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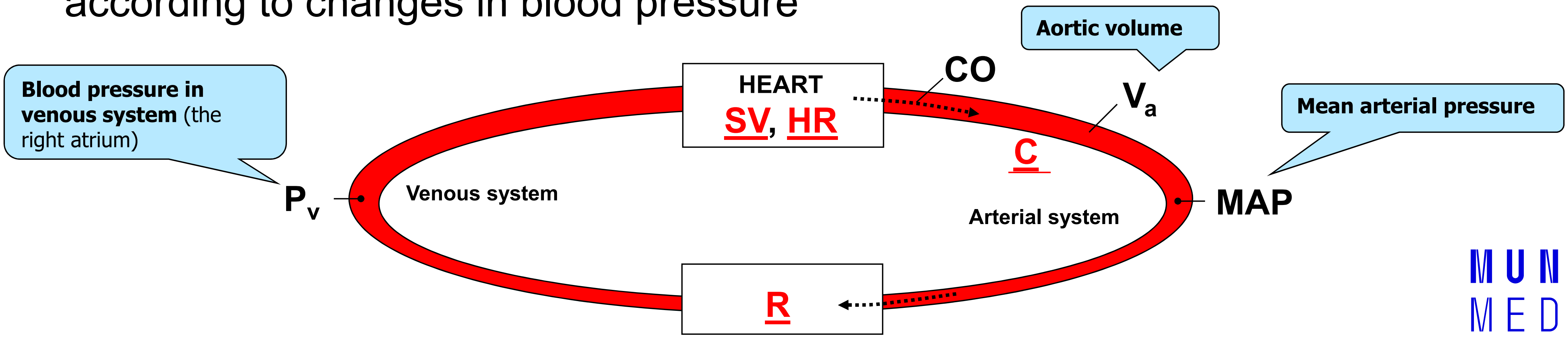
Digital model of aortic function

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

Definitions of keywords and symbols

- *Stroke volume* (SV) – a volume of blood ejected from the left ventricle to the aorta during one contraction
- *Heart rate* (HR) – number of heart contractions in 1 minute
- *Cardiac output* (CO) – blood flow through the heart or the aorta in one minute, CO = SV * HR
- *Peripheral vascular resistance* (R) – resistance of small arteries to blood flow (mainly arterioles and capillaries)
- *Compliance of the aorta* (C) – the ability of the aorta to change its volume according to changes in blood pressure



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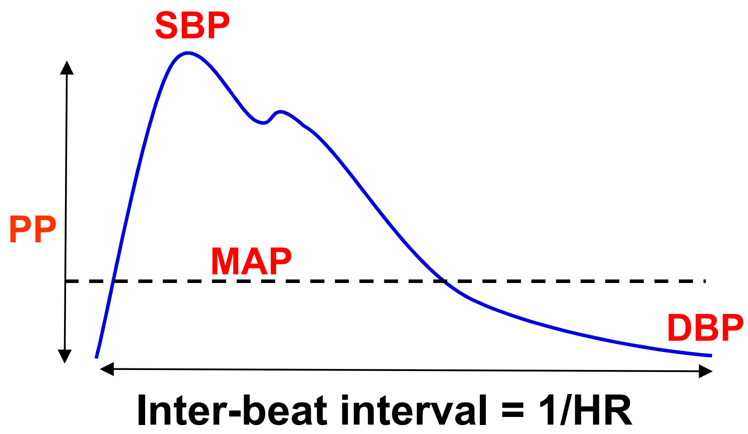
Definition of keywords – arterial BP curve

- *Systolic blood pressure* (SBP) – the highest BP in the inter-beat interval
- *Diastolic blood pressure* (DBP) – the lowest BP in the inter-beat interval
- *Mean arterial pressure* (MAP) – mean value of blood pressure in the inter-beat interval
- *Pulse pressure* (PP) – blood pressure amplitude in the inter-beat interval, PP = SBP – DBP



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Derivation of hemodynamic parameters

