CARDIOVASCULAR FORMULAS

- Normal values
- Heart rate 60 - 100 bpm
- PR interval 0.12 - 0.20 s
- QRS interval ≤ 0.12 s
- QT interval < half RR interval (males < 0.40 s; females < 0.44 s)
- P wave amplitude (in lead II) ≤ 3 mV (mm)
- P wave terminal negative deflection (in lead V1) ≤ 1 mV (mm)
- Q wave < 0.04 s (1 mm) and < 1/3 of R wave amplitude in the same lead

Cardiac out put [CO]= heart rate x SV ***CO = SV x HR***

Cardiac ouput = SV x pulse rate

$$\frac{\text{SV} \times \text{pulse rate}}{1000} = \text{L/mn}$$

SV [stroke volume] = CO/HR =cardiac out put/ heart rtate

systemic vascular resistance **Mean Ao pressure – mean RA pressure/cardiac output**

Oxygen delivery = CO x arterial oxygen content (CaO2)

PP = SV/2 PULSE PRESSURE =STROKE VOLUME/2

SV=PPX2

PP = 3(MP – DP)

DP [DIASTOLOC PRESSURE] = SP – PP [SYSTOLIC PRESSURE]-PULSE PRESSURE

MP [MEAN BLOOD PRESSURE]= DP + ⅓PP =

MAP=COX resistance

BP=VOLUME/TPR (TOTAL PERIPHERAL RESISTANCE)

Changes in CO

- ↓ SV in ventricular tachycardia
- if HR is too high, diastolic filling is incomplete and CO decreases
- exercise
- CO maintained by SV in early stages of exercise
- CO maintained by HR in late stages of exercise

CARDIAC OUTPUT

* VOL of BLOOD EJECTED by LEFT VENTRICLE PER UNIT TIME

FICK PRINCIPLE

* AT REST: O_2 IN − O_2 OUT
=
O_2 ORGAN has USED

* CO = O_2 CONSUMPTION / ARTERIOVENOUS O_2 DIFFERENCE

↓

NORMAL CO ~ 5 L/min

CARDIAC OUTPUT
FICK PRINCIPLE

Fick Principle

- Calculate cardiac output by measuring myocardial oxygen consumption.

$$\text{Cardiac output} = \frac{\text{Total } O_2 \text{ Consumption}}{[O_2]_{\text{pulmonary vein}} - [O_2]_{\text{pulmonary artery}}}$$

Example:

$$\text{Cardiac output} = \frac{200 \text{ ml } O_2/\text{min}}{0.15 \text{ ml } O_2/\text{ml blood} - 0.1 \text{ } O_2/\text{ml blood}} = 4000 \text{ ml/min}$$

EDV

- volume of blood in ventricle before ejection

ESV

- volume of blood in ventricle after ejection

Changes in SV

- ↑ SV in anxiety, exercise, pregnancy
- ↓ SV in failing heart

"SV CAP"

- Stroke Volume affected by Contractility, Afterload, Preload
- ↑ SV via (1) ↑ contractility, (2) ↓ afterload, (3) ↑ preload

↑ Contractility, ↑ SV via

- catecholamines
    - ↑ activity of Ca2+ pump in SR
- ↑ intracellular Ca2+
- ↓ extracellular Na+
    - ↓ activity of Na+/Ca2+ exchanger

- *PP = SV/2 PULSE PRESSURE =STROKE VOLUME/2*
- *SV=PPX2*

- *PP = 3(MP – DP)*

- *DP [DIASTOLOC PRESSURE] = SP – PP*

- *MP [MEAN BLOOD PRESSURE]= DP + ⅓PP =*
- *Mean arterial pressure= TOTAL peripheral resistance x CO*

Pulse pressure :120/80= 120-80 = 40mmhg

PP reflects volume of blood ejected from left ventricle on a single beat
PP ∝ SV

normal 120mmHg - 80mmHg = 40mmHg or 33% of systolic pressure
high 160mmHg - 80mmHg = 80mmHg or 50% of systolic pressure

Pulse pressures of 50 mmHg or more can increase your risk of heart disease, heart rhythm disorders, stroke and more

A narrow pulse pressure — sometimes called a low pulse pressure — is where your pulse pressure is one-fourth or less of your systolic pressure (the top number). This happens when your heart isn't pumping enough blood, which is seen in heart failure and certain heart valve diseases. It also happens when a person has been injured and lost a lot of blood or is bleeding internally.

$$\%\ \text{CHANGE IN CO} = \frac{\text{CO AFTER EXERCISE} - \text{CO REST}}{\text{CO AT REST}} \times 100$$

$$\text{Ejection Fraction (EF)} = (\text{SV} / \text{EDV}) \times 100\%$$

Cardiac Index (CI) = Q / Body Surface Area (BSA) = SV × HR/BSA

BSA is Body Surface Area in square metres.

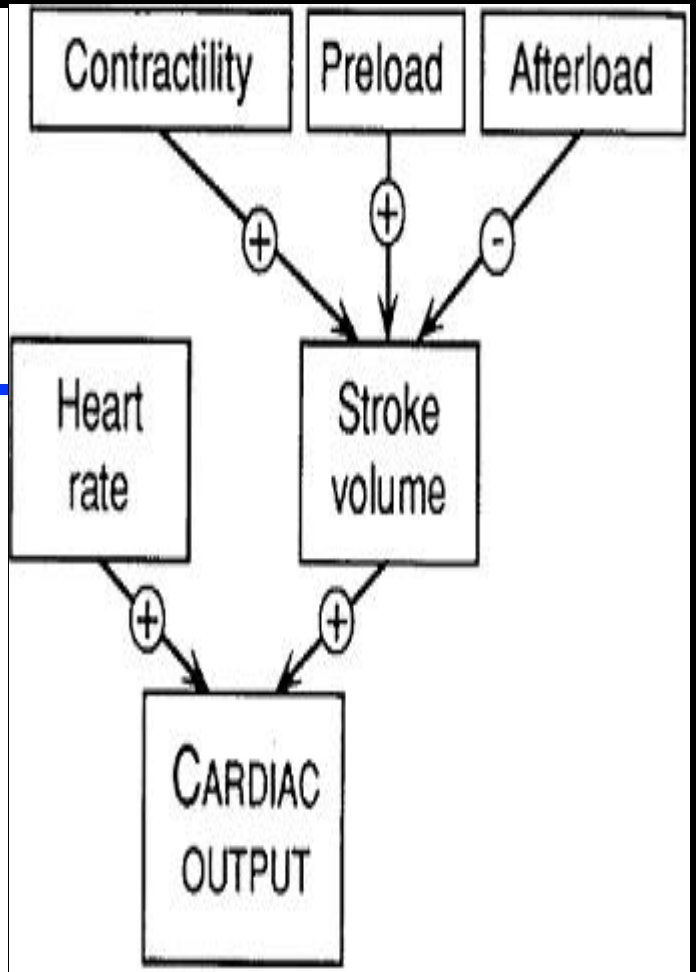
$$BSA(m^2) = \sqrt{\frac{weight\ (\text{kg}) \times height\ (\text{cm})}{3600}}$$

$$SV = EDV - ESV \qquad SV \propto \frac{EDV}{ESV}$$

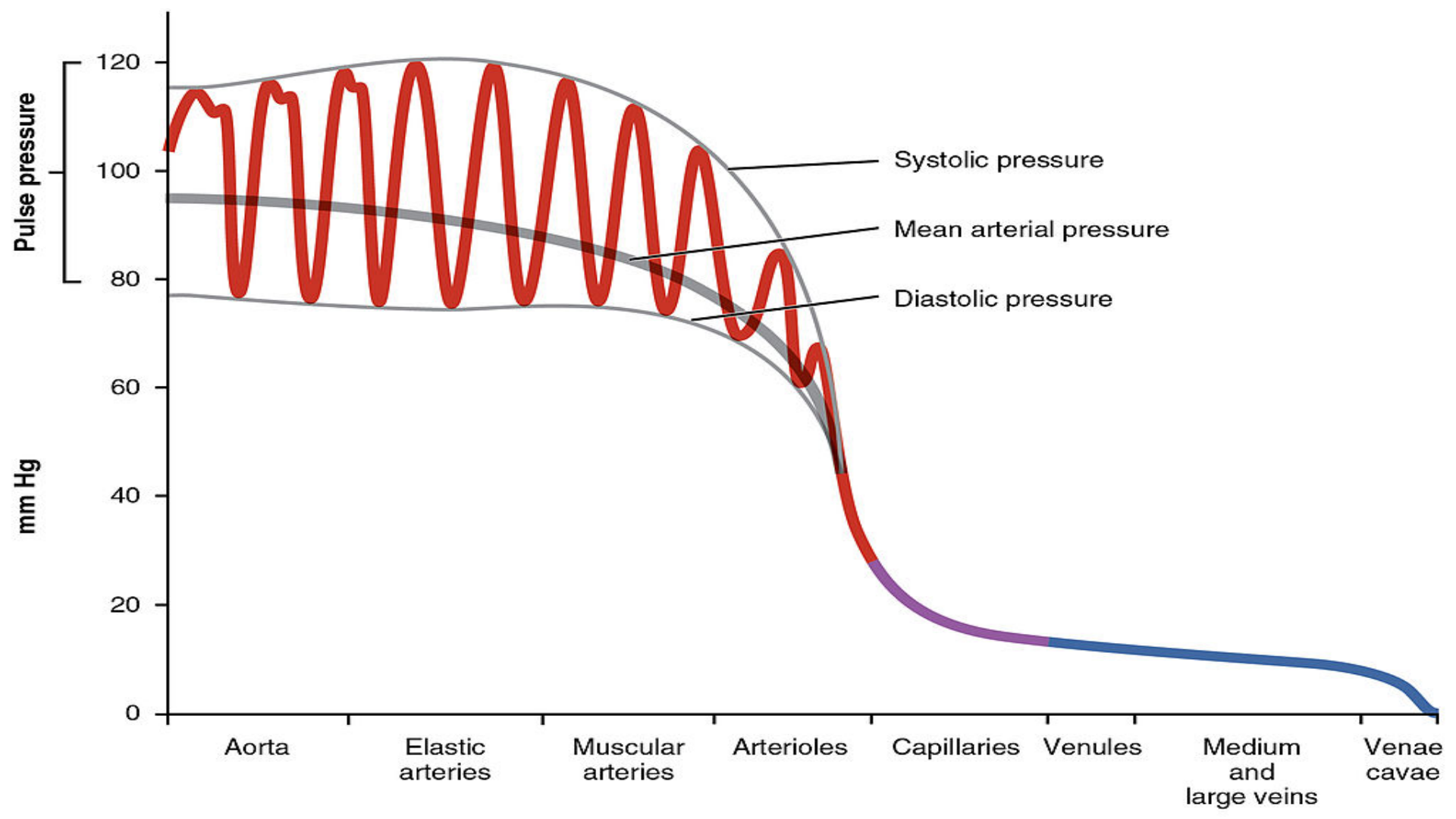
↑ Preload → ↑ EDV → ↑ SV

↑ Afterload → ↑ ESV → ↓ SV

↑ Inotropy → ↓ ESV → ↑ SV



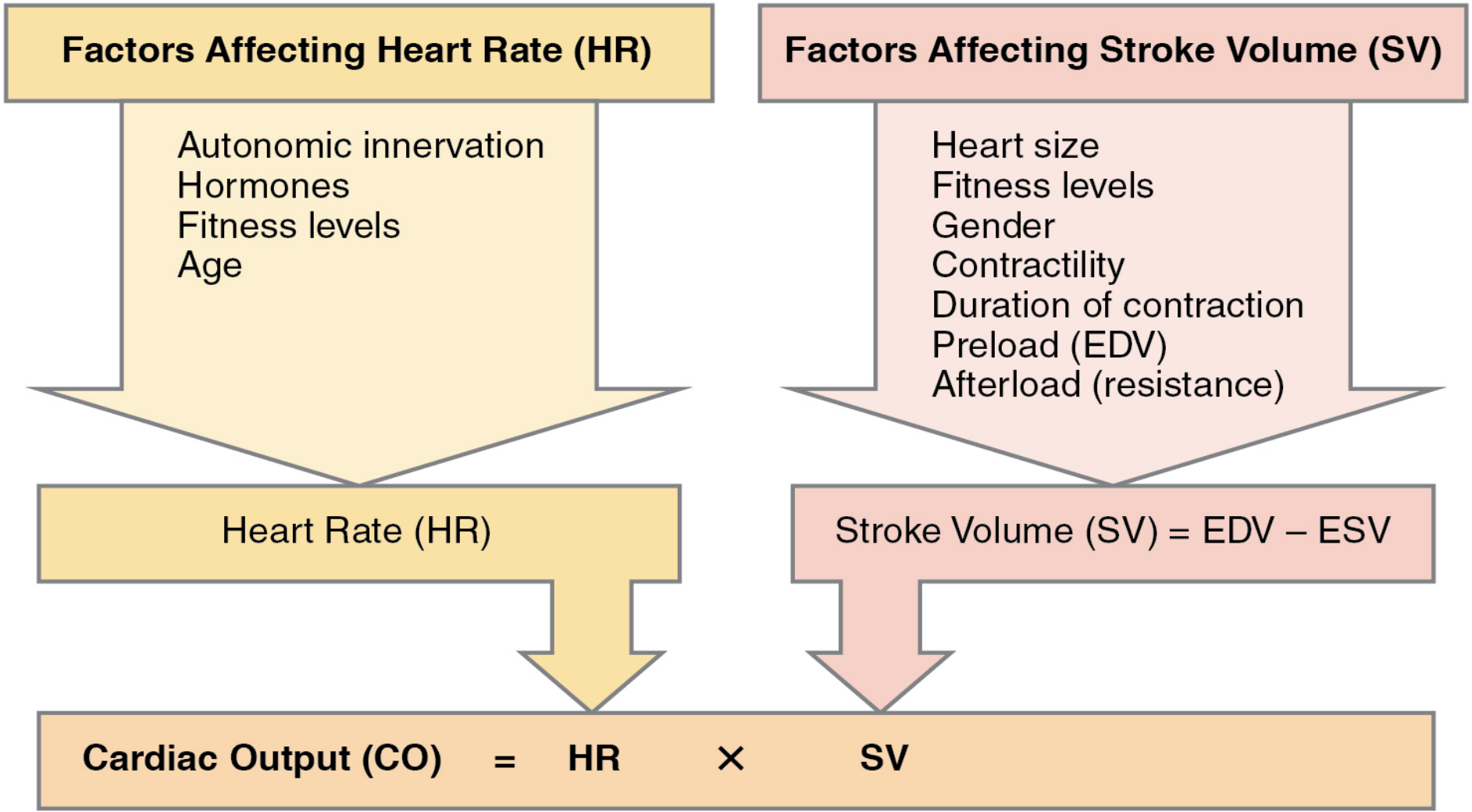
	Factors Affecting Stroke Volume (SV)		
	Preload	**Contractility**	**Afterload**
Raised due to:	• fast filling time • increased venous return **Increases end diastolic volume,** **Increases stroke volume**	• sympathetic stimulation • epinephrine and norepinephrine • high intracellular calcium ions • high blood calcium level • thyroid hormones • glucagon **Decreases end systolic volume,** **Increases stroke volume**	• increased vascular restistance • semilunar valve damage **Increases end systolic volume** **Decreases stroke volume**
Lowered due to:	• decreased thyroid hormones • decreased calcium ions • high or low potassium ions • high or low sodium • low body temperature • hypoxia • abnormal pH balance • drugs (i.e., calcium channel blockers) **Decreases end diastolic volume,** **Decreases stroke volume**	• parasympathetic stimulation • acetylcholine • hypoxia • hyperkalemia **Increases end systolic volume** **Decreases stroke volume**	• decreased vascular resistance **Decreases end systolic volume** **Increases stroke volume**


Pulse pressure
120
100
80
60
40
20
0
mm Hg
Systolic pressure
Mean arterial pressure
Diastolic pressure
Aorta
Elastic arteries
Muscular arteries
Arterioles
Capillaries
Venules
Medium and large veins
Venae cavae

Pulse vs Pulse Pressure

More Information Online WWW.DIFFERENCEBETWEEN.COM

	Pulse	Pulse Pressure
DEFINITION	Pulse is the rhythmic dilation of an artery that results from beating of the heart	Pulse pressure is the difference between the systolic and diastolic blood pressures
NORMAL VALUE	72 per minute	40 mm Hg
UNIT	Number per minute	mm Hg


Factors Affecting Heart Rate (HR)
Autonomic innervation
Hormones
Fitness levels
Age
Factors Affecting Stroke Volume (SV)
Heart size
Fitness levels
Gender
Contractility
Duration of contraction
Preload (EDV)
Afterload (resistance)
Heart Rate (HR)
Stroke Volume (SV) = EDV – ESV
Cardiac Output (CO) = HR × SV

Mean Arterial Pressure

Mean Arterial Pressure (MAP)

Range = 70 – 110 mmHg

The average pressure of the arteries

$$MAP = \frac{(2 \times DBP) + SBP}{3}$$

MAP is multiplied by 2 because diastolic phase lasts longer than the systolic phase

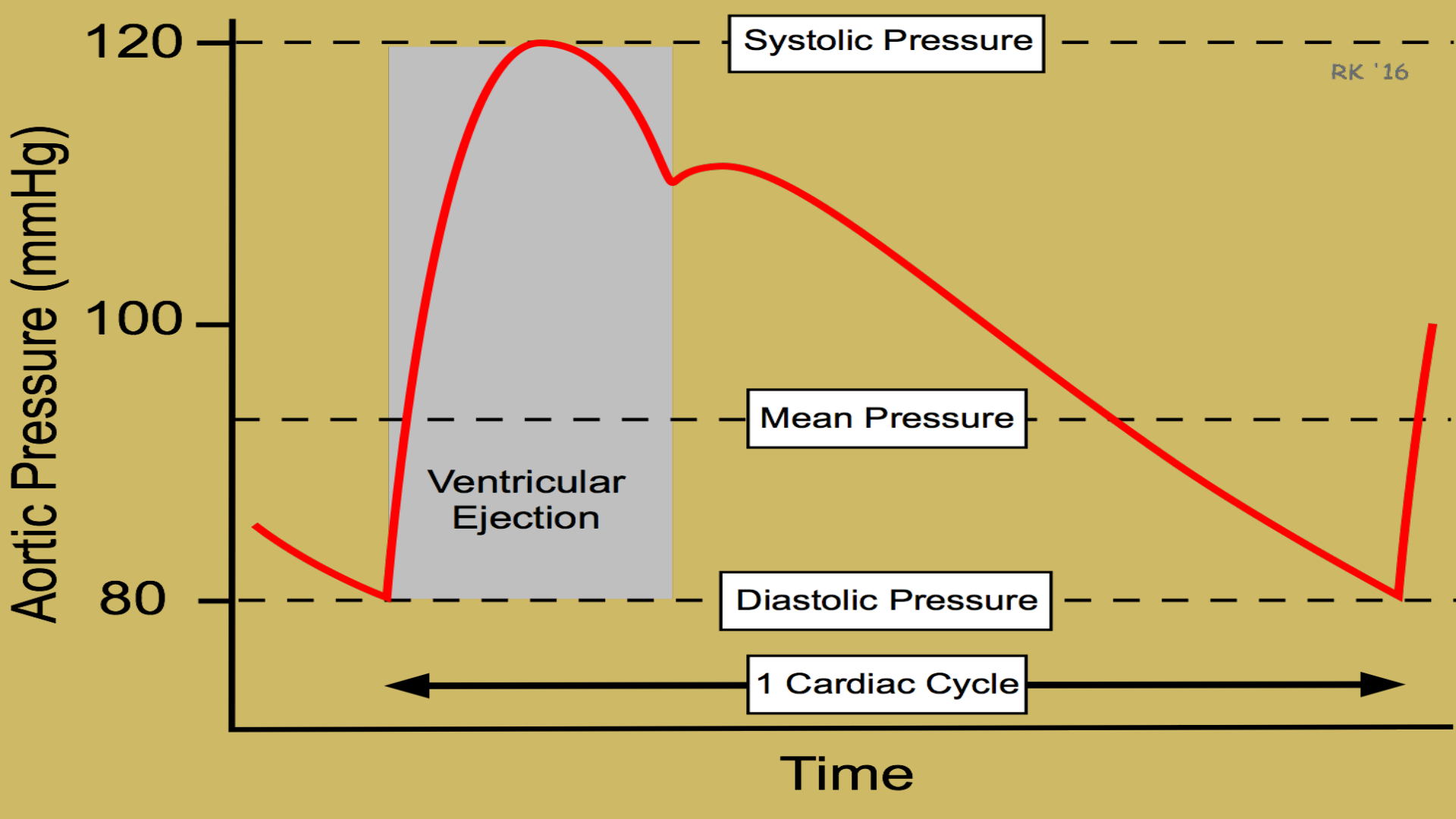
If B/P 120/75, then MAP = _____

Mean Arterial Pressure (MAP) = average pressure in a complete cardiac cycle

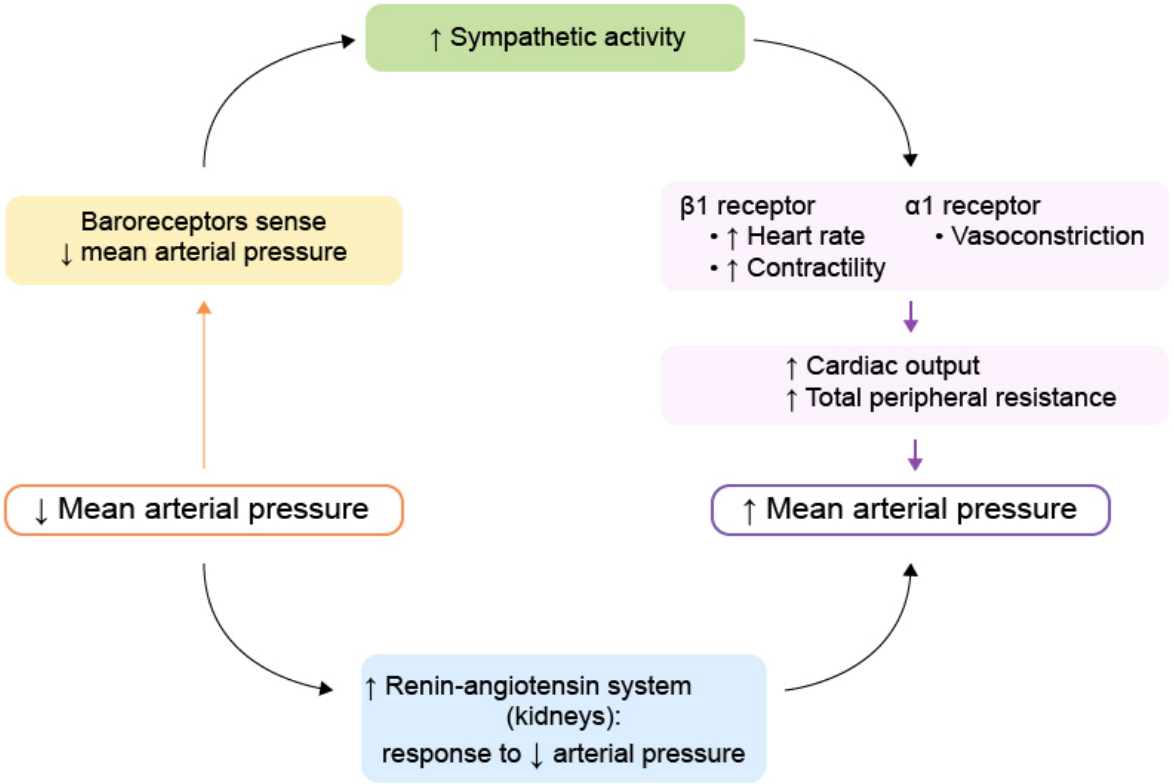
Equations

- MAP = CO x Total Peripheral Resistance (TPR)
- MAP = 2/3 Diastolic Pressure + 1/3 Systolic Pressure
- MAP = 1/3 PP + Diastolic Pressure

as HR increases, diastole decreases and systole increases in the percentage of time spent, thus influencing the MAP


120
100
80
Aortic Pressure (mmHg)
Systolic Pressure
RK '16
Mean Pressure
Ventricular
Ejection
Diastolic Pressure
1 Cardiac Cycle
Time

Maintanence of Mean Arterial Pressure



Mean arterial pressure = Cardiac output x Total peripheral resistance

•Mean arterial pressure (MAP) is maintained by _

- •baroreceptors
- •chemoreceptors
- •renin-angiotensin-aldosterone system
- •antidiuretic hormone (ADH)
- •atrial natriuretic peptide (ANP)

- Preload = aka ventricular EDV
    - preload "pumps up the heart"
- ↑ preload by
    - exercise (slightly)
    - ↑ blood volume
        - e.g., over-transfusion
    - excitement
        - sympathetics
- Pathology
- right wall myocardial infarction (inferior wall)
    - ST elevation seen in leads II, III, and avF
    - preload dependent for cardiac function, thus do not diurese
- Afterload = aka MAP
        - ∝ TPR
- Pharmacology
    - venodilators (e.g., nitroglycerin) ↓ preload
    - vasodilators (e.g., hydrAlAzine) ↓ Afterload (Arterial)

Ejection Fraction (EF) = SV/EDV

fraction of EDV ejected per SV
an index of ventricular effectiveness
↓ EF via systolic heart failure
an index of cardiac contractility
↑ EF, ↑ contractility
EF ~ 0.55 or 55%

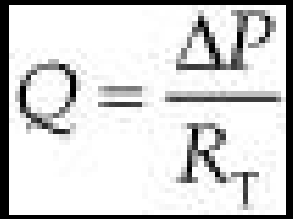
- Cardiac output (CO) curve describes a state of cardiac function a plot of the relationship between CO and right atrial pressure
  - ↑ venous return → ↑ right atrial pressure → ↑ end-diastolic volume (EDV), end-diastolic fiber length → ↑ CO
  - ↓ venous return → ↓ right atrial pressure → ↓ EDV, end-diastolic fiber length → ↓ CO

$Q = SV \times HR$	cardiac output
$SV = \frac{Q}{HR}$	stroke volume
$HR = \frac{Q}{SV}$	heart rate

$CI = \frac{Q}{BSA}$	cardiac index
$Q = CI \times BSA$	cardiac output
$BSA = \frac{Q}{CI}$	body surface area

$SV = EDV - ESV$	stroke volume
$EDV = SV + ESV$	end diastolic volume
$ESV = EDV - SV$	end systolic volume

Measure	Typical value	Normal range
end-diastolic volume (EDV)	120 ml	65 - 240 ml
end-systolic volume (ESV)	50 ml	16 - 143 ml
stroke volume (SV)	70 ml	55 - 100 ml
ejection fraction (E_f)	58%	55 to 70%
heart rate (HR)	70 bpm	60 to 100 bpm
cardiac output (CO)	4.9 L/minute	4.0 - 8.0 L/min



Q = flow
P = change in pressure
R_T = *total resistance*

CO = cardiac output
MAP = mean arterial pressure
P_{RA} = right atrial pressure
TPR = total peripheral resistance

How does increasing the pressure gradient influence flow through the circuit?
Increases the flow

$HR_{max} = 220 - age$

65% intensity: (220 − (age = 40)) * 0.65 → 117 bpm

85% intensity: (220 − (age = 40)) * 0.85 → 153 bpm

Solving for heart rate reserve.

$$HR_{reserve} = HR_{max} - HR_{rest}$$

$$HR_{max} = 220 - age$$

maximum heart rate most commonly found

$$HR_{max} = 205.8 - 0.685 \times age$$

maximum heart rate by Inbar

$$HR_{max} = 206.3 - 0.711 \times age$$

maximum heart rate by Londeree and Moeschberger

$$HR_{max} = 217 - 0.85 \times age$$

maximum heart rateby Miller

Cardiac You Should Know!

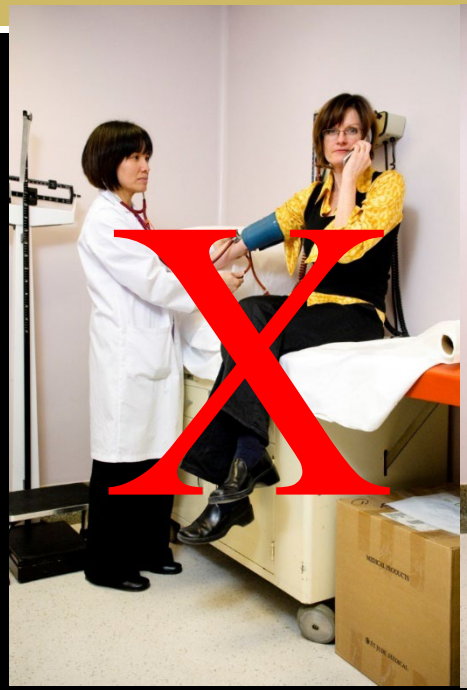
Pulse Pressure (PP)

Diastolic minus Systolic = 40

Low < 25	High >40
Low Bash!	High & AFAR !
B-Bleeding	A-Atherosclerosis
A-Aortic	F-Fever
S-Stenosis	A-Aortic
H-Heart Failure	R-Regurge

NCLEX FOCUS Bleeding Trend when BP Matters!

Blood Pressure Assessment: Patient position



What should we consider when taking an accurate BP?

Appropriate cuff size	No strenuous exercise 2 hour prior
Rest for five minutes	Keep BP arm at heart level
Calm, comfortable environment	Cuff edge is 3 cm above elbow crease
No tight clothing on arm or forearm	Initial: 3 readings on both arms; f/u on arm with highest BP. If unable to get initial 3 readings use non-dominant arm
No crossing of legs	
No talking during measurement	F/U-3 BP readings every 1-2 minutes; leave room after first successful reading
Ensure bladder/bowel is empty	
No smoking/nicotine/caffeine/light activity 30min prior	

Arm Circumference

- BP cuff too large = a low BP reading
- BP cuff too small = a high BP reading

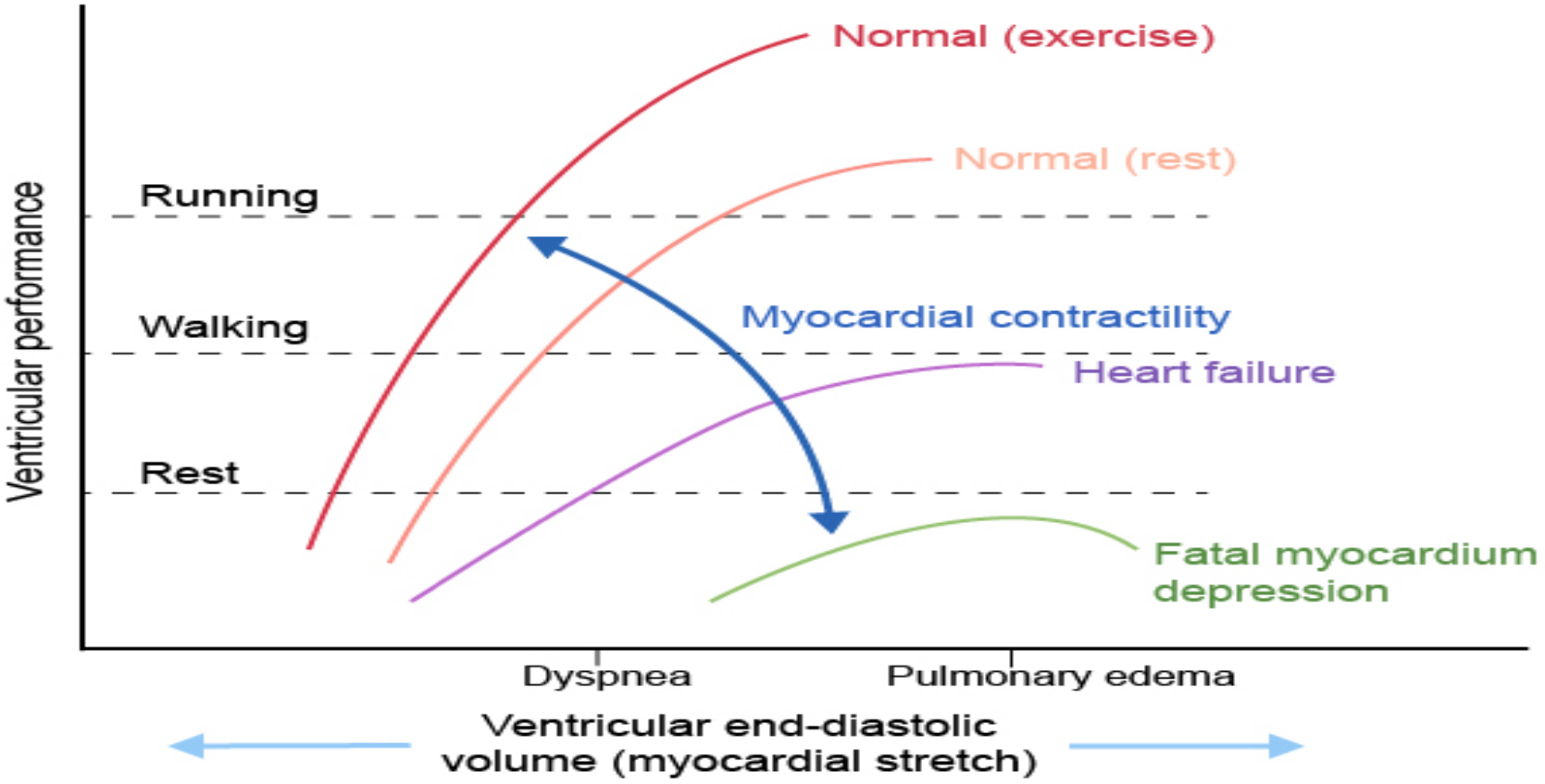
Arm Circumference (cm)	Size of Cuff (cm)
From 18 – 26 cm	9 X 18 (child/small adult)
From 26 – 33 cm	12 X 23 (regular adult)
From 33 – 41 cm	15 X 33 (large adult)
> 41 cm	18 X 36 (extra large adult)

$$\frac{Volume\ (ml) x\ Calibration\ (\frac{drops}{ml})}{Time\ (minutes)} = \text{Flow Rate (drops / min)}$$

For example, they might order to administer 1000 ml of saline solution in 8 hours, which is equivalent to 125 ml per hour.
These are units of flow. To illustrate the change of units, I will write the following expression:

1000ml/8hours = 125 ml/hour = 3000 ml/24 hours

Frank-Starling Relationship



Lucy Liu

Important Formulas

- CO=HR x SV = VR in most pts.

$$\text{Resistance} = \frac{8\eta l}{\pi \bullet r^4}$$

- Tension $= \frac{\text{(Pressure inside the chamber x radius)}}{\text{(2 x wall thickness)}}$

  More generally, T ~ P x R

- Mean Art. P. = (1/3 Pulse PP.) + Diast. P
- Stroke Volume=EDV-ESV
- Ejection Fraction= SV/EDV. Normal EF is 0.5-0.75

- Fick's :CO = O_2 Uptake / ([Arterial O_2] - [Venous O_2])

More info reviews and question

What does the cardiovascular system consists of ?

Heart & blood vessels

What are three types of blood vessels?

arteries, veins, and capillaries

What is the five finger (Harvey's) approach to cardiology?

History; PE; ECG; X-RAY; Lab Test

What is the "standard care" medications for all CAD patients?

Beta blocker, Aspirin, Statin, and ACE-I/ARB

What are the top five risk factors for cardiac disease?

Smoking, dyslipidemia, HTN, DM, obesity

What sound comes primarily from the mitral valve closing?

S1

What 2 valves would be involved in the splitting of S1?

Mitral and tricuspid

What is the amunt of blood that the ventricles eject per minute?

Cardiac Output=(HRxSV)

What is the main goal of anti-thrombotic therapy?

decrease the risk of thrombosis by interfering with clotting mechanisms

Where does myocardium receives its blood supply from the coronary arteries?

Aorta

How can you calculate the pulse pressure?
Pulse pressure = systolic - diastolic

What is the major determinant of pulse pressure (PP)?
Stroke volume (SV), rising SV leads to a higher PP

What happens to the pulse pressure when the compliance decreases?
Increases (think: atherosclerosis)

What is the mean arterial pressure (MAP)?
Average arterial pressure with respect to time

How can you determine MAP?

- $MAP = CO \times TPR$ or
- $MAP = 1/3(\text{systolic}) + 2/3(\text{diastolic})$
- *CO* = cardiac output
- *TPR* = total peripheral resistance

Which is lower, venous pressure or right atrial pressure?
Atrial pressure; recall that pressure drives blood flow

What is meant by laminar flow?
The movement of fluid through vessels in an organized way (think: water in a garden hose)

What is turbulent flow?
Fluid movement that is disorganized (think: white water rapids)

When is the systolic pressure measured?
At the peak of cardiac contraction

When is diastolic pressure measured?
At the nadir of cardiac relaxation

Basic definitions

- **Heart rate** (HR)
  - The number of heart contractions per minute (bpm)
  - Normal heart rate at rest is between 60 and 100 bpm
- **Stroke volume** (SV): The volume of blood pumped by the left or right ventricle in a single heartbeat.
  - **SV = end-diastolic volume (EDV) − end-systolic volume (ESV)**
- **Pulse pressure**: Difference between diastolic blood pressure (DP) and systolic blood pressure (SP) of the heart cycle (SP - DP).
  - **Normally: 30–40 mm Hg**
  - Directly proportional to SV and inversely proportional to arterial compliance
    - Low/narrow pulse pressure due to: ↓ SV (e.g., congestive heart failure, shock, cardiac tamponade, aortic stenosis)
    - High/wide pulse pressure due to: ↑ SV (e.g., exercise, hyperthyroidism, aortic regurgitation) or stiff arteries
- **Ejection fraction (EF)**: The proportion of EDV ejected from the ventricle.
  - **EF = SV / EDV = (EDV - ESV) / EDV**
  - **Normally = 50–70%**
  - Represents an index of myocardial contractility: e.g., ↓ myocardial contractility → ↓ EF (seen in systolic heart failure, where EF is < 40%)
- **Cardiac output**: The volume of blood the heart pumps through the circulatory system per minute (~ 5 L/min at rest)
  - **Cardiac output (CO) = heart rate (HR) × stroke volume (SV)**
  - **Measurement**
    - **Via Fick principle**: cardiac output is proportional to the quotient of the total body oxygen consumption and the difference in oxygen content of arterial blood and mixed venous blood
      - **Cardiac output (CO)** = oxygen consumption rate / arteriovenous oxygen difference = **(O_2 consumption) / (arterial O_2 content − venous O_2 content)**
    - **Via mean arterial pressure (MAP): MAP = cardiac output (CO) × total peripheral resistance (TPR)**
      - Mean arterial pressure (MAP) = 1⁄3 systolic blood pressure + ⅔ diastolic blood pressure = (SP + 2 x DP) / 3
  - As HR increases, diastole is shortened, which decreases CO due to less filling time

- **Total peripheral resistance** (TPR): amount of resistance to blood flow in the systemic circulation = (mean arterial pressure – central venous pressure) / cardiac output
  - Increased in case of vasoconstriction of arterioles (e.g., in hemorrhage) → ↑ afterload and ↓ venous return
  - Decreased in case of vasodilation of arterioles (e.g., in exercise) → ↓ afterload and ↑ venous return
- **Volumetric flow rate**: The volume of blood that flows across a valve per second
  - Volumetric flow rate (Q) = flow velocity (v) x cross-sectional area (A)
    - This quantity Q is conserved by virtue of the conservation of mass → $Q_1 = Q_2$ so $A_1V_1 = A_2V_2$
    - Used to calculate flow across stenotic valves, vessels of different diameters, etc.

During exercise, a healthy young adult can increase their CO to approx. 4–5 times the resting rate of 5 L/min, to approx. 20–25 L/min.

This increase in CO is achieved through a significant increase in HR and a slight increase in SV.

The increased HR shortens the filling time (diastole), which limits the increase in SV.

As HR reaches ≥ 160/m, maximum CO is therefore reached and begins to decrease, as SV declines faster than HR increases.

The cardiac cycle can be divided into two phases: the systole, in which blood is pumped from the heart, and the diastole, in which the heart fills with blood. Systole and diastole are each subdivided into two further phases, resulting in a total of **four phases** of heart action. Pressure and volume in the ventricles and atria change in a characteristic manner due to contraction and relaxation processes, with the pressure in the left ventricle changing the most and the pressure in the atria the least.

Systole

1.) Isovolumetric contraction

•Main function: ventricular contraction

•Occurs in early systole, directly after the atrioventricular valves (AV valves) close and before the semilunar valves open

•All valves are closed

•Ventricle contracts (i.e., pressure increases) with no corresponding ventricular volume change

- LV pressure: 8 mm Hg → ~ 80 mm Hg (when aortic and pulmonary valves open passively)
- LV volume: remains ~ 150 mL

•The period of **highest O_2 consumption**

2.) Systolic ejection

•Main function: Blood is pumped from the ventricles into the circulation and lungs.

•Follows isovolumetric contraction

•Occurs during systole, between the opening and closing of the aortic valve

•Ventricles contract (i.e., pressure increases) to eject blood, thereby decreasing the ventricular volume

- Pressure: first increases from ~ 80 mm Hg to 120 mm Hg and then decreases until aortic and pulmonary valves close
- Volume: ejection of ~ 90 mL SV (150 mL → 60 mL)

Diastole

3.) Isovolumetric relaxation

•Main function: ventricular relaxation

•Follows systolic ejection

•Occurs between aortic valve closing and mitral valve opening

•All valves closed (volume remains constant)

- **Dicrotic notch**: slight increase of aortic pressure in the early diastole that corresponds to closure of the aortic valve

•The ventricle relaxes (i.e., pressure decreases) with no corresponding ventricular volume change until ventricular pressure is lower than atrial pressure and atrioventricular valvesopen

- Pressure: decreases to ~ 10 mm Hg
- Volume: remains at ~ 60 mm Hg

4.) Ventricular filling

•Main function: ventricles fill with blood

Rapid filling

•Follows isovolumetric relaxation

•Occurs in early diastole; immediately after mitral valve opening

•Blood flows passively from the left atrium to the left ventricle

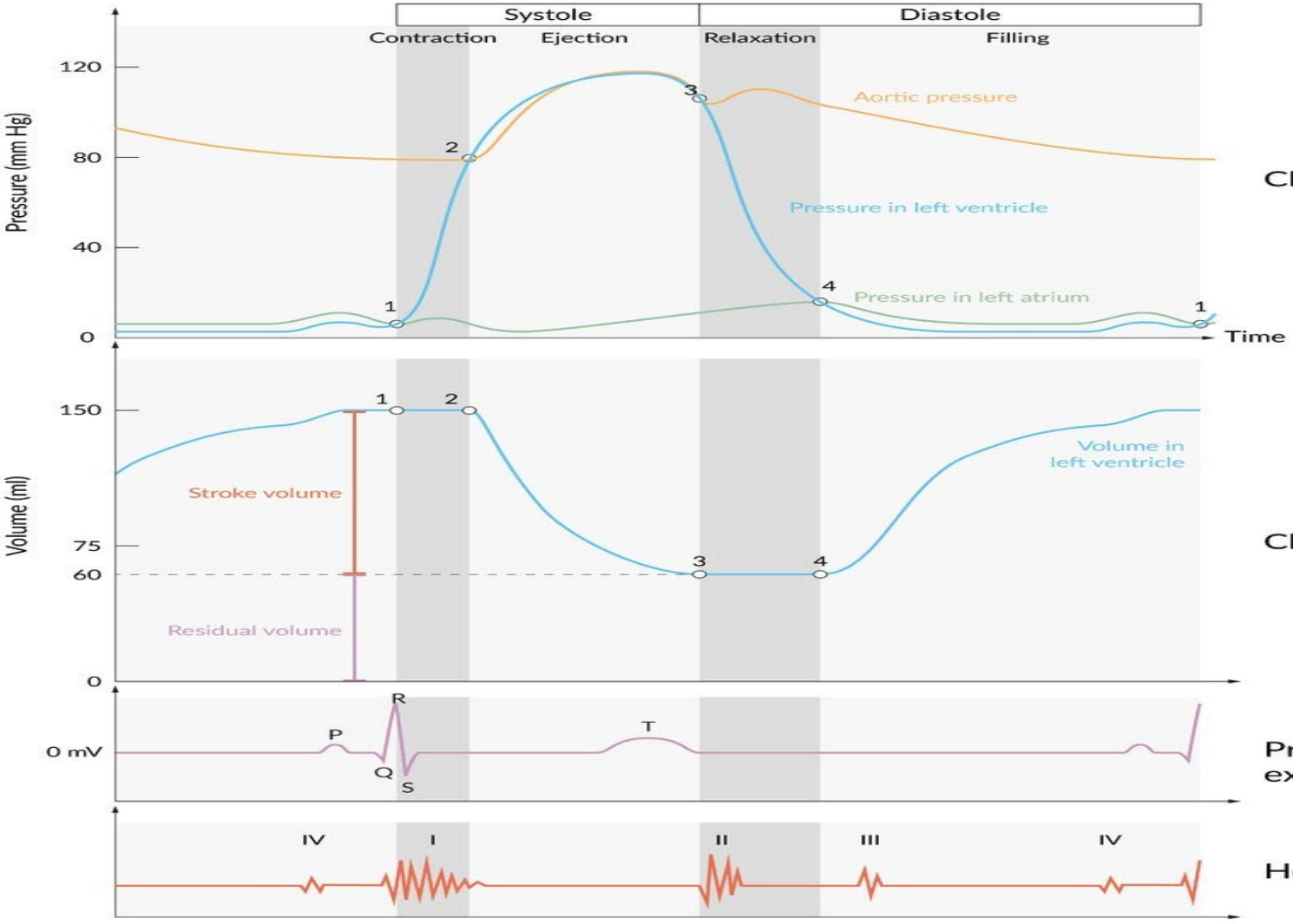
•The **largest volume of ventricular filling** occurs during this phase

Reduced filling

•Follows rapid filling

•Occurs in late diastole; immediately before mitral valve closing

- Pressure: ~ 8 mmHg
- Volume: ventricle fills with ~ 90 mL (60 mL → 150 mL)

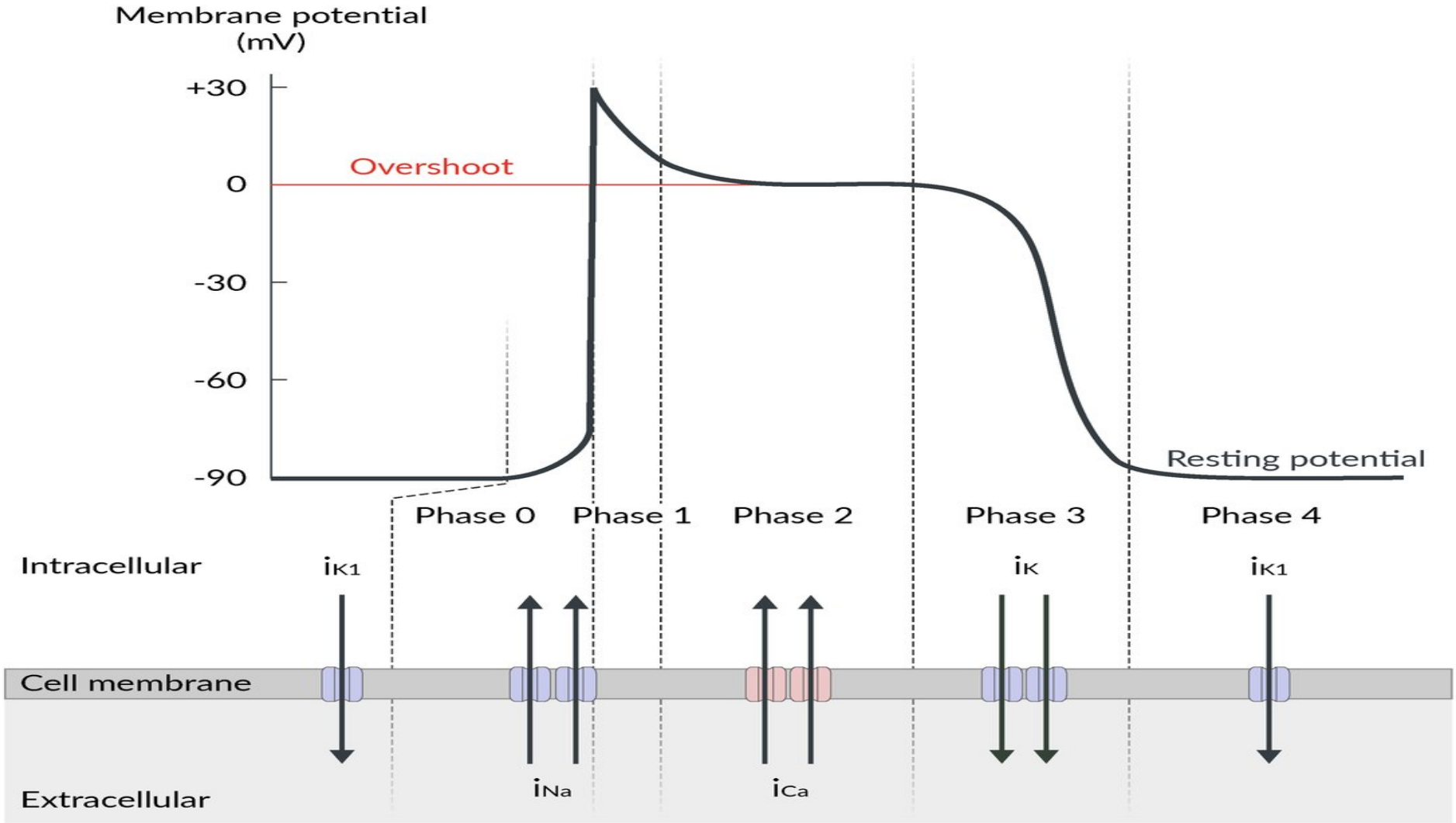


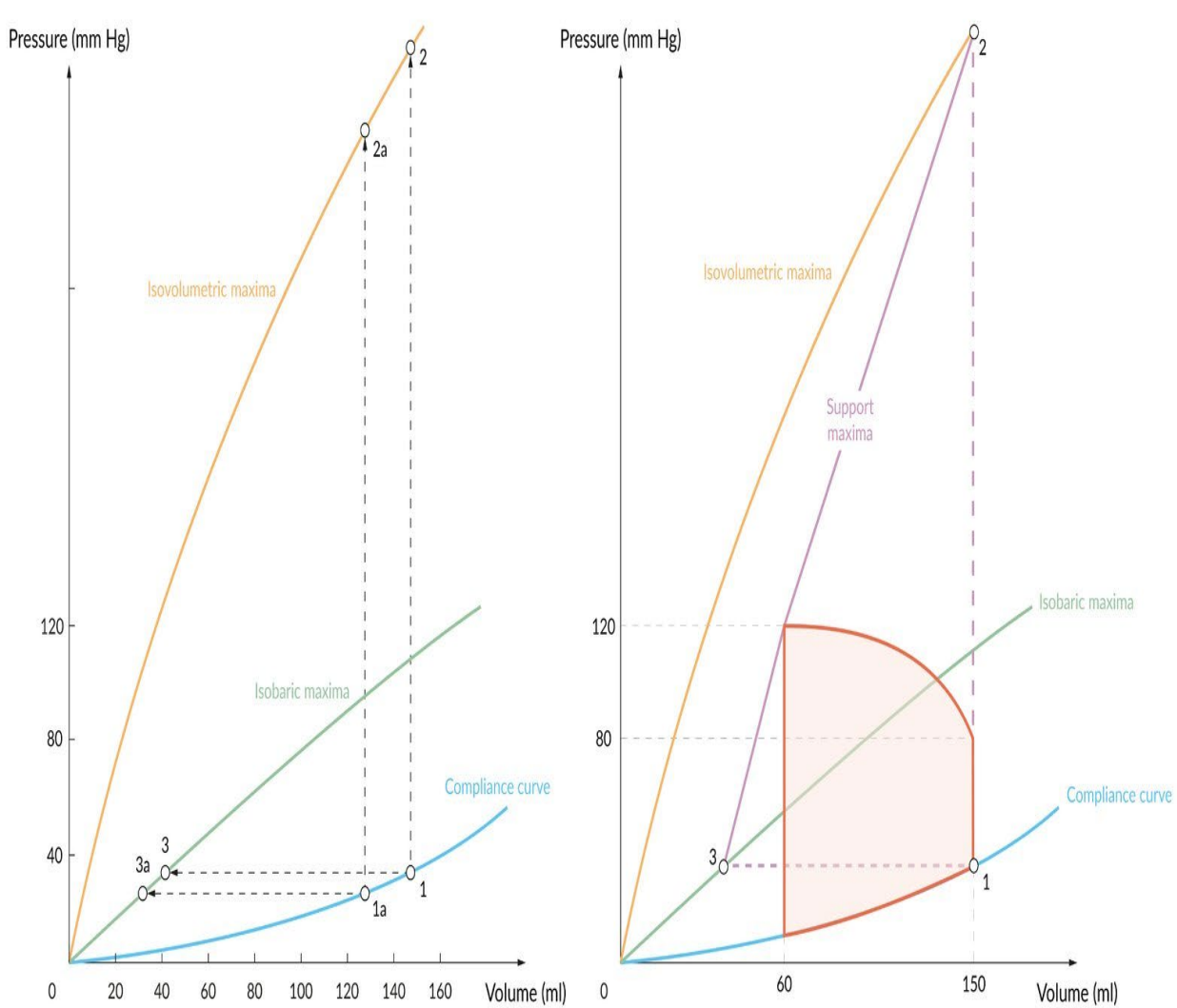
Changes in pressure

Changes in volume

Propagation of excitation

Heart sounds


Membrane potential
(mV)
+30
0
-30
-60
-90
Overshoot
Resting potential
Phase 0
Phase 1
Phase 2
Phase 3
Phase 4
Intracellular
iK1
iK
iK1
Cell membrane
iNa
iCa
Extracellular



Left ventricular pressure-volume diagram

- **Used to**: measure cardiac performance
- **Shape**: roughly rectangular; each loop is formed in an anti-clockwise direction
- **Course**:
  - (1) End-diastolic state: left ventricle filled with blood
  - (1) → (2): Isovolumetric contraction with closed mitral and aortic valves
  - (2): Pressure becomes higher than the aortic pressure and the aortic valve opens → initiates ventricular ejection
  - (2) → (3): Volume and pressure decrease until pressure falls below aortic pressure and aortic valve closes
  - (3): End-systolic state
  - (4): Pressure falls, volume remains constant (isovolumic relaxation)
  - (4) → (1): Pressure falls below atrial pressure and mitral valve opens; the ventricle is filled with blood
  - (1): End-diastolic point; contraction begins

Name		Definition	Site	Direction of flow	Activation phase (affected tissue)
Calcium channels	**Voltage-gated L-type calcium channel** (i_{Ca})	Ca^{2+} channels on the surface of myocytes, which open at about -40 mV and allow intracellular calcium influx	Cell membrane	Extracellular calcium → cytoplasm	Plateau phase (myocardium) and raising phase (SV node)
	Ryanodine receptor	Ca^{2+} channel in the membrane of the SR that opens after binding of Ca^{2+} (referred to as calcium-induced Ca^{2+} release)	Membrane of SR	Ca^{2+} from SR → cytoplasm	Plateau phase (myocardium)
Calcium pumps	**SERCA** (sarcoplasmic Ca^{2+}-ATPase)	Ca^{2+} pumps and exchanger that remove Ca^{2+} from the cytosol, thereby terminating a contraction	Membrane of SR	Ca^{2+} in cytoplasm→ SR	Plateau phase (myocardium)
	Na^{+}/Ca^{2+}-exchanger		Cell membrane	Ca^{2+} in cytoplasm→ extracellular	

Cardiac channels

- The action potentials of the pacemaker centers are transmitted to the cells of the myocardium via the cardiac conduction system, thereby depolarizing the cells (electromechanical coupling).
- As a result, voltage-activated calcium channels open, causing calcium ions to flow into the cardiomyocytes.
- Calcium binds to regulatory proteins of myofilaments(troponin) and allows interaction of actin and myosin.
- The muscle cell contracts.
- The exact course of the molecular interaction of actin and myosin (filament sliding theory) is dealt with in the basics of muscle tissue.
- **Calcium channels and calcium pumps**

Other cation channels
All are located in the cell membrane.

Name		Definition	Ion and direction of flow	Activation phase (affected tissue)
Funny channels (HCN, I_f)		Nonselective cation channels (e.g., for Na^+, K^+) in pacemaker cells that open as the membrane potential becomes more negative (hyperpolarized)	Cations extracellular → intracellular	Raising phase (sinus node)
Fast sodium channels (I_{Na})		Na^+ channels that rapidly open and close following depolarization	Na^+ extracellular → intracellular	Depolarization(myocardium)
Potassium channels	**Inward rectifier K^+ channels**	K^+ channels that open below −70 mV and stabilize the resting potential of the myocardiocytes by outflow of K^+	K^+ intracellular → extracellular	Resting potential(myocardium > sinus node)
	Delayed rectifier K^+ channels(I_{Kr} & I_{Ks})	K^+ channels that can be rapidly (I_{Kr}) or slowly (I_{Ks}) activated upon depolarization	K^+ intracellular → extracellular	Repolarization (sinus node and myocardium)

Cardiac action potential	**cardial action potential** (myocardium, bundle of His, Purkinje fibers)	**Pacemaker action potential** (SA node and AV node)
Phase 0 (Upstroke and depolarization)	•An action potential from a pacemaker cell or adjacent cardiomyocyte causes the transmembrane potential (TMP) to rise above −90 mV •Fast voltage-gated Na^+ channels open at -65 mV → rapid Na^+ influx into the cell → TMP rises further until slightly above 0 mV (overshoot)	•At TMP -40 mV (threshold potential of pacemaker cells): L-type Ca^{2+} channels open, TMP raises to +40 mV (overshoot**/upstroke**) •**No rapid depolarization** phase because fast voltage-gated Na^+ channels are inactivated in pacemaker cells → results in slower conduction velocity between atria and ventricles.
Phase 1 (Early repolarization)	•Voltage-gated Na^+ channels close •Transient K^+ channels start to open (outward flow of K^+ returns TMP to 0 mV)	•**Absent**
Phase 2 (Plateau phase)	•K^+ efflux through delayed rectifier K^+ channels and Ca^{2+} influx through voltage-gated L-type Ca^{2+} channels, which triggers Ca^{2+} release from the sarcoplasmic reticulum (i.e., Ca^{2+}-induced Ca^{2+} release) and contraction of the myocyte •TMP is maintained at a plateau just below 0 mV	•**Absent**

Phase 3 (Repolarization)	•Rapid repolarization due to: • Inactivation of voltage-gated Ca^{2+} channels • K^+ efflux through delayed rectifier K^+ channels continues: persistent outflow of K^+ exceeds Ca^{2+} inflow and brings TMP back to -90 mV •The sarcolemmal Na^+-Ca^{2+} exchanger, Ca^{2+}-ATPase, and Na^+-K^+-ATPaserestore normal transmembrane ionic concentration gradients (Na^+ and Ca^{2+} ions return to extracellular space, K^+ to intracellular space)	•Closure of voltage-gated Ca^{2+} channels and •Opening of delayed rectifier K^+ channels → K^+ efflux (TMP returns to -60 mV)
Phase 4 (Resting phase)	•Resting membrane potential stable at -90 mV due to a constant outward leak of K^+ through inward rectifier channels •Na^+ and Ca^{2+} channels closed	•**No resting phase** (unstable membrane potential) • Gradual Na^+/K^+ entry via funny channels I_f (referred to as the funny current or **pacemaker current**) → slow spontaneous depolarization (TMP raises above -60 mV) → no external action potential needed (**automaticity of SA and AV nodes**) • At TMP -50 mV: T-type Ca^{2+} channels open. Shortly before reaching the threshold potential (-40mV), L-type Ca^{2+} channel begin to open (see phase 0)

Refractory period

- To ensure the proper length of time for chamber emptying (during systole) and refilling (during diastole) before the next contraction, and to prevent tetany of cardiac muscle, it is imperative that every contraction of the myocardium is followed by a sufficiently long period of relaxation.
- Therefore, a heart muscle cell is not re-excitable for a short time after depolarization, which is known as the refractory period.
- Due to the very long action potential of cardiomyocytes (200–400 ms), the first excited cardiomyocytes are still refractory while the last are still excited. On the one hand, this prevents circulatory excitations and, on the other hand, gives the cardiomyocytes enough time to contract and relax, without being disturbed by re-excitation!

•Refractory period: the time from phase 0 until the next possible depolarization of a cardiomyocyte

- Ensures sufficient time for chamber emptying (during systole) and refilling (during diastole) before the next contraction
- Prevents tetany of cardiac muscle
- Depends on the number of sodium channels ready to be reactivated
    - **Absolute refractory period**: The fast sodium channels are completely deactivated during the plateau phase of the action potential of the myocardium so that no new action potential can be generated.
    - **Effective refractory period**: An interval of time during which stimuli cannot generate a new action potential in a depolarized cardiac cell. The sodium channels are in an inactivated state until the cell fully repolarizes.
    - **Relative refractory period**: The fast sodium channels can be partly activated at a TMB -40 mV; a very strong stimulus can generate a new weak action potential in this state.

•**Supernormal period**: period of supernormal excitability of the myocardium during repolarization (some parts of the heart are excited and others unexcited)

- The firing frequency of the SA node is faster than that of other pacemaker sites (e.g., the AV node. The SA node activates these sites before they can activate themselves (known as overdrive suppression).
- The plateau phase of the myocardial action potential is longer than the actual contraction. This allows the heart muscle to relax after each contraction and prevents a permanent contraction (so-called tetany)!
- Cells in the relative refractory and supernormal period are particularly susceptible to arrhythmias (e.g., ventricular fibrillation) when exposed to an inappropriately timed stimulus. During cardioversion, shock delivery needs to be synchronized with an R wave on ECG (indicating depolarization) and needs to be avoided during the relative and supernormal refractory periods (T waves, indicating repolarization)!

Regulation of cardiac activity

The heart can generate excitement on its own due to its pacemaker cells, but it must adapt its work to daily life requirements. Adaptation to short-term changes is provided by the Frank-Starling mechanism. Long-term changes in cardiac activity are regulated by the autonomic nervous system. The electrical activity of the heart can be recorded by electrocardiography. See ECG for an overview and interpretation of ECGs.

Frank-Starling mechanism

•**Definition**: Compensatory mechanism of the heart that adjusts stroke volume according to the venous return in order to maintain cardiac output.

- Length-tension relationship: larger volumes of blood in the ventricles stretch the cardiac muscle fibers and thereby lead to an increase in the force of contraction (↑ preload→ ↑ end-diastolic length of cardiac muscle fibers → ↑ force of contraction (i.e., ↑ stroke volume).

•**Aim**: Stroke volume of both ventricles should remain the same

•**Basic terms**

- **Preload**: The extent to which heart muscle fibers are stretched before the onset of systole. Depends on end-diastolic ventricular volume (EDV), which changes according to:
  - Venous constriction: ↑ venous tone → ↑ venous blood return to the heart → ↑ EDV → ↑ preload
  - Circulating blood volume: ↑ circulating blood volume → ↑ EDV → ↑ preload
- **Afterload**: The force against which the ventricle contracts to eject blood during systole.
  - Afterload is primarily determined by the mean arterial pressure (MAP) in the aorta, which is influenced by total peripheral resistance.
  - ↑ Afterload → ↑ left ventricular pressure → ↑ left ventricular wall stress
  - According to LaPlace's law, ↑ left ventricular pressure → ↑ left ventricular wall stress
    - Left ventricular (LV) wall stress = (LV pressure × radius)/ 2×LV wall thickness

- In chronic hypertension with a chronically increased afterload, the left ventricle undergoes hypertrophy to decrease left ventricular wall stress (↑ LV wall thickness → ↓ LV wall stress).
- While an increase in preload leads to an increase in stroke volume, an increase in afterload leads to a decrease in stroke volume!

A 51-year-old white male presented to the cardiac cath lab with a recent, progressive history of shortness of breath, chest pain on exertion, and fatigue. The patient has a history of poorly controlled hypertension, hyperlipidemia, family history of coronary artery disease, and arthritis. Based on the patient history, a left and right heart catheterization and coronary angiography were ordered for the patient. The coronary arteries demonstrated no obstructive lesions. A left ventriculogram (LV gram) demonstrated an ejection fraction of 40%, with global hypokinesis.

More information:

Weight 234 lbs
Height 6'0"
Hemoglobin 16.5
Heart rate 110
Pa Sat 52%
Ao Sat 96%
Creatinine 1.07
Potassium 3.9
Platelets 234
INR 1.0
Blood pressure 160/90mmHg
Pulse ox 94%
The diagnosis for this patient is left heart failure.

What is the normal mean pressure range for the right atrium?

A. 2-6mmHg

B. 4-18mmHg

C. 25/5mmHg

D. 12-16mmHg

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B. 4-18mmHg

C. 25/5mmHg

D. 12-16mmHg

The normal pressure for the right atrium is around 2-6mmHg.

What is the normal pressure for the right ventricle?

A. 12/16/14

B. 25/5

C. 75/15/15

D. 40/15

Which portion of the ventricular waveform represents the preload state?

A. Systolic peak

B. Beginning diastole

C. End diastolic pressure

D. The ventricular upstroke

Based on the heart rate and cardiac output, what is the patient's stroke volume?

A. 333mL

B. 30.3mL

C. 8.5L/min

D. 200L/min

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Normal and Pathological Electrocardiograms