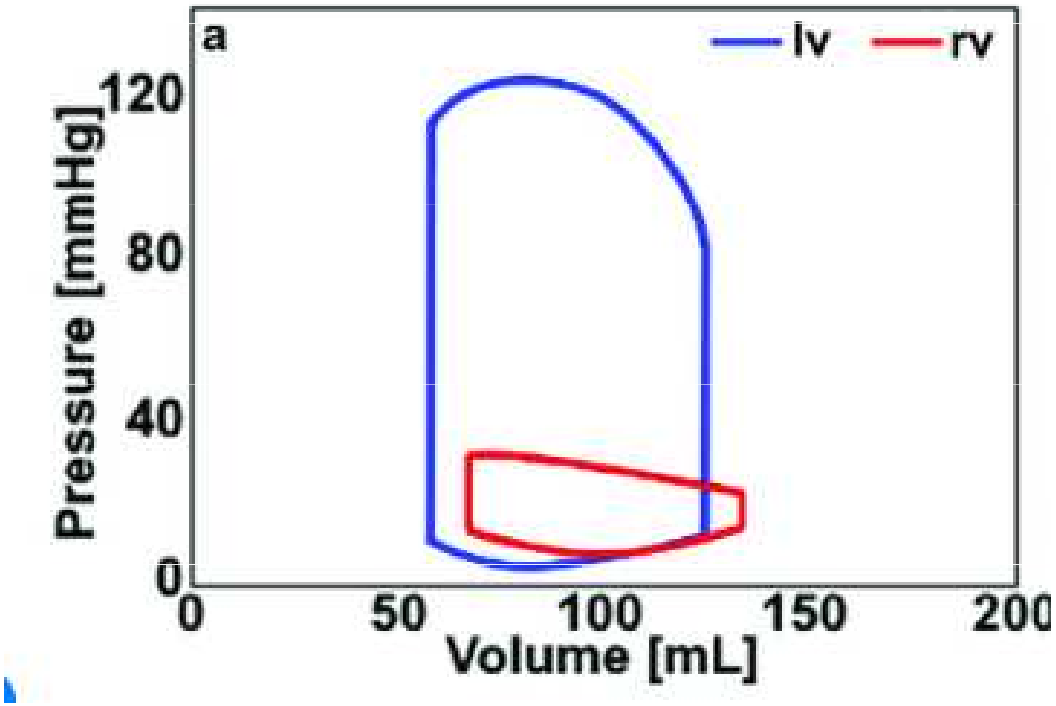
P-V diagram (Left ventricle)



Systole = IVC + E
IVC = 0.06 s
E = 0.21 s
Diastole = IVR + I
IVR = 0.07 s
I = 0.49 s

MUNI MED

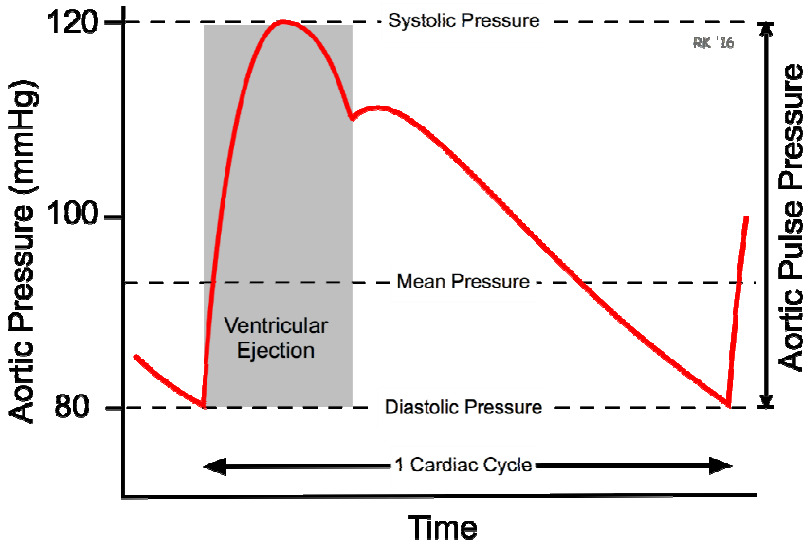
P-V diagram



MUNI MED

Arterial blood pressure

- stable blood flow thanks to aortic compliance
  - the aorta expands and holds the ejected blood volume (change of kinetic energy into elastic) and during diastole, it contracts and moves the blood further into the bloodstream (change of elastic energy to kinetic)

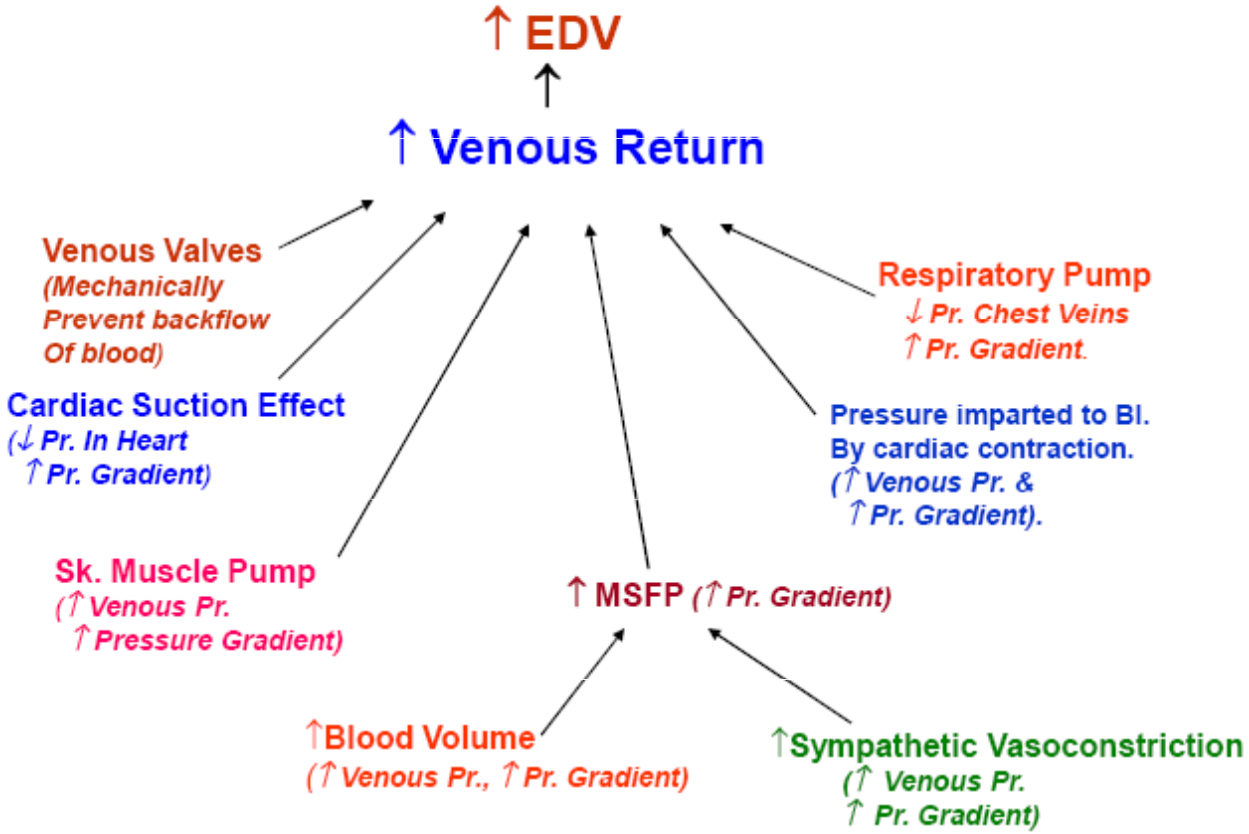


MUNI MED

Blood pressure in veins

- low pressure system
- peripherial pressure in veins is usually between 8 and 10 mmHg
- central vein pressure is aproximately 0–6 mmHg

Blood pressure in veins

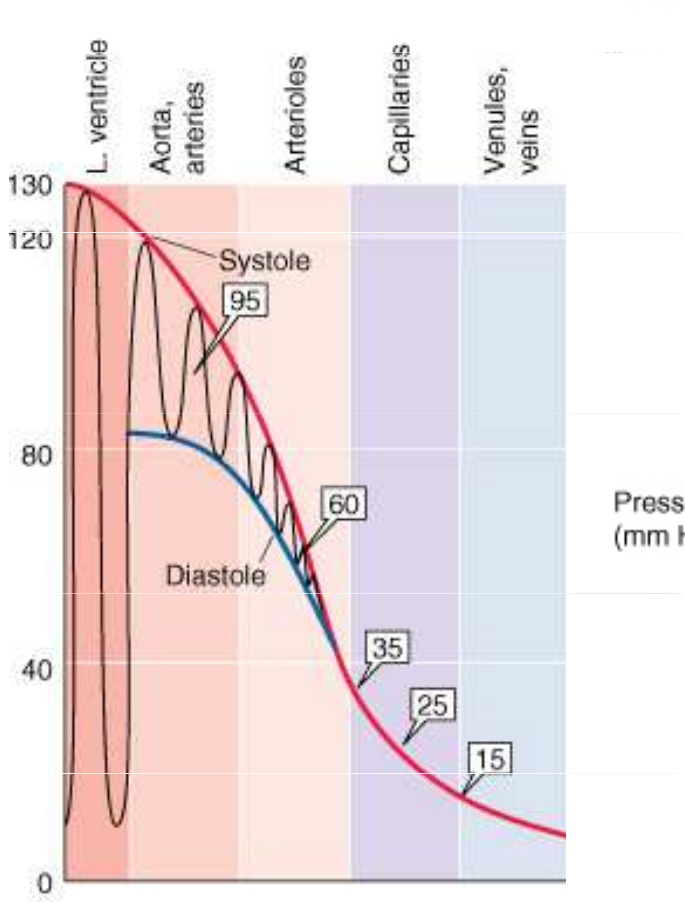


(Regulation of Venous Return)

MUNI MED

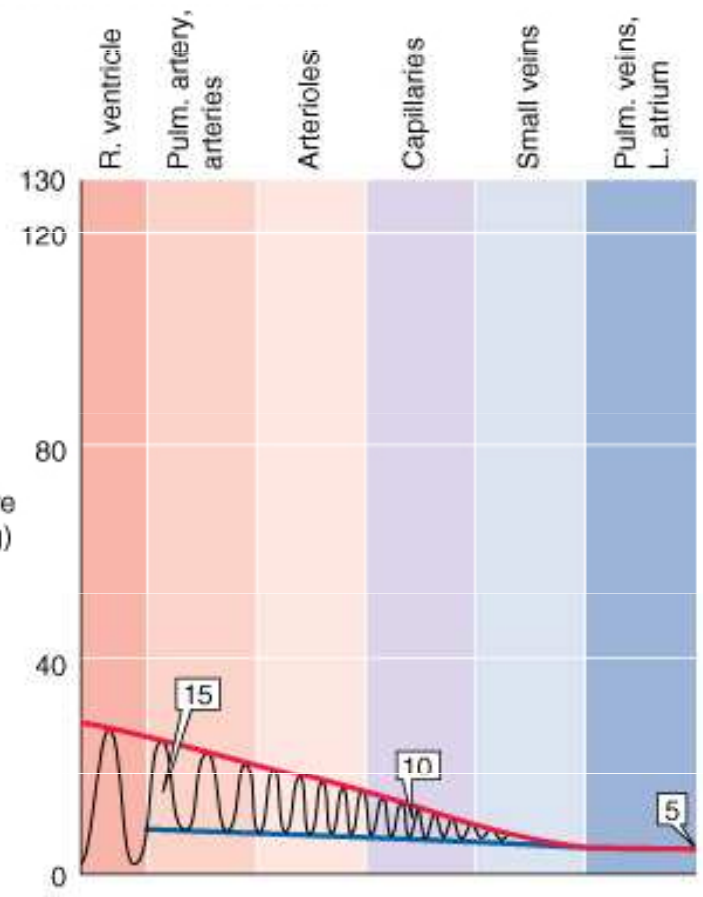
Blood pressure

Large circle



Pressure (mm Hg)

Small circle



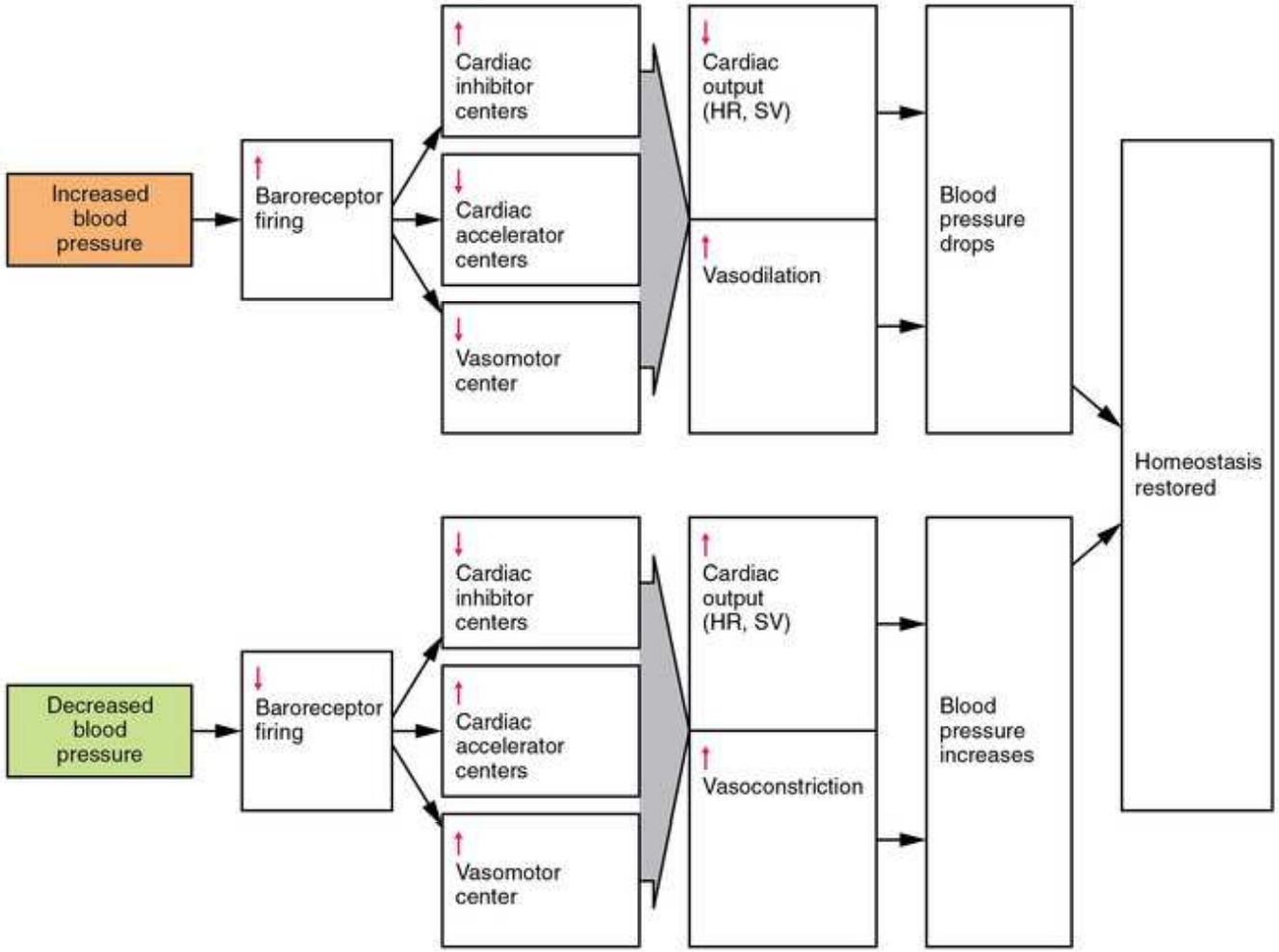
Boron and Boulpaep, Medical physiology

MUNI MED

Blood pressure regulation

- Short-term – neural control – mainly by baroreflex
  – chemical substancis
- Middle-term – hormonal regulation - renin-angiotensin-aldosterone system (RAAS)
- Long-term – hormonal regulation of blood volume

Short-term BP control – baroreflex



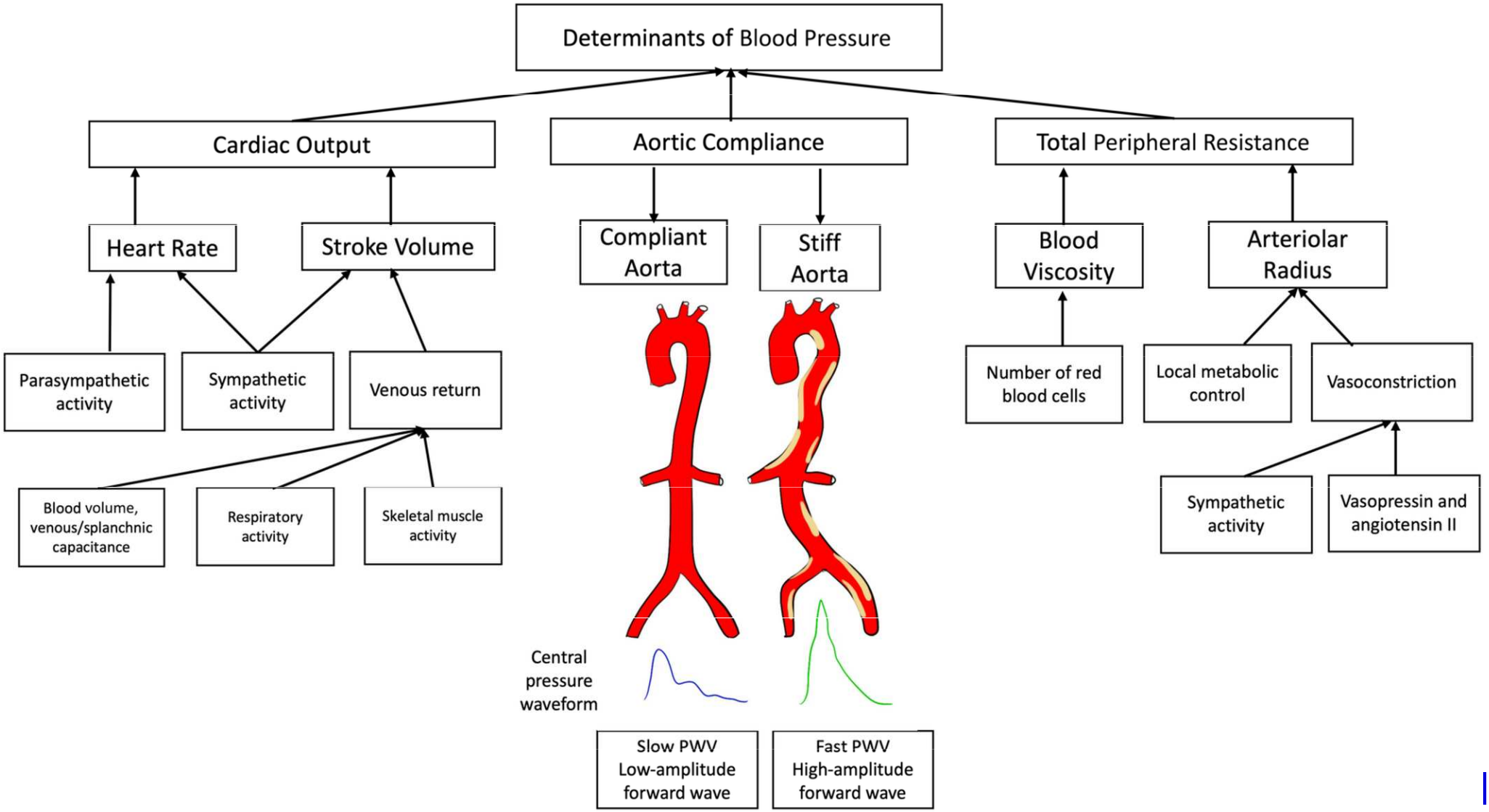
MUNI MED

BP control – substances

- vasoconstrictors
  - ATP, epinephrine, norepinephrine, antidiuretic hormone, and angiotensin II
- vasodilators
  - epinephrine, atrial natriuretic peptide, histamin, arginine (→NO), and lactic acid (metabolic reaction)

Blood pressure changes

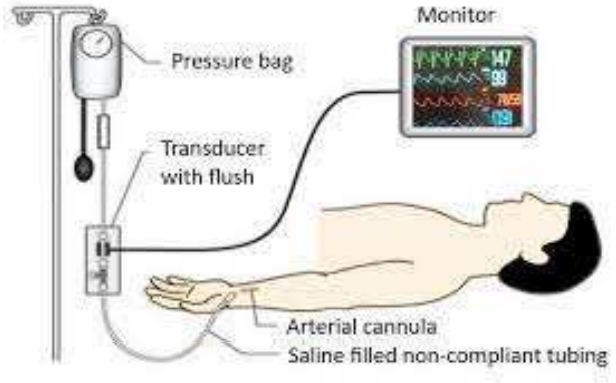
- Short-term influences
  - blood volume – influence on cardiac output (bleeding, dehydration)
  - external pressure to the vessels – intrathoracic and intraabdominal pressure (cough, defecation, childbirth, artificial ventilation)
  - position – orthostasis/clinostasis: redistribution of blood due to gravity
  - CNS – emotions, mental stress, …
  - physical exercise – BP changes depend on intensity, duration and type of exercise
  - heat (↓ TPR), cold (↑ TPR)
  - alcohol, drugs,…
- Long-term influences
  - age (the fastest changes during childhood and adolescence, in adults slow increase in SBP)
  - sex (men have higher BP)
  - genetic background


Determinants of Blood Pressure
Cardiac Output
Aortic Compliance
Total Peripheral Resistance
Heart Rate
Stroke Volume
Compliant Aorta
Stiff Aorta
Blood Viscosity
Arteriolar Radius
Parasympathetic activity
Sympathetic activity
Venous return
Number of red blood cells
Local metabolic control
Vasoconstriction
Blood volume, venous/splanchnic capacitance
Respiratory activity
Skeletal muscle activity
Sympathetic activity
Vasopressin and angiotensin II
Central pressure waveform
Slow PWV
Low-amplitude forward wave
Fast PWV
High-amplitude forward wave

II
MED

Methods of the arterial BP measurement

- Invasive
  - arterial catether



MUNI
MED

Methods of the arterial BP measurement

- Invasive
  - arterial catether
- Non-invasive
  - Auscultatory (sphygmomanometer, stethoscope)

Methods of the arterial BP measurement

- Invasive
  - arterial catether

- Non-invasive
  - Auscultatory (sphygmomanometer, stethoscope)
  - Oscillometric

MUNI MED

Methods of the arterial BP measurement

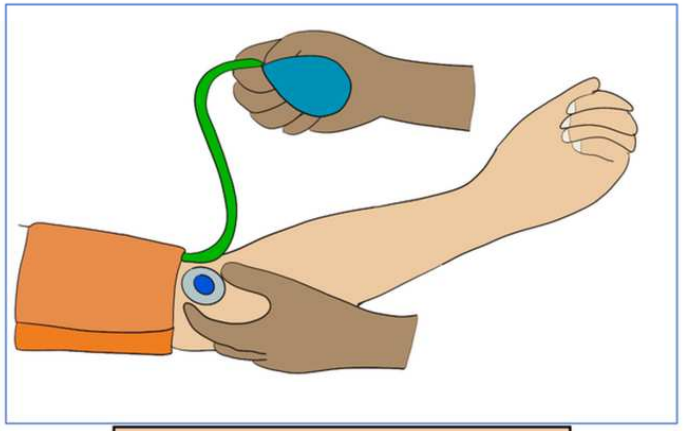
- Invasive
  - arterial catether

- Non-invasive
  - Auscultatory (sphygmomanometer, stethoscope)
  - Oscillometric

  - Photoplethysmographic/Peňáz/volume-clamp method

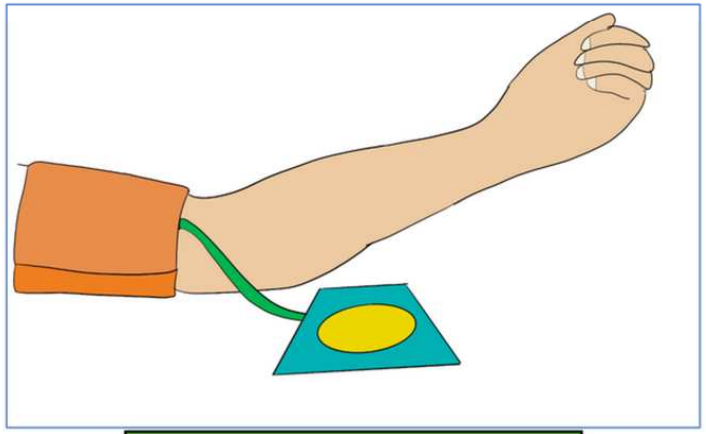
MUNI MED

Cuffed



Manual- Auscultatory method

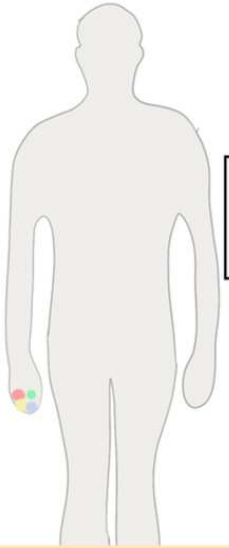
- Office-based blood pressure (BP) measurement
- Long-term (visit-to-visit) BP variability
- Validated devices
- Cheap and widely available
- Potential false assessment: Masked hypertension, white-coat hypertension



Automatic- Oscillatory method

- Home based BP measurement
- Medium-term (day-to-day) and short-term (hour-to-hour) BP variability
- Cheap and widely available
- Require patient education on proper methodology
- Interreader and intrareader variability- may require calibration and recalibration

Cuffless



Based on photoplethysmography (PPG)

- Continuous BP measurement
- Long-term, medium-term, short-term, very-short-term (beat-to-beat) BP variability
- Easy to use
- No cuff-related discomfort
- Potential use in telemedicine
- Simultaneous measurement of other parameters -HR, HRV, QTc interval, oxygen saturation.
- Need rigorous validation studies
- Limited data on clinical application

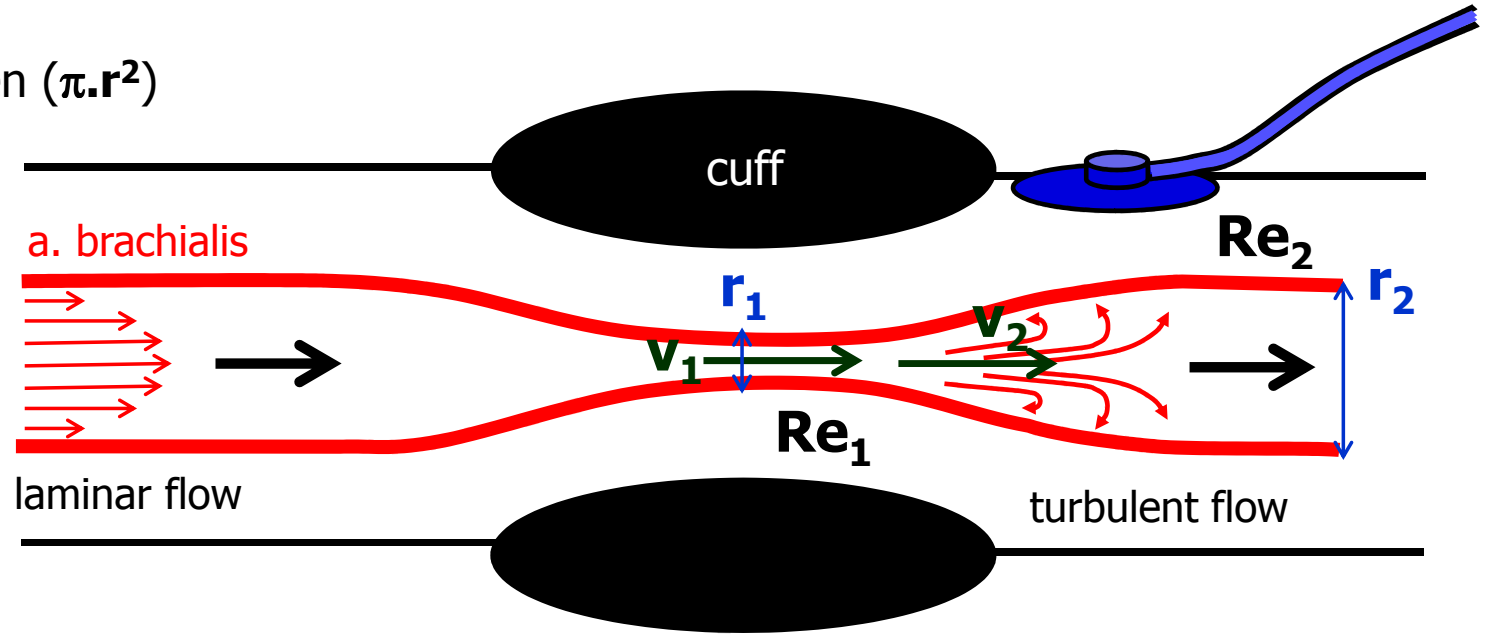
Basic principle: Laminar / turbulent flow

(Korotkoff sounds in auscultatory method; oscillation in oscilometric method).

$$Re = \frac{v \cdot S \cdot \rho}{\eta}$$

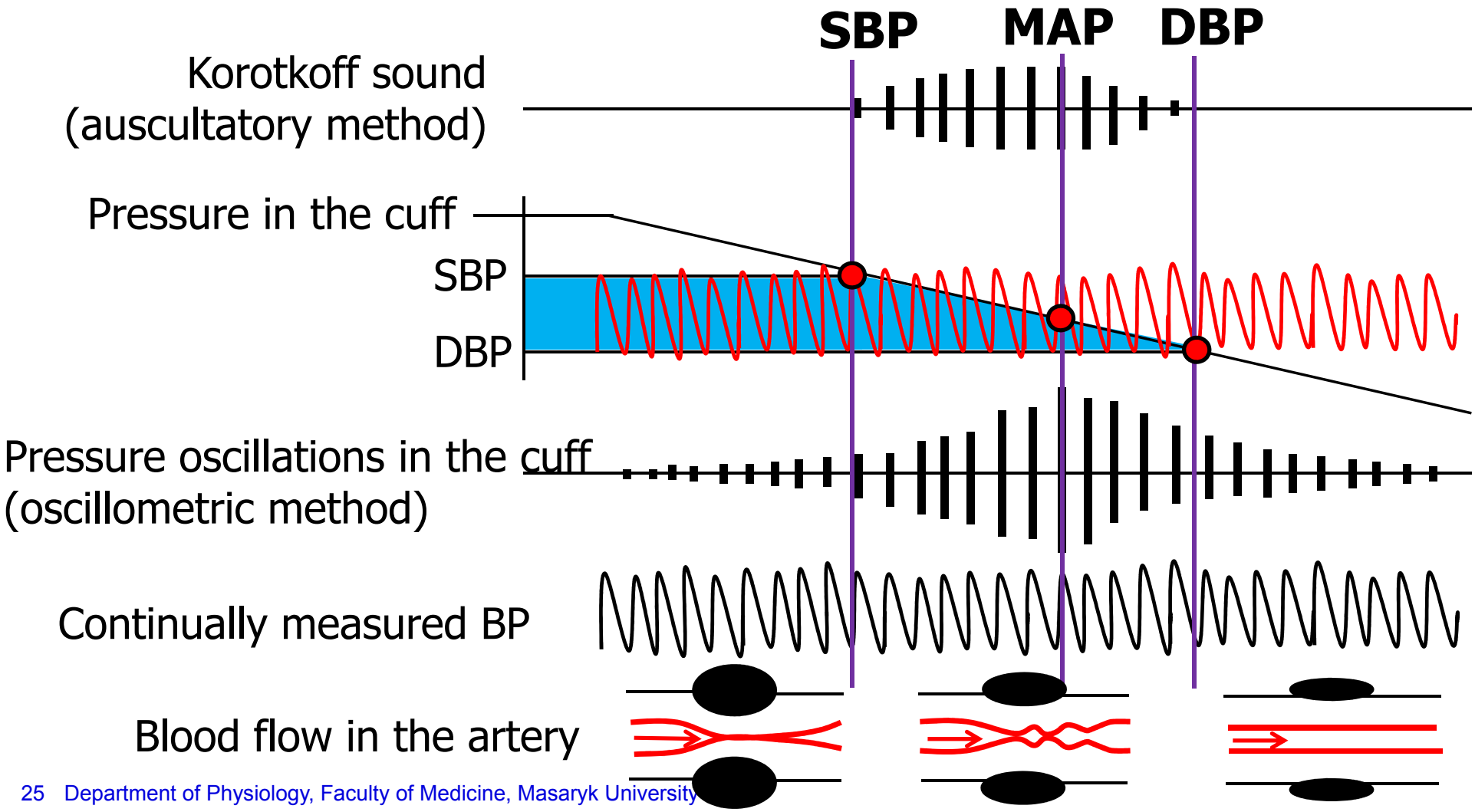
laminar flow Re < 2000
turbulent flow Re > 3000

Reynolds number Re: predicts the transition from laminar to turbulent of flow
v: velocity of blood flow
S: area of vascular lumen ($\pi.r^2$)
ρ: density of blood
η: viscosity of blood
(lower in anemia)



MUNI MED

Principles of BP measurement



MUNI MED

Photoplethysmographic/Peňáz/volume-clamp method

- **Peňáz method** - it is based on clamping the volume of finger arteries by fast changes of pressure in a special cuff equipped with a photoelectric plethysmograph to measure the vascular volume

- **Photopletysmography** - an optical method for measuring the amount of light that is absorbed or reflected by blood vessels in living tissue. The amount of light absorbed or reflected in photoplethysmography depends on the amount of blood in the optical path.

Assesmemt of BP varaibility

- Very short term – from continous BP measurement
  - Neurohormonal factors (baroreflex, sympathetic activation)
  - Nitric oxide, renin-angiotensin-aldosterone system
  - Enviromental, behavioral, and emotional factors
- Short tem (within 24-h)
  - Neurohormonal factors (baroreflex, sympathetic activation)
  - Environmental, behavioral, and emotional
  - Circadian rhythm

Assesmemt of BP varaibility

- Medium term (day to day)
  - drugs
  - vascular factors (endothelial damage, arterial compliance)
  - age
- Long tern (visit to visit)
  - drugs
  - seasonal changes
  - vascular factors (endothilial damage, arteriál compliance)
  - age

method	advantages	disadvantages	measured value
auscultatory	• exact estimation of SBP/DBP • easy, it doesn´t require electricity	• subjective, experience is necessary • SBP/DBP from different IBI	SBP and DBP
oscillometry	• exact estimation of MAP • automatic, fast • BP can be measured by layman, cheap (home measurement)	• DBP/SBP is calculated (dependence on model, influenced by a shape of pulse wave) • SBP/DBP from different IBI • false values during arrhythmia	MAP, sometimes SBP (it depends on a device)
24-hour BP monitoring	• BP record from whole day • diagnosis of white-coat hypertension	• disruptive influence of measuring (during sleeping) • SBP/DBP from different IBI	BP is measured each 15–60 min
photople-thysmography (Peňáz)	• continual BP record • possibility of beat-to beat SBP/DBP calculation (BP variability analysis)	• measurement on a finger, brachial BP is calculated • expensive device	continual BP record

MUNI MED

Rules for BP measurement

- Environment: pleasant room temperature, quiet surroundings
- Position: the patient sits with his back leaning backwards, both legs are on the floor, forearm rests on a surface
- Reasonable cuff size, correct positioning at heart level
- The measurement happens at rest and starts after 5 – 10 minutes of sitting down
- Measurement by auscultatory method
  - Inflate the cuff to a pressure 30 mmHg higher than the pressure at which the radial pulse disappeared
  - The pressure reduction rate in the cuff is 2 – 3 mmHg/s
  - The pressure value is determined with 2 mmHg accuracy
- The BP should be measured 3 times at least five minutes apart and the final BP value is a mean value of the last two measurements

Diagnosis of hypertension

	blood pressure	SBP [mmHg]	DBP [mmHg]	possible complications
normal	optimal	<120	<80	
	normal	120 – 129	80 – 84	
	high normal	130 – 139	85 – 90	
hypertension	1. stage	140 – 159	90 – 99	without organ changes
	2. stage	160 – 179	100 – 109	hypertrophy of L ventricle, proteinuria, angiopathy, ...
	3. stage	> 180	> 110	morphological and functional changes of some organs, retinopathy, heart and renal insufficiency, ischemia of CNS, bleeding in CNS

- Isolated systolic hypertension: SBP> 140 and DBP <90 mmHg
- High normal BP – annual monitoring recommended
- Home measurement to exclude white coat hypertension
- Hypertension is diagnosed when:
  - average BP from 4–5 examinations is > 140/90 mmHg
  - BP during a home measurement repeatedly > 135/80 mmHg
  - mean BP from 24-hour monitoring is > 130/80 mmHg

MUNI MED