Flow rate formula:

$$CO = \frac{\Delta P}{R} = \frac{MAP - P_v}{R}$$

$$MAP - P_v = CO \cdot R$$

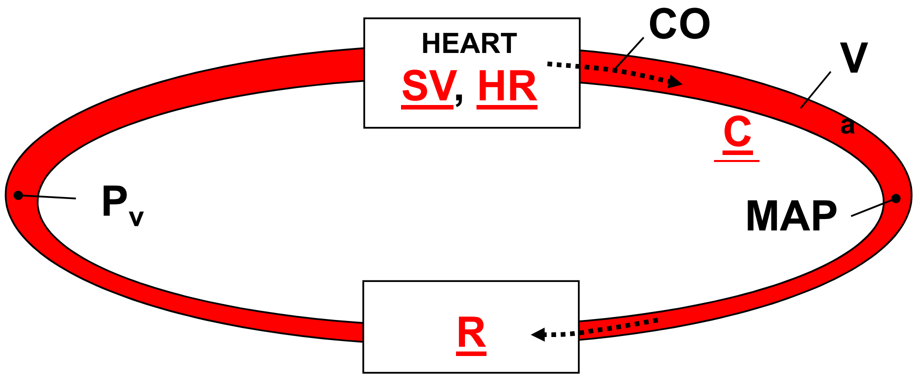
$P_v \to 0$

BP in venae cavae near the heart is close to zero

And

$CO = HR \cdot SV$

$$\boldsymbol{MAP \cong CO \cdot R = HR \cdot SV \cdot R}$$



Compliance formula:

$$C = \frac{\Delta V}{\Delta P}$$

A change in aortic blood volume is stroke volume

$\Delta V = SV$

A change in aortic BP is pressure pulse

$\Delta P = PP = SBP - DBP$

$$C = \frac{\Delta V}{\Delta P} = \frac{SV}{PP}$$

$$\boldsymbol{PP = \frac{SV}{C}}$$

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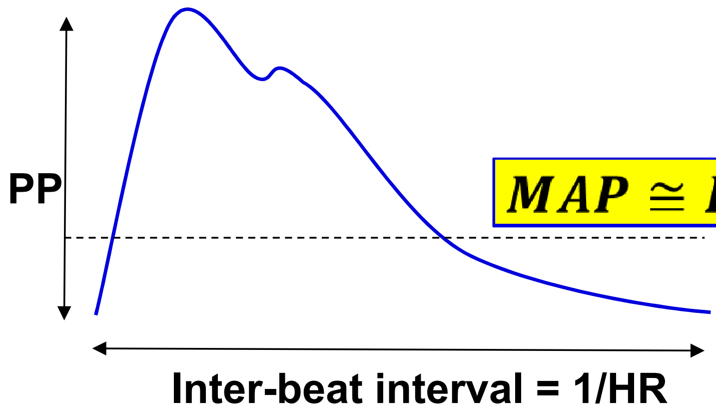
Final definition of arterial BP curve

The arterial blood pressure curve can be divided into the steady component and the pulsatile component

- **The steady component** – MAP, the driving force for blood flow
  Mean arterial pressure is directly proportional to heart rate, stroke volume and peripheral vascular resistance
- **The pulsatile component** – PP, a consequence of the pulsating character of blood pumping by the heart, alternation of systolic and diastolic pressures
  Pulse pressure is directly proportional to stroke volume and inversely proportional to aortic compliance

