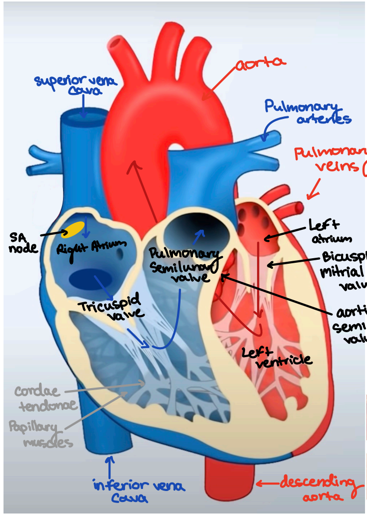
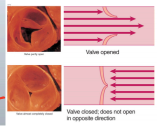
Cardiovascular System





- function is impacted by endocrine system, nervous system, and kidneys

Ventral(front); dorsal(back)

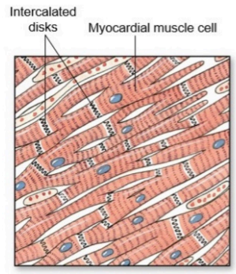
- semilunar valves=between ventricles and arteries—all valves are one way

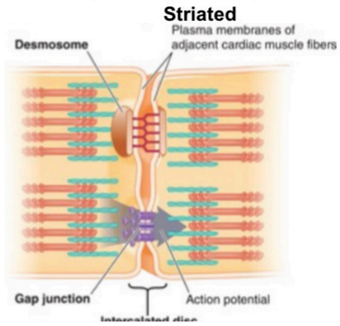
Cardiac Muscle Structure

- involuntary striated—able to see lines because sarcomeres are organized
- individual cells each have their own nucleus unlike multinucleated skeletal muscle

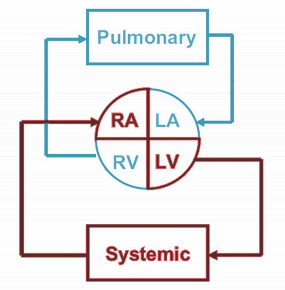
Intercalated Discs

- combination of gap junctions and desmosomes at cell junctions between cardiac muscle cells that allow heart to contract in unison
  - Desmosomes—structure of proteins that brings the cell together; prevent the cell from tearing apart during contraction
    - Gap Junction—allows for flow of ions between cells
      - there are gap junctions b/t cells in our atria and gap junctions b/t cells in our ventricles but no gap junctions between atria and ventricles(they are separated)





- arteries—> capillary—> blood vessel—> capillary—> veins(portal system—connect capillary beds)
- blood sent to all organs in parallel, can be simplified in a circuit



Pulmonary Circuit

- Left AV valve opens when A(atrial) pressure> V(ventricular) pressure

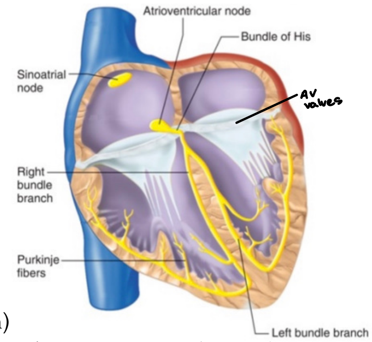
Systemic Circuit

- Right AV valve opens when A pressure> V pressure

Semilunar valves open when ventricular pressure is higher than aortic/pulmonary pressures

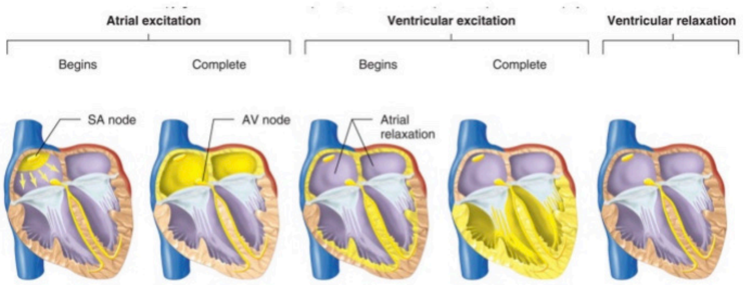
Heart contracts to apply a force that allows blood to go through the entire body and come back(systolic bp)

- Systolic bp or pressure in mmHg in aorta~120-180mmHg
- Blood coming back to atria has almost no pressure (0-10mmHg)



Systolic bp—force heart exerts on walls of arteries each time it beats

Diastolic bp—force heart exerts on walls of arteries in between beats



SA node—pacemaker

- 70blm(100bmp w/o parasympathetic system)
- AV node(r-bpm) and Purkinje Fibers(25-40bpm) can act as pacemakers under some conditions

AV node

- routes direction of electrical signals so heart contracts from apex to base
- AV node delay—slower conductional signals through nodal cells

SA node—pacemaker, initiates each wave of excitation w/ atrial contraction

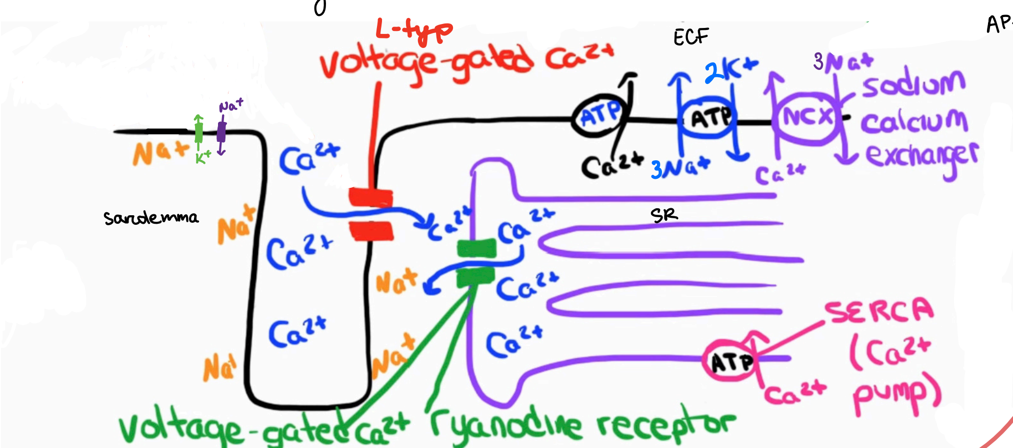
- bundle of His and other parts of conducting system deliver excitation to apex of heart so ventricular contraction occurs in an upward sweep

Electrical Activity of Heart

Cardiomyocytes—99%, striated muscle, produce contractions

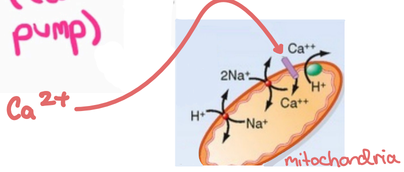
Conduction System—1%; electrically excitable, do not have organized sarcomeres, job to independently fire AP and set rhythm of the heart

Exitation Contraction Coupling

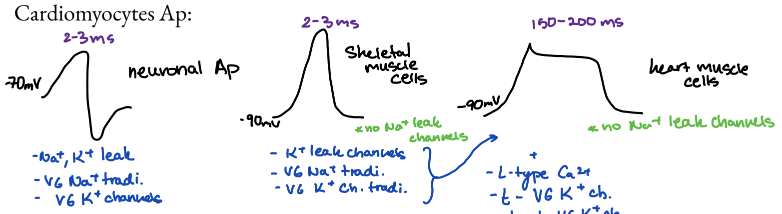


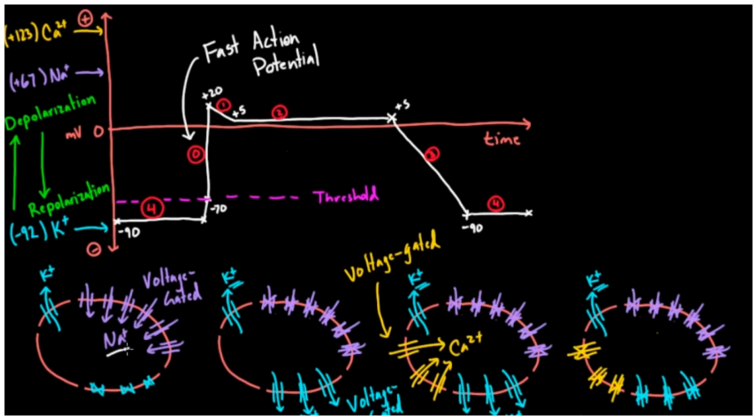
AP→ T-tubules → L-type Voltage-gated Ca^{2+} channels open → ryanodine receptors → ↑[Ca^{2+}] ↓ muscle contraction

* Depolarization to threshold caused by Na^+ entering through gap junctions
↓
Ca^{2+} entering through VG Ca^{2+} channels + leaving ER contribute to contractile power
↓
Ca^{2+} eliminated by transporters + pumps
↓
goes to ECF, SR, + Mitochondria → muscle relaxation



Cardiomyocytes Ap:



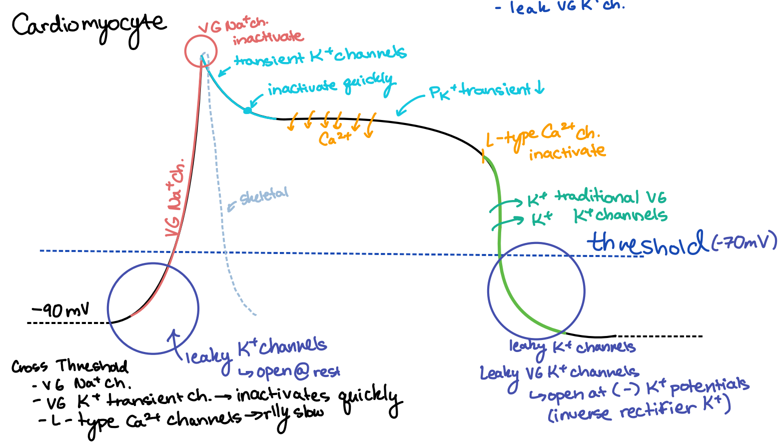


AP —> Na+ enters via gap junctions —> VG Na+ channels open @ threshold —> fast depolarization VG Na+ channels inactivate ~35mV

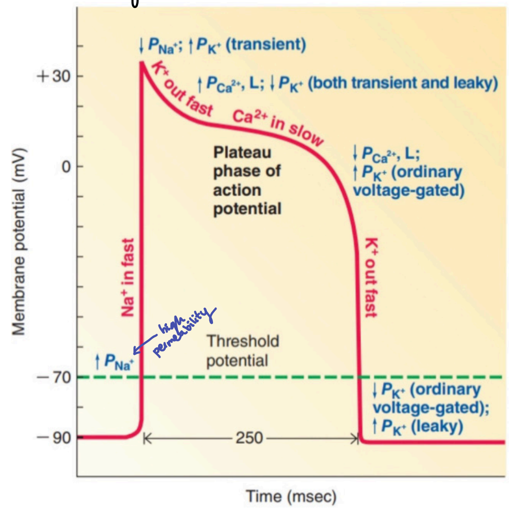
—> transient K+ channels activate + inactivate quickly —> L-type Ca2+ channels open ↑Ca2+ K+ from transient K+ channels resists this → plateau —> L-type Ca2+ channels inactivate

—> K+ depolarizes cell through traditional VG K+ channels —> ~-70mV ordinary channels inactivate + leaky channels activate

Cardiomyocyte



- Plateau phase rate of influx of Ca2+ to the inside of the cell is equal to the rate of K+ leaving the cell
- at rest traditional VG K+ channels are closed and leaky ones are open
    - once L-type Ca2+ channels inactivate traditional VG K+ channels depolarize cell



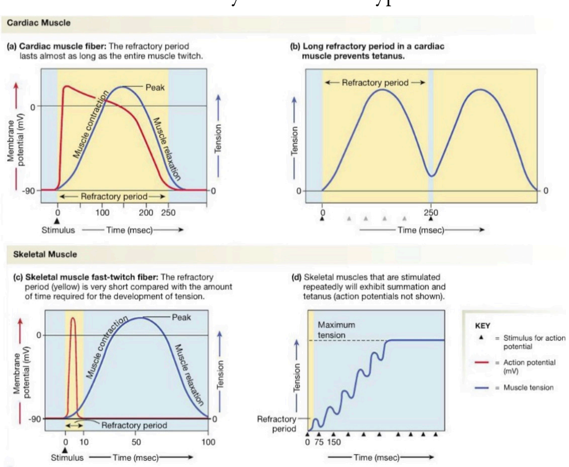
Comparing Skeletal and Cardiac Muscles

Skeletal: AP—> latency period(time b/t action potential and onset of contraction)—> muscle twitch

- latency period caused by excitation contraction coupling—> transmit AP to muscle, have to propagate down T-tubules and allow Ca2+ release(electrical events—> Ca2+ release—> contraction)

Cardiac: AP—> Ca2+ come in from L-type Ca2+ channels and SR —> muscle contracts in presence of Ca2+

- Contraction will start during AP because AP is so long; cannot sum muscle twitches in the same way we do with skeletal muscle
- relaxation only starts when L-type Ca2+ channels close



Cardiac Muscle—AP refractory period lasts almost as long as the entire muscle twitch

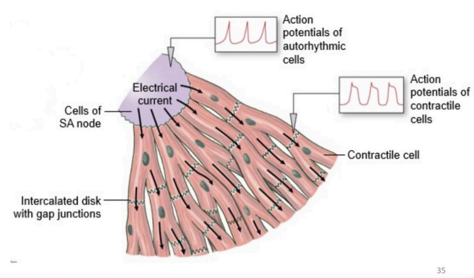
- long refractory period prevents tetanus

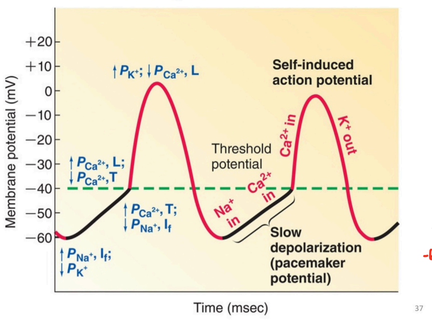
Skeletal Muscle—short refractory period compared to amount of time required to complete a full muscle twitch

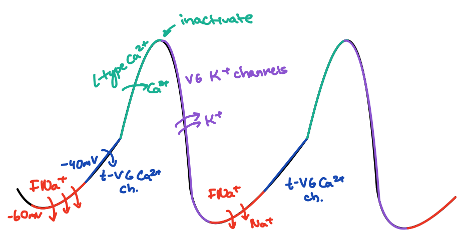
- skeletal muscles that are stimulated repeatedly will exhibit summation and tetanus

Autorhythmic cells:

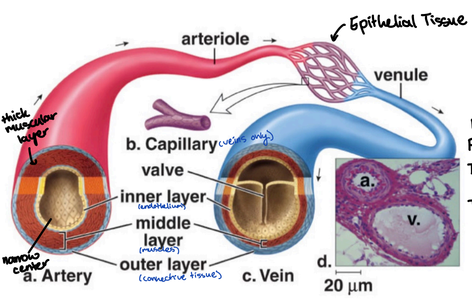
- always changing in voltage, no real resting potential
- do not have traditional VG Na+ channels
    - Funny VG Na+ channels—open at hyperpolarized potentials called IF (funny current)
    - T-type VG Ca2+ channels(inactivate quickly)
    - L-type VG Ca2+ channels
    - several VG K+ channels







*funny channels open when membrane voltage becomes less than -40mV



Diffusion across Capillaries

Net filtration (-) ⟶ favor abs.
(+) ⟶ favor filtration

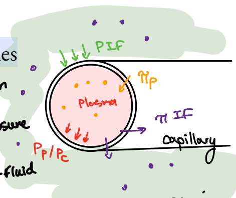
P_c - capillary hydrostatic pressure

P_{IF} - Interstitial Fluid hydrostatic pressure

π_p - osmotic force due to plasma protein concentration

π_{IF} - Osmotