CARDIAC MECHANICS

HEART AS A PUMP

CARDIAC CYCLE

HEART FAILURE

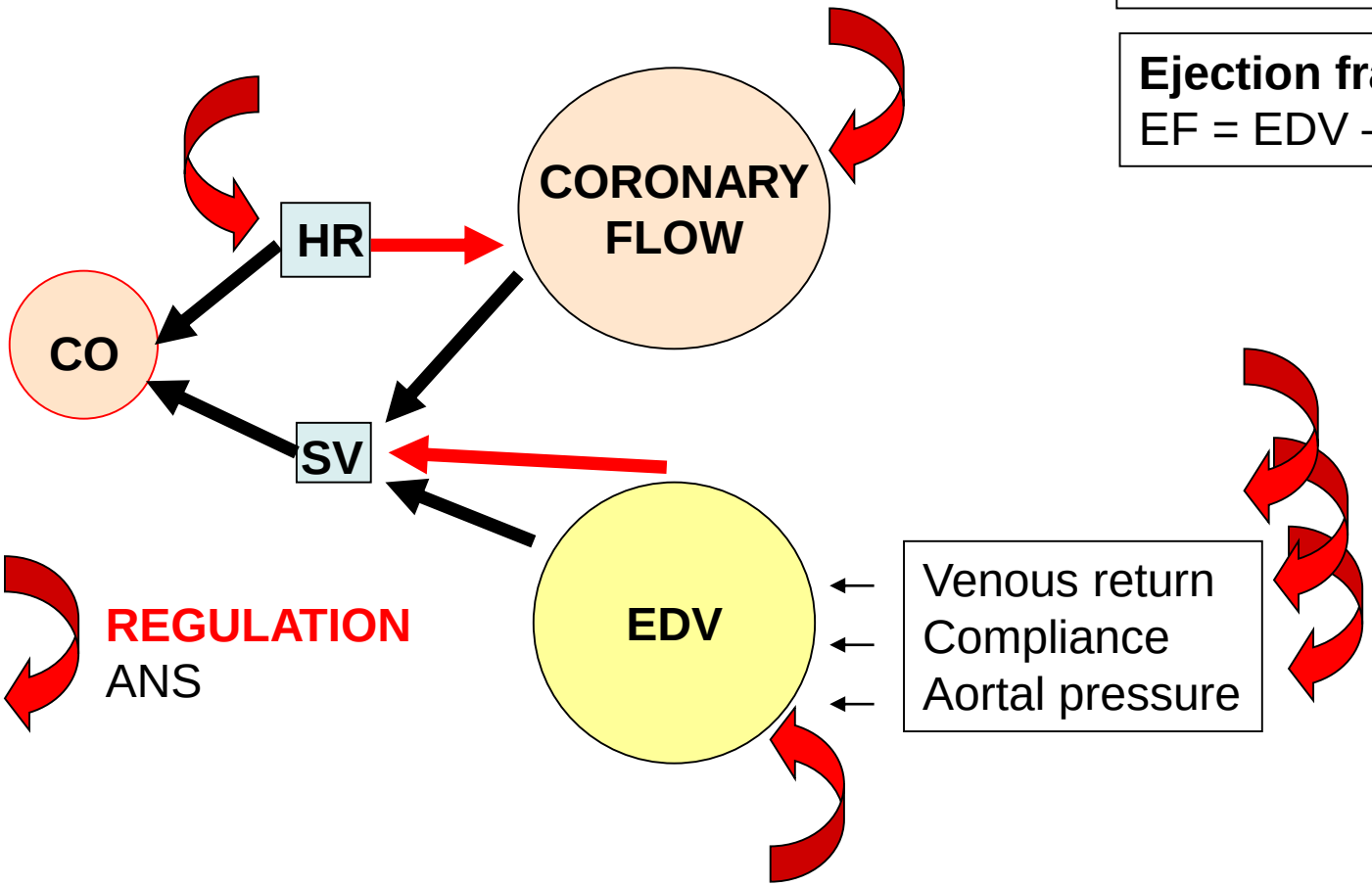
CARDIAC OUTPUT (CO)

LV = RV

CO = HR x SV 5l/min

SV = EDV - ESV 70ml

Ejection fraction
EF = EDV – ESV / EDV >60%



AUTOREGULATION of cardiac contraction

Heterometric: Starling law

Homeometric: Frequency effect

CONTRACTILITY

Ability to contract

Depends on:……..

CARDIAC RESERVE = maximal CO / resting CO **4 - 7**

CORONARY RESERVE = maximal CF / resting CF **3,5**

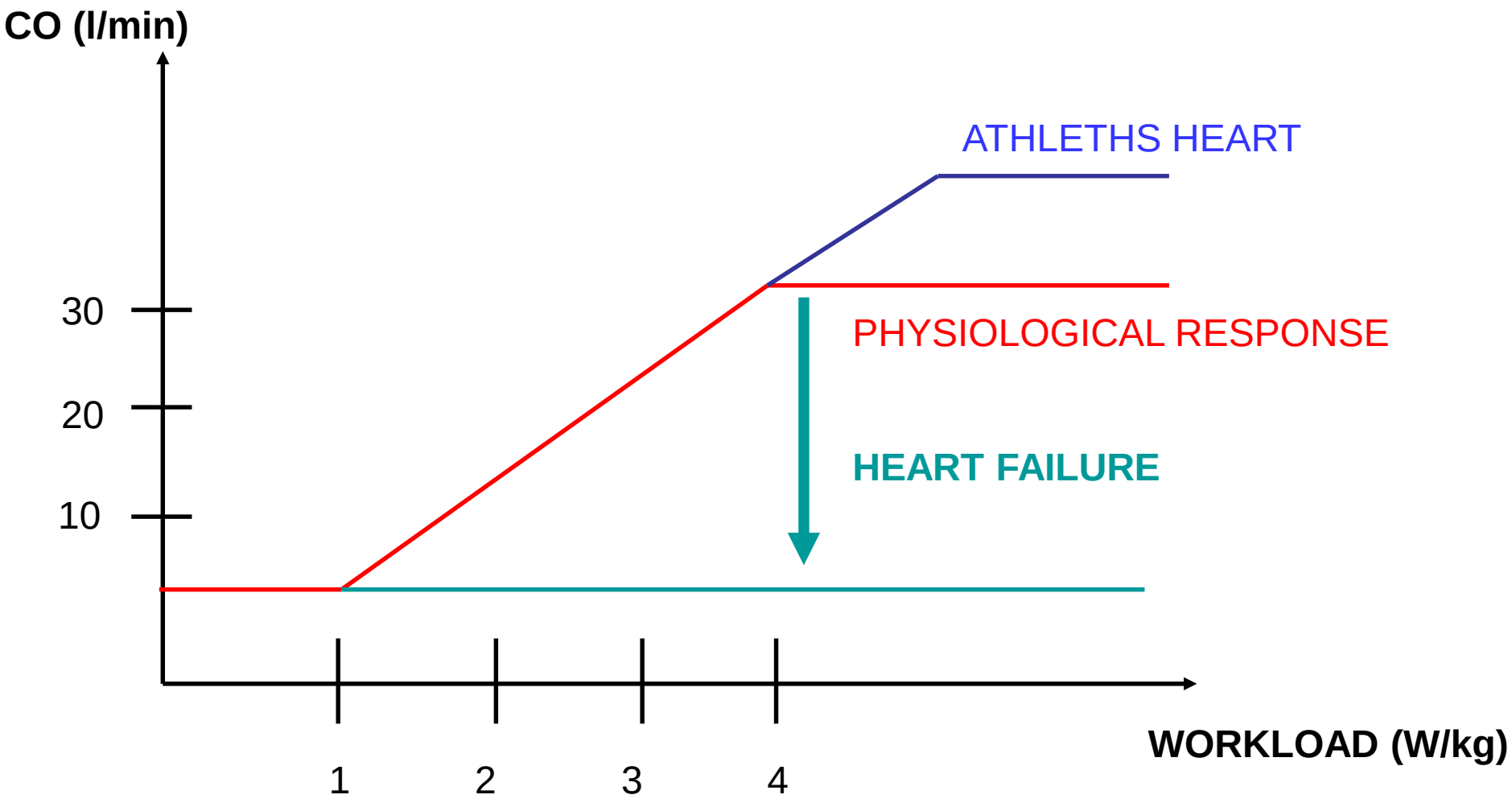
CHRONOTROPIC RESERVE = maximal HR / resting HR **3 - 5**

VOLUME RESERVE = maximal SV / resting SV **1,5**

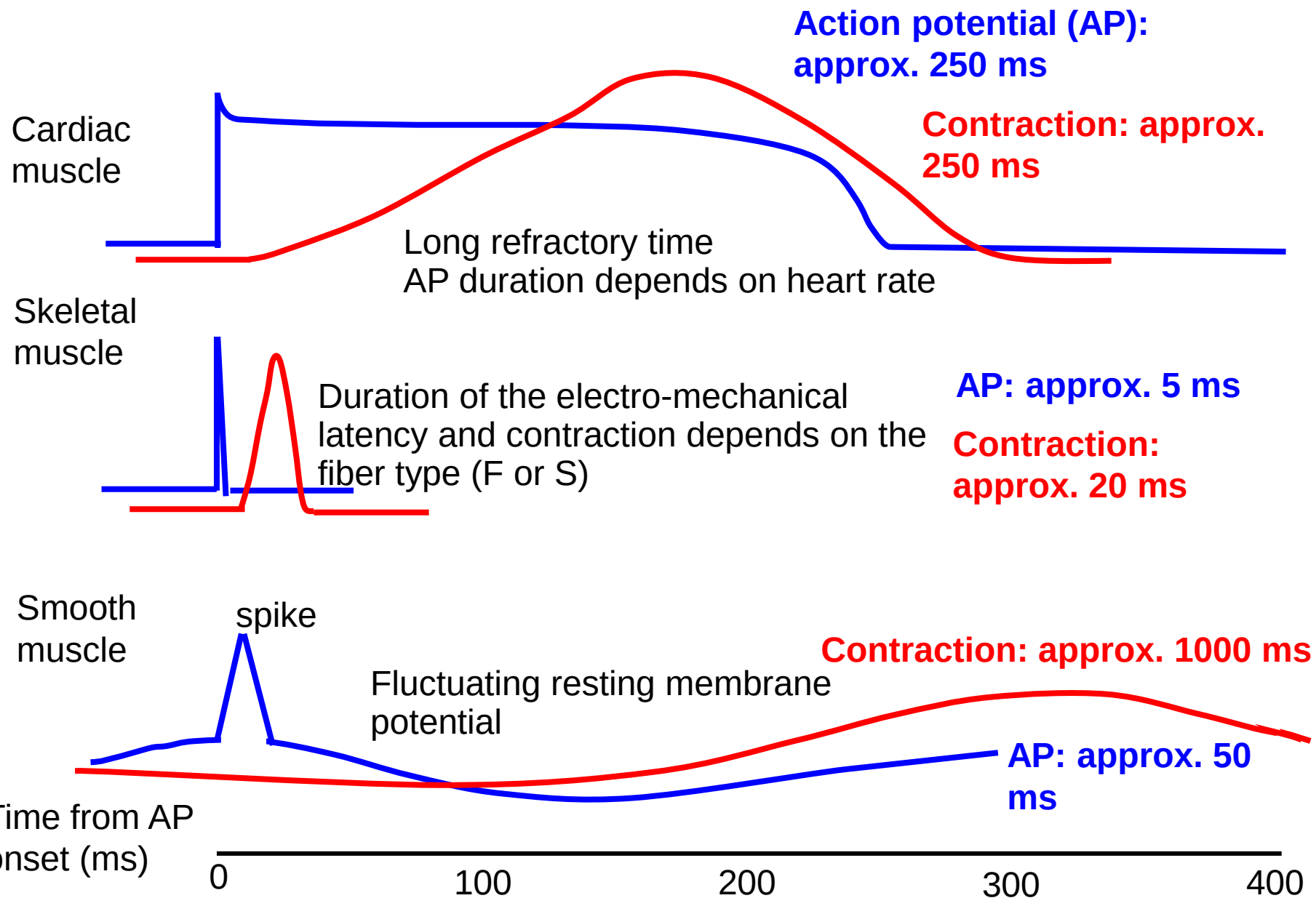
CARDIAC INDEX = CO / body surface

CF = coronary flow

CARDIAC RESERVE

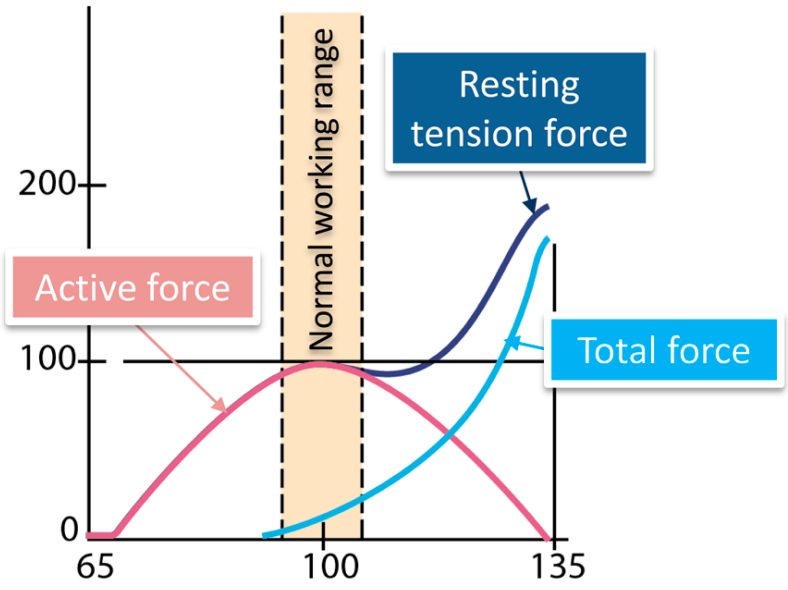


Skeletal, cardiac and smooth muscle – action potential and contraction



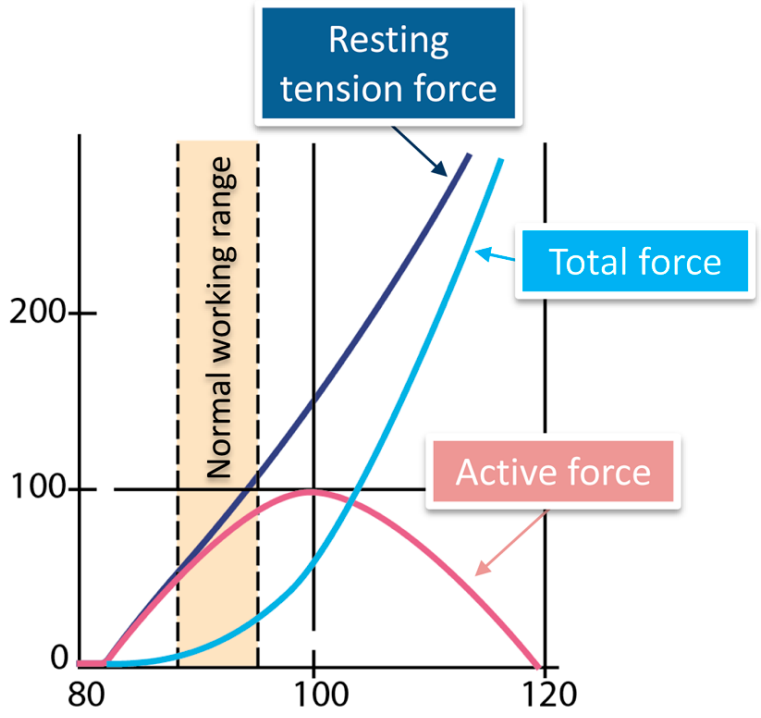
LENGTH – TENSION RELATIONSHIP

1. Striated muscle



Relative muscle lenght
(lenght at max. force, L_{max} = 100%)

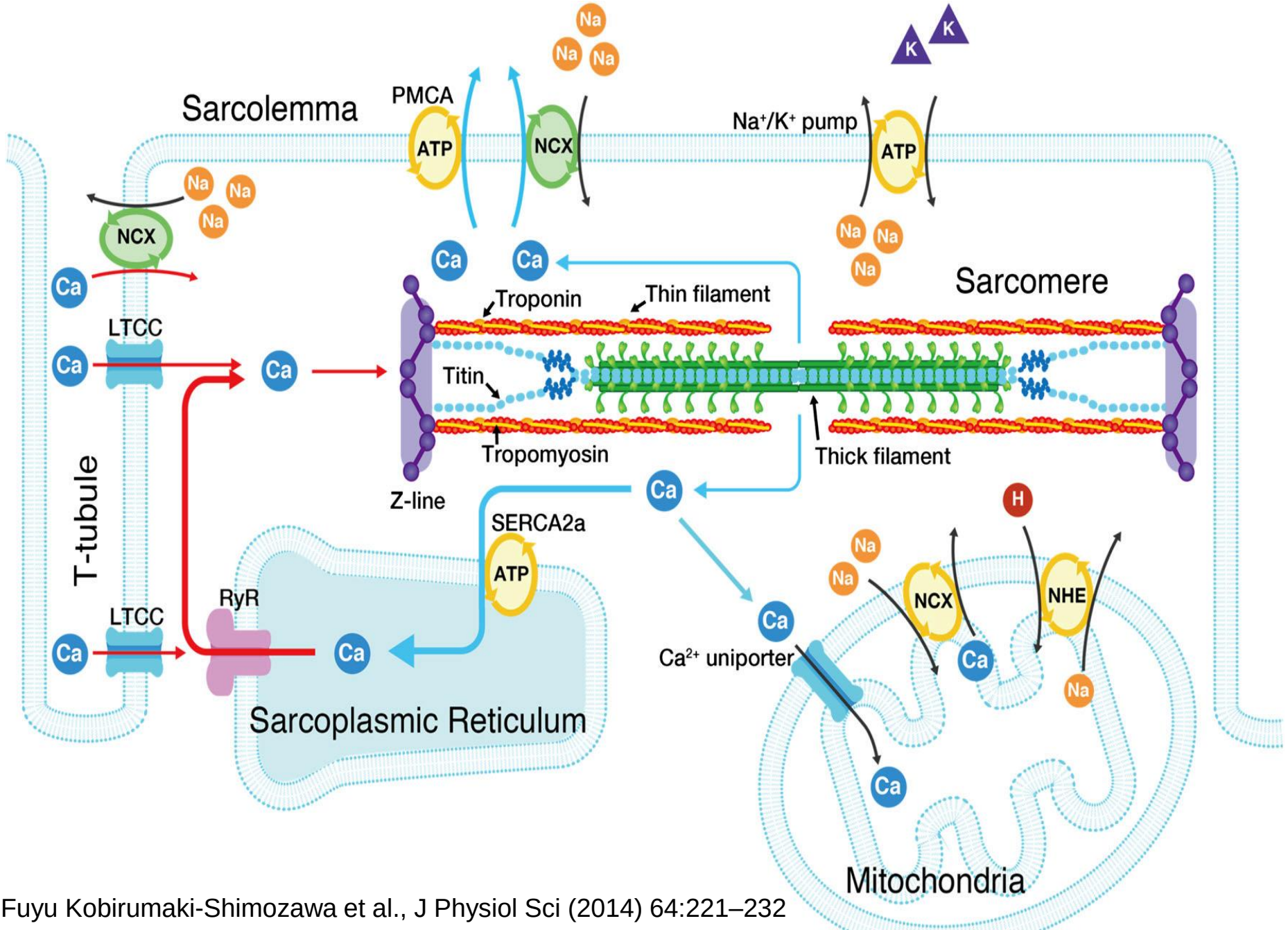
2. Cardiac muscle



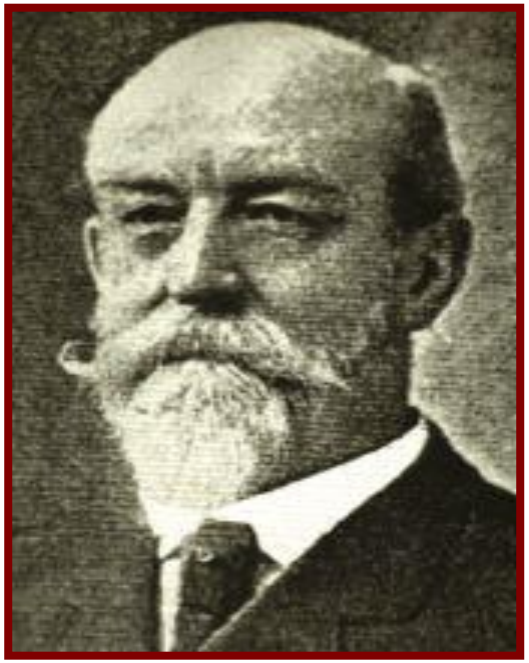
Relative muscle lenght
(lenght at max. force, L_{max} = 100%)

Passive tension, active tension, isometric contraction, isotonic contraction, auxotonic contraction

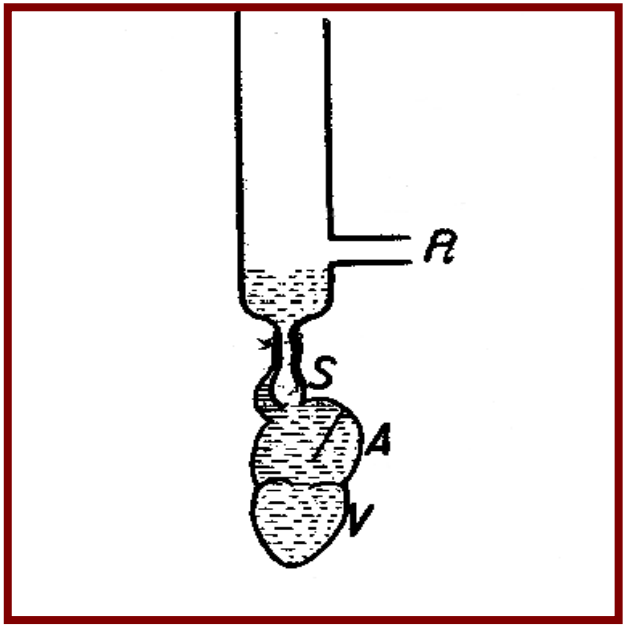
STARLING LAW

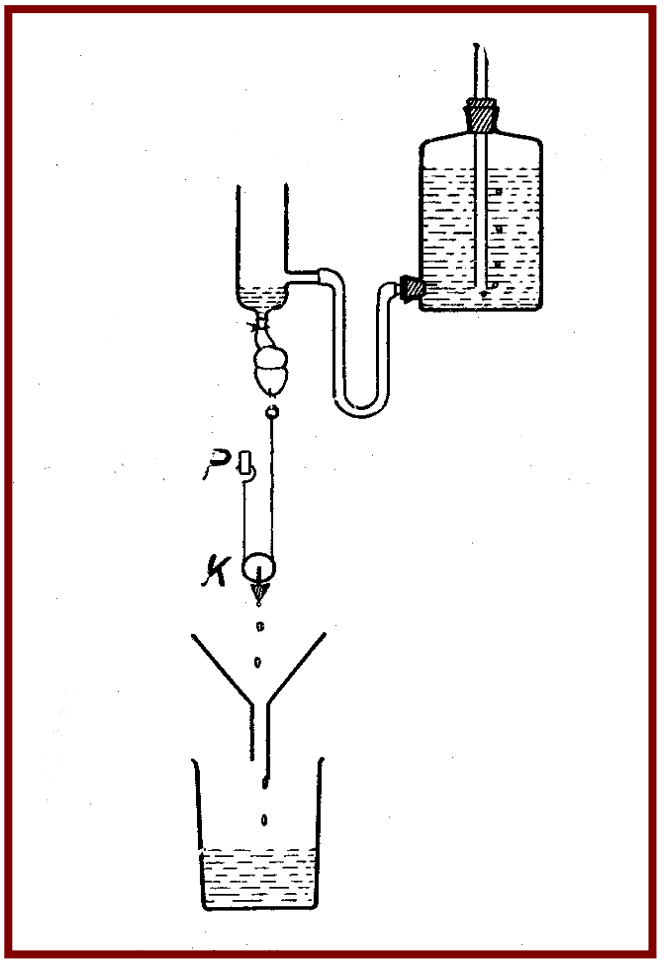


Fuyu Kobirumaki-Shimozawa et al., J Physiol Sci (2014) 64:221–232



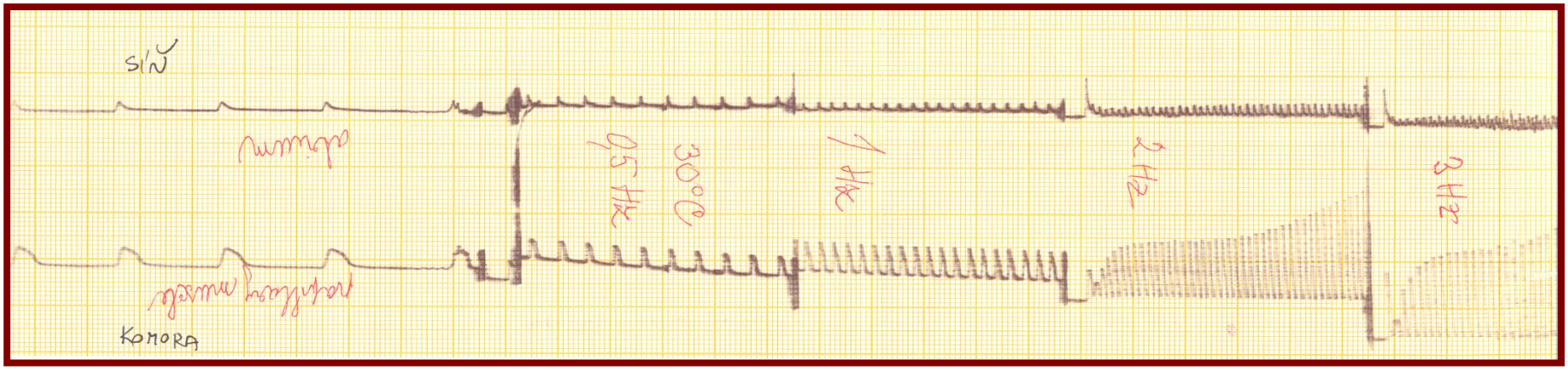
Henry Pickering Bowditch
(1840 – 1911)

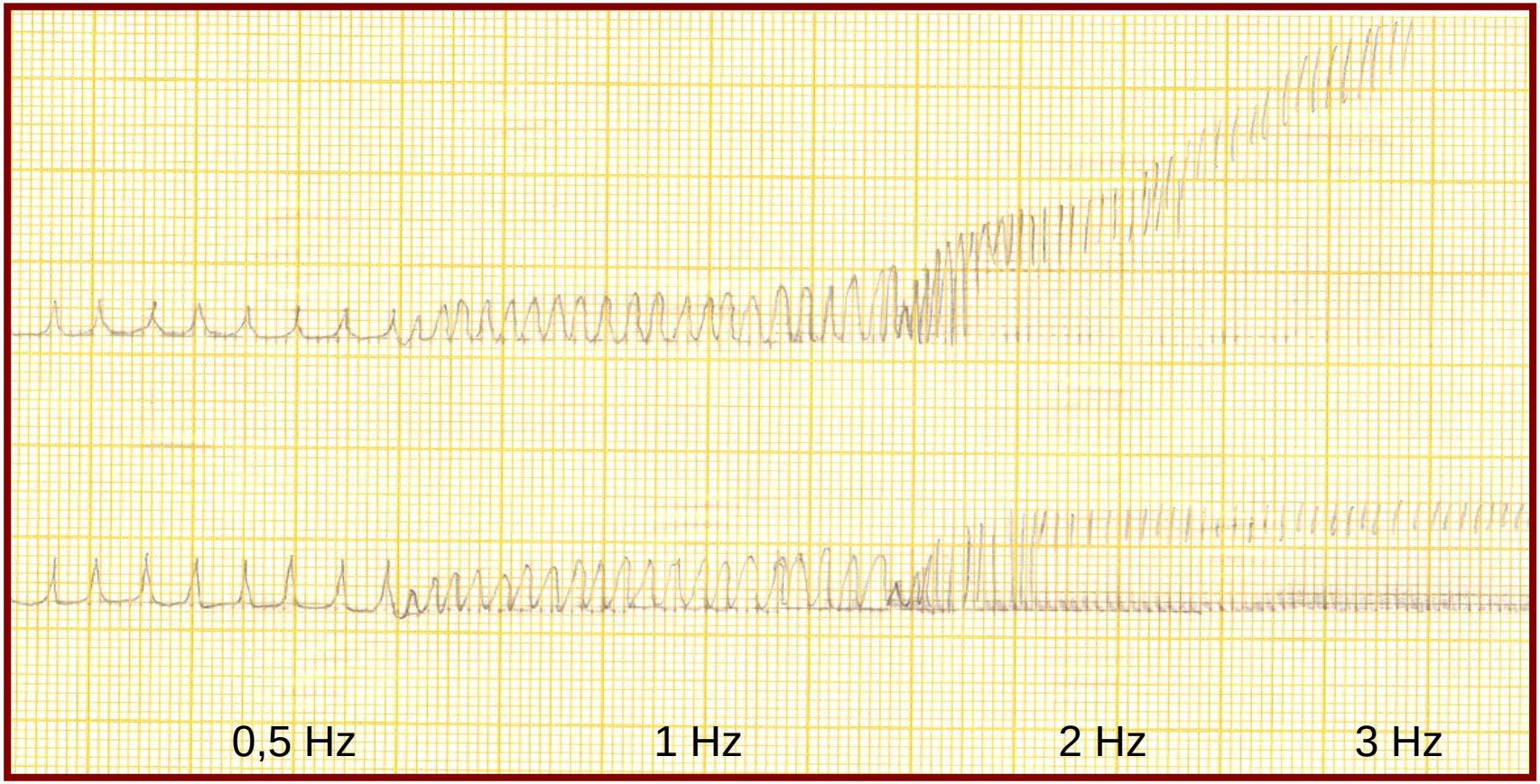




HOMEOMETRIC AUTOREGULATION
(FREQUENCY EFFECT)

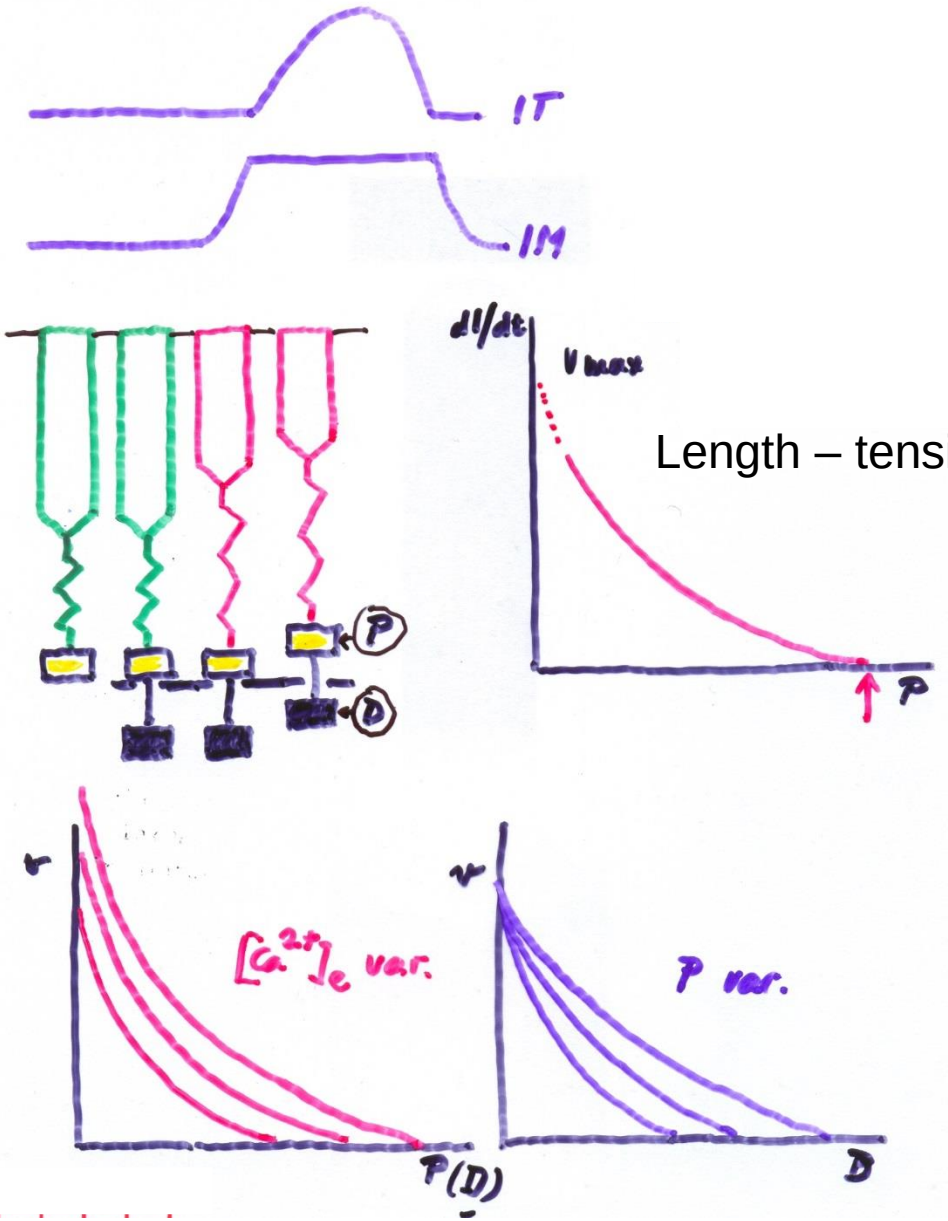
During increasing HR (stimulation frequency) the force of developed contraction rises
Ratio between intra- and extracellular calcium concentrations increases


SIN
0,5 Hz
30°C
1 Hz
2 Hz
3 Hz
KOMORA


0,5 Hz
1 Hz
2 Hz
3 Hz

AFTERLOADED CONTRACTION

PRELOAD, AFTERLOAD



Length – tension relationship

AB –isovolumic contraction
BC – ejection
CD – isovolumic relaxation
DA – filling

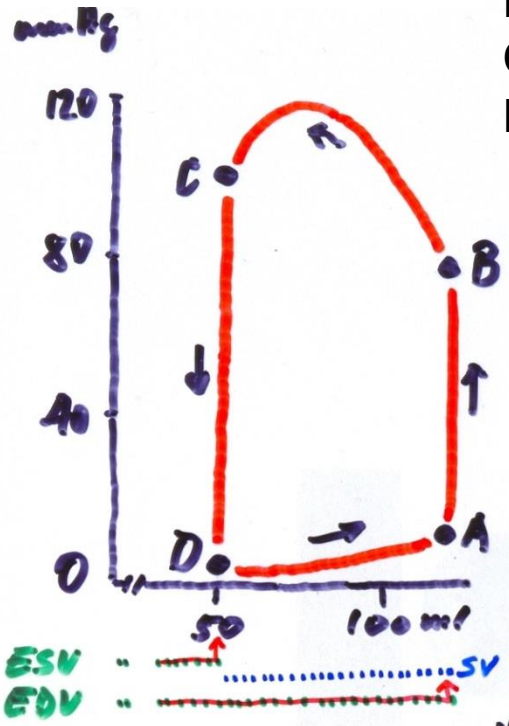
LAPLACE LAW

T = P. r / h

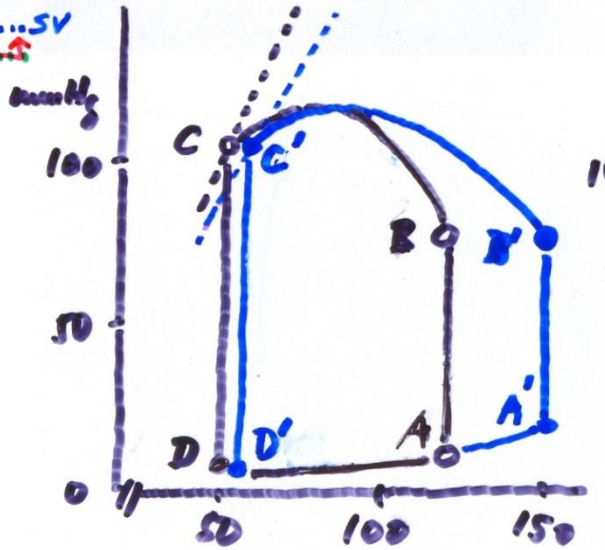
↑ P = T .↑ h /↓ r

HYPERTROPHY

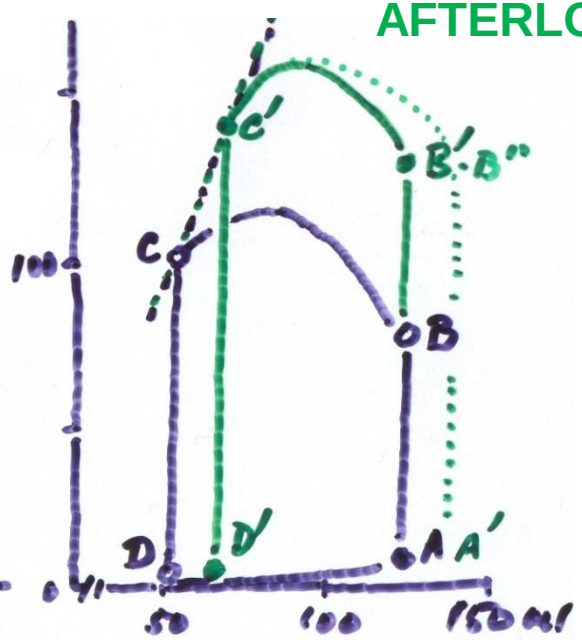
1. **↑T =↑VO_2**
2. **↑ h**



PRELOAD



AFTERLOAD

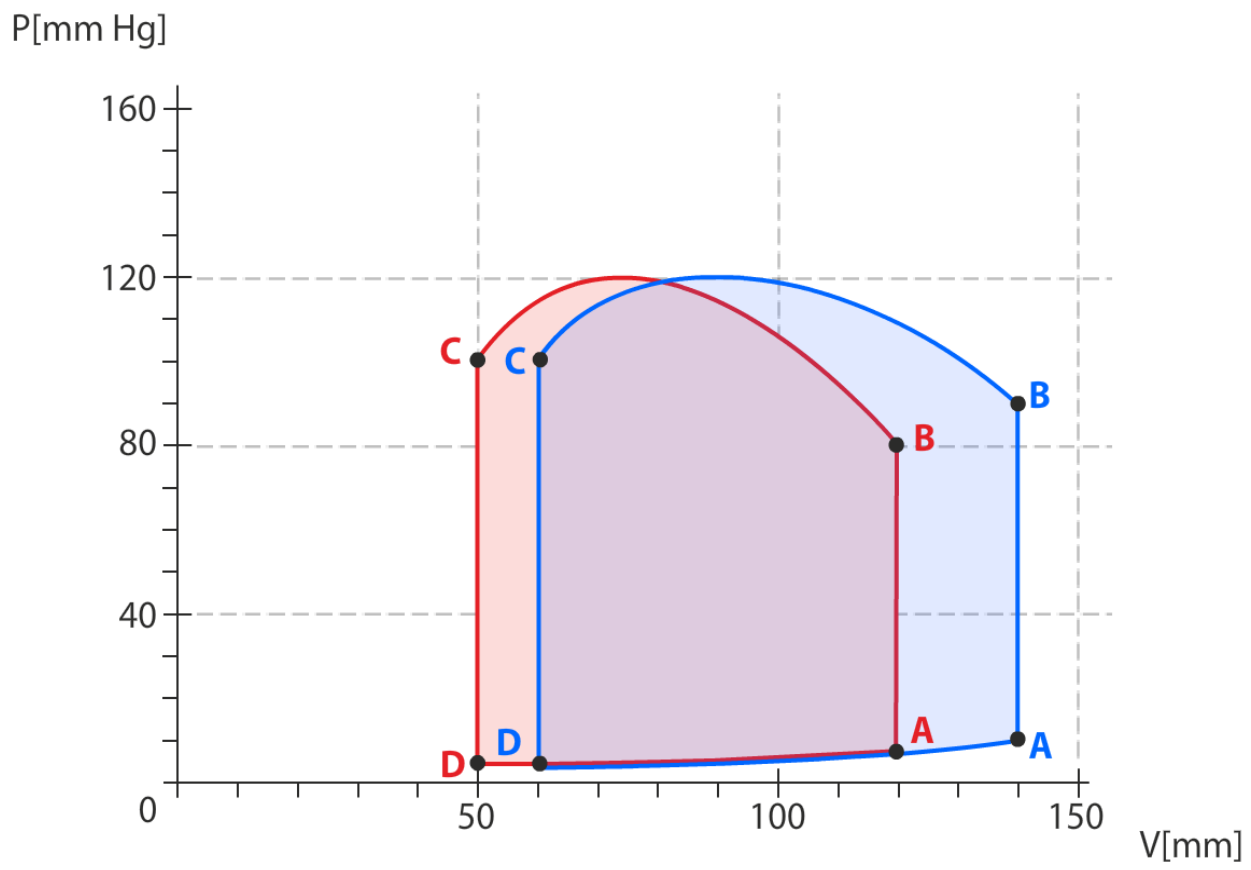


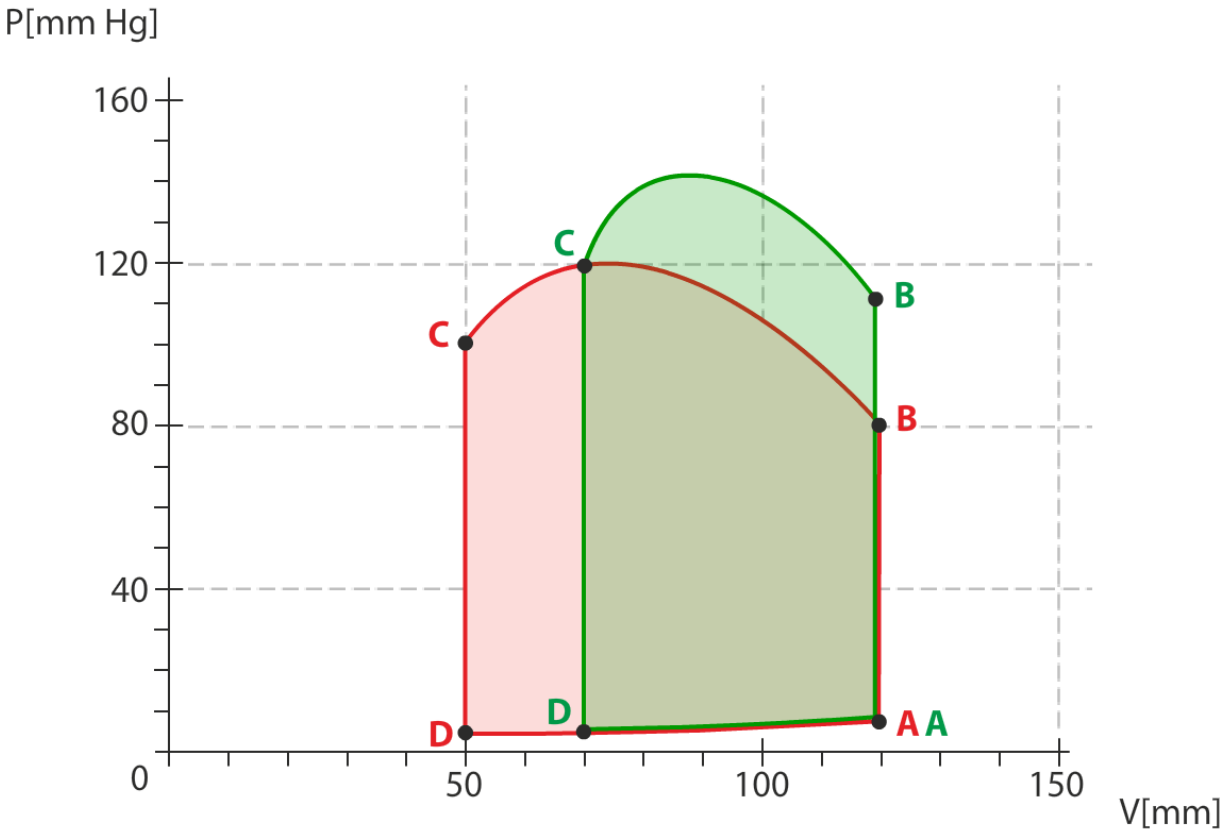
$P = \underline{T} \cdot 2h \cdot \underline{r^{-1}}$ **Ventricular filling:** r and T rise, P first falls down, then rises up (length/tension relationship)

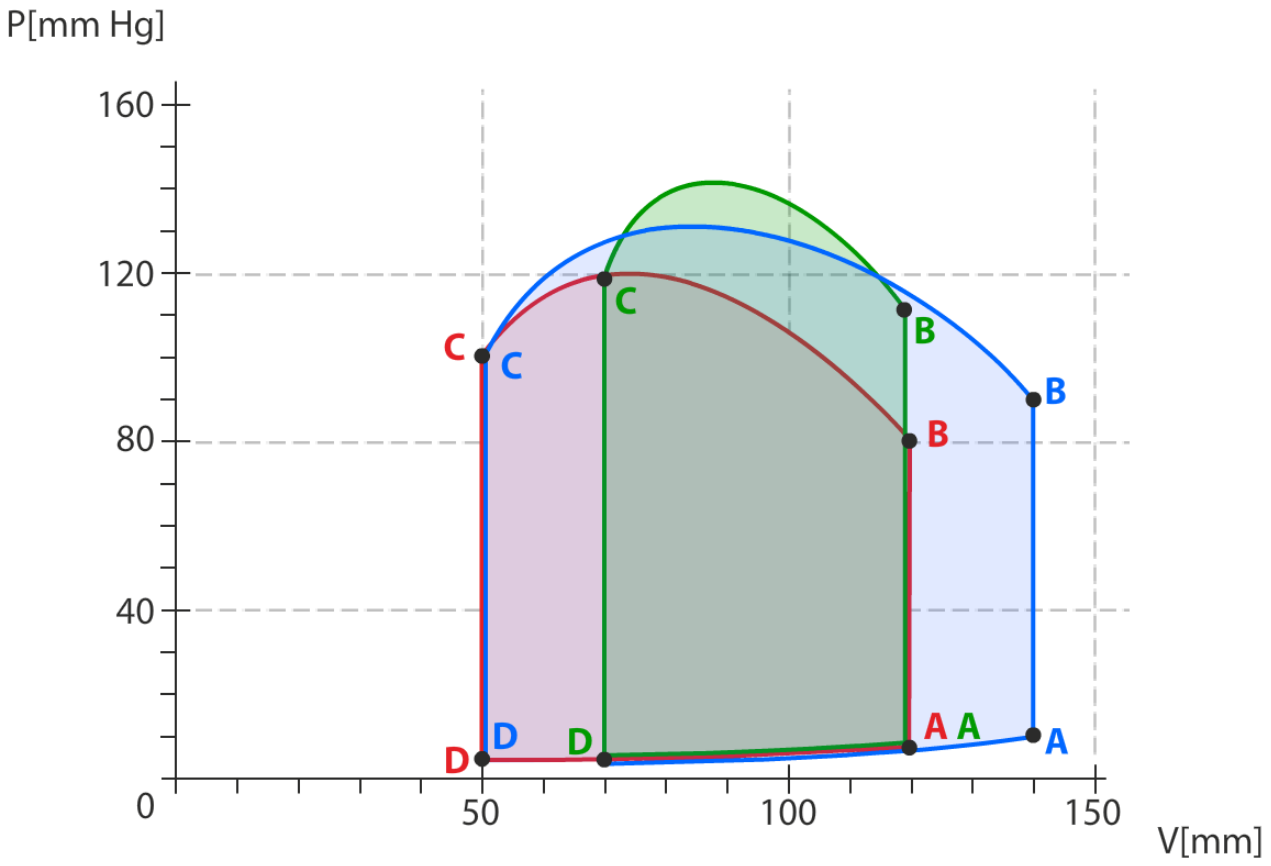
$\underline{P} = \underline{T} \cdot 2h \cdot r^{-1}$ **Isovolumic contraction**: T rises up, valves closed – increase in P

$\underline{P} = T \cdot 2\underline{h} \cdot r^{-1}$ **Ejection**: r decreases, h rises, thus P increases (even at the same T)

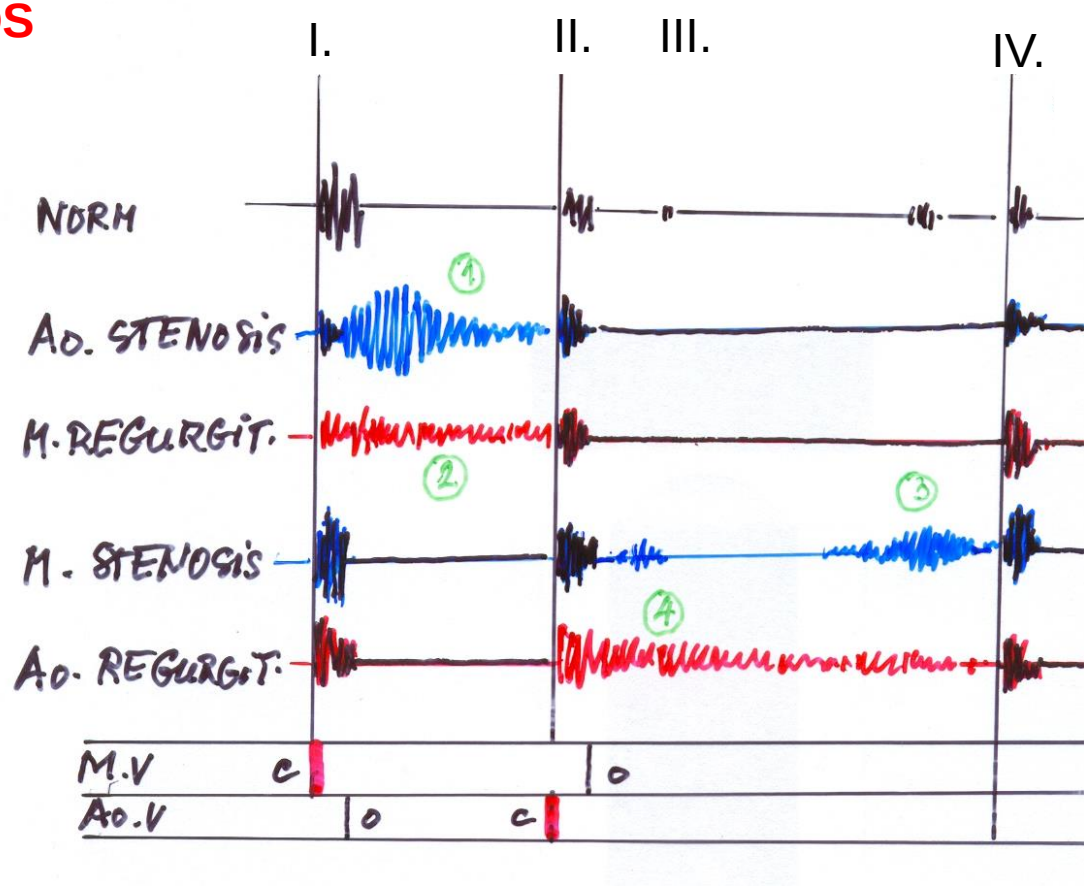
$P = T \cdot 2h \cdot r^{-1}$ **Isovolumic relaxation**: T decreases, valves closed – decrease in P


P[mm Hg]
160
120
80
40
0
50
100
150
V[mm]
C
C
B
B
D
D
A
A


P[mm Hg]
160
120
80
40
0
50
100
150
V[mm]
C
C
B
B
D
D
A
A


P[mm Hg]
160
120
80
40
0
50
100
150
V[mm]
C
C
C
B
B
B
D
D
D
A
A
A

HEART SOUNDS



I. – mitral (+ tricuspidal) valve closure

II. - aortal (+ pulmonary) valve closure

III. - fast filling of ventricles - pathological

IV. - contraction of atria – mostly pathological

Caused by vibration of:

- **Closure and stretching of valves**
- Izovolumic contraction of heart muscle (papill. muscles, tendons)
- Turbulent blood flow

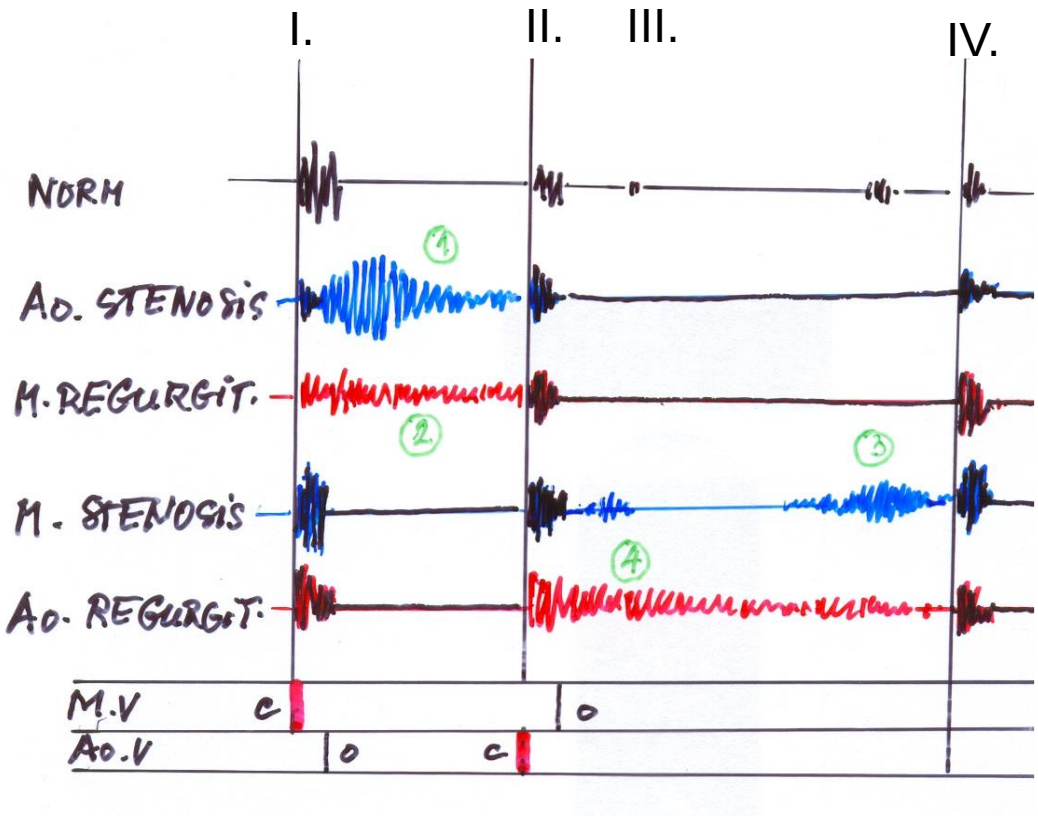
Vibration of ventricular wall

MURMURS – pathological phenomena

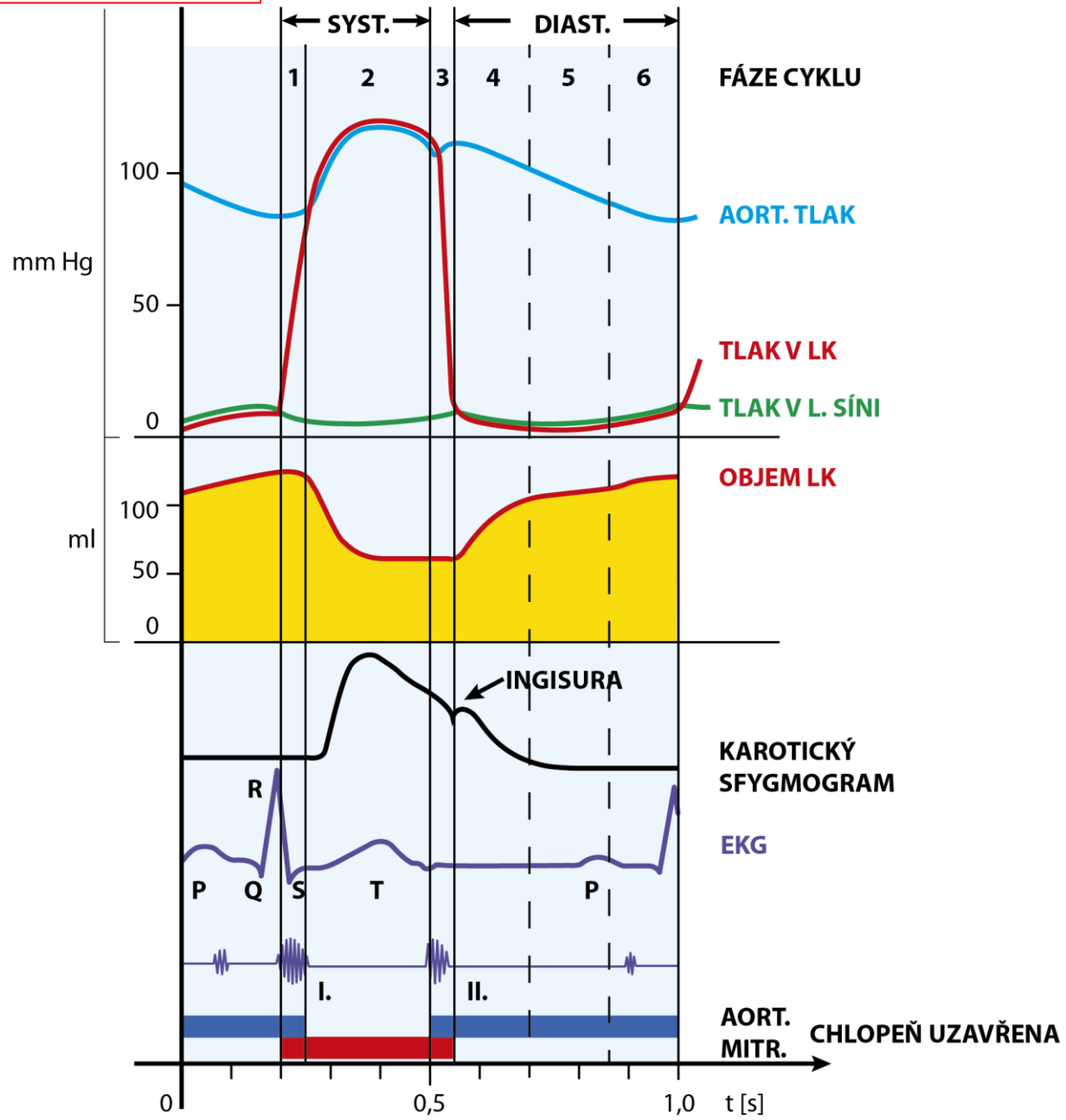
TURBULENT BLOOD FLOW

1. **SYSTOLIC**:
- Stenosis – aortal, pulmonary **(1)**
- Regurgitation – mitral, tricuspidal **(2)**
2. **DIASTOLIC**:
- Stenosis – mitral, tricuspidal **(3)**
- Regurgitation – aortal, pulmonary **(4)**
3. **SUSTAINED**:
- Defects of septum

Splitting of I. or II. sound: asynchronous closure of M - T valve (I.) or Ao - P valve (II.) (inspiration, hypertension….)



POLYGRAPHY (polygram)



HEART FAILURE

The heart is not able pump sufficient amount of blood into periphery at normal venous return.

MOST OFTEN CAUSES:

• Severe arrhythmias

• Overload – *volume* (aortal insufficiency, a-v shunts) or *pressure* (hypertension and aortal stenosis – left overload, pulmonary hypertension and stenosis of pulmonary valve – right overload)

• Cardiomyopathy

SYMPTOMS: fatigue, oedemas, venostasis, dyspnoea, cyanosis

ACUTE x CHRONIC. COMPENSATED x DECOMPENSATED.

HEART FAILURE COMPENSATION

BAROREFLEX

Physiological role: compensation of decrease in minimal volume of circulating fluids

Signal: BP decrease (orthostase, work vasodilatation)

Sensor: baroreceptors

Response: activation of SAS (increased HR, inotropy, BP)

Pathological signal: long-lasting decrease of BP due to heart insufficiency

Results: increased energy outcome – **vicious circle**

ACTIVATION OF RAAS

Physiological role: compensation of loss of circulating fluids (bleeding)

Signal: decrease in renal perfusion

Sensor: juxtaglomerular system of kidney

Response: BP increase (angiotenzin II.), water retention (aldosteron)

Pathological signal: decrease in renal perfusion due to heart insufficiency

Results: increased preload and afterload, increased energy outcome – **vicious circle**

DILATATION (STARLING PRINCIPLE)

Physiological role: compensation of momentary right-left differences

Signal: orthostase, deep breathing, beginning of exercise

Pathological signal: continual blood stasis in the heart

Results: increased energy outcome – **vicious circle**

HYPERTROPHY

Physiological role: preservation of energetically demanding tension of ventricular wall

Signal: $P = \sigma \cdot 2\,h / r$, intermittent BP increase (athletes heart)

Response: concentric remodelling

Pathological signal: continual increase of preload or afterload

Results: worsening of oxygenation, fibrotisation – **vicious circle**