The arterial pressure curve can be constructed based on knowledge of HR, SV, R and C

$$PP = \frac{SV}{C}$$



$$MAP \cong HR \cdot SV \cdot R$$

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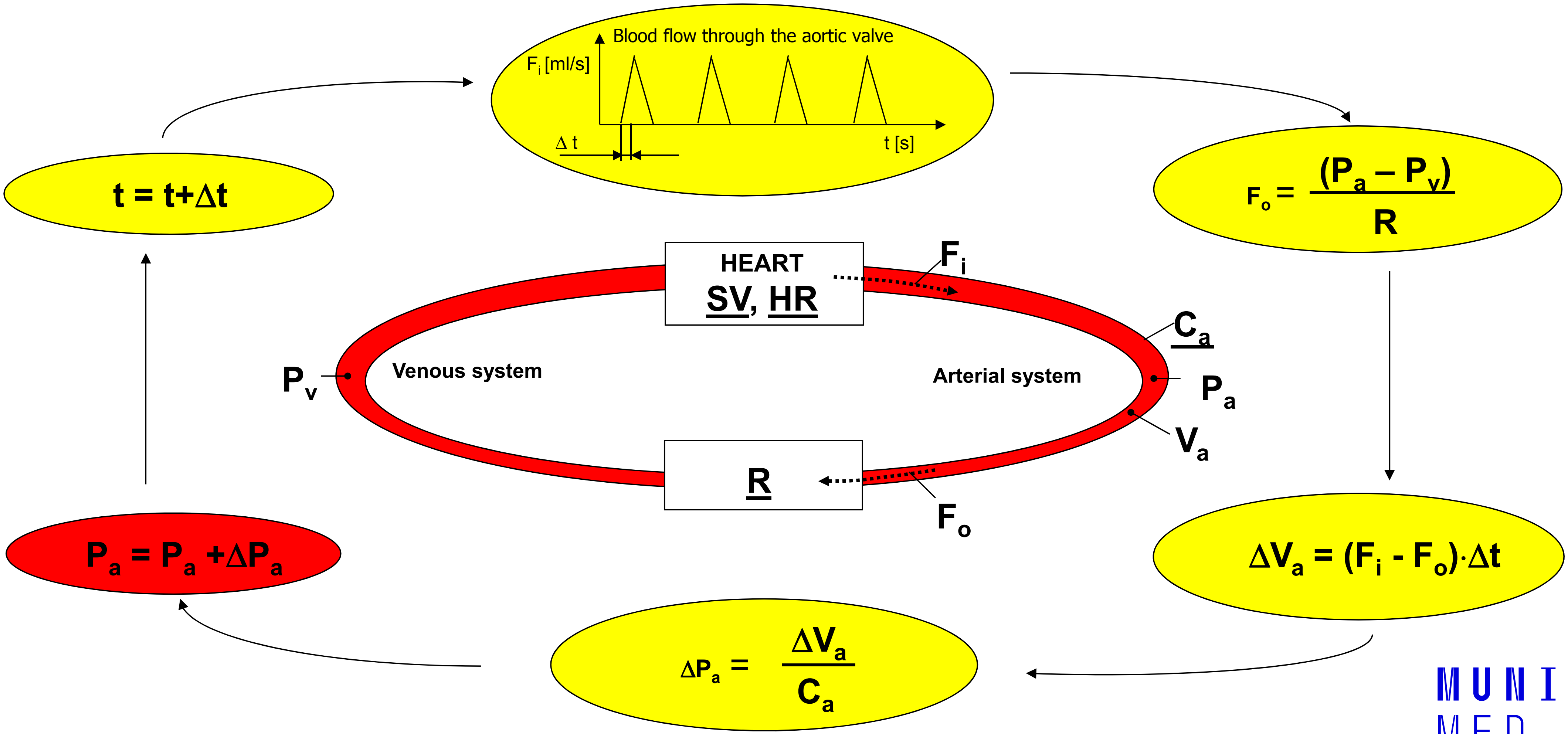
Model of aortic function

Arteriální BP in time t: P_a



Peripheral venous resistence – R

- Resistance is a pressure gradient that we need to develop to maintain a flow through the tube (e.g. if the tube narrows, a higher pressure needs to be exerted to maintain that flow)
- The resistance of the vessel is determined by **the Hagen-Poiseuille law** for tube resistance
  r – radius of the vessel (in the vascular system, the radius equals the sum radius of all vessels at a given level, e.g. all capillaries); η – viscosity; L – blood vessel lenght
  Units: mmHg.s/L, mmHg.min/L kPa.min/L, dyn.s/cm^3,…

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

- The vessel‘s radius as the largest effect on the R because it is in the 4th power (reducing the radius by only 16% leads to a doubling of resistance!)
- The total vascular resistance of the large circulation in humans: 700-1600 dyn.s/cm^3
- Small arteries and arterioles (resistance vessels) have the greatest effect because they have a large proportion of smooth muscle in their walls, thus they can significantly change their radius. The lowest resistance is in a capillary bed (capillaries are small but there are many of them).
- Increase in R (common situations)
  - sympathetic activation (most blood vessels have mainly vasoconstrictive alpha receptors) – for example, baroreflex response to the orthostatic change of position, stress, other vasoconstrictive hormones
  - cold (a jump into the cold water after sauna)
- Decrease in R
  - baroreflex response to the clinostatic change of position, heat (sauna)
  - dynamic physical exercise (the more muscles are involved, the lower the R)

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Stroke volume, heart rate – SV, HR

- The sympathetic nervous system increases the heart activity – number and force of contraction – to increase the cardiac output

SV is determined by

- Sympathetic regulaction of contraction force
- Ventricular filling (venous return) which also affects contractility (Frank-Starling)

- Increase in SV
  - clinostatic change in position (before baroreflex reaction, ↑ blood volume (rapid infusion IV)
- Decrease in SV
  - orthostatic change of position (before baroreflex reaction), ↓ blood volume (dehydration, blood loss, blood donation)

HR changes are a reflection of the sympathetic-vagal balance

- Increase in HR
  - Mental, physical and emotional stress
- Decrease in HR
  - Sleep

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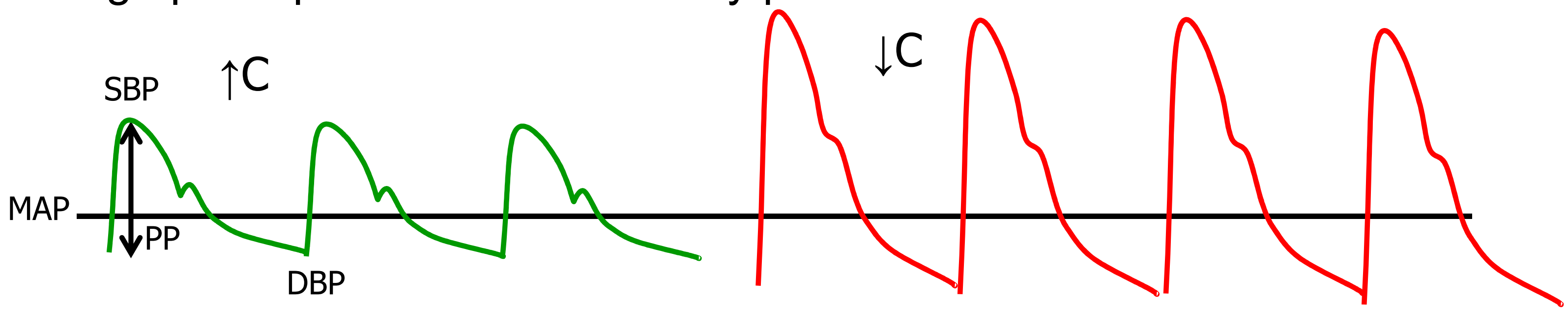
Aortic function

- During systole, 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)
- Aortic function:
  - Continuationization of blood flow (blood flow does not stop in diastole)
  - Damping of pulse pressure (while maintaining MAP)

- Aortic compliance is highest in childhood, with age it decreases (loss of elastic fibres). Diseases that reduce compliance are e.g. diabetes and hypertension.
- Decreased C – increase in SBP and a slight decrease in DBP (isolated systolic hypertension)
  - The heart must work against higher pressure in systole, exhaustion of the heart
  - High pulse pressure mechanically puts more strain on the vessels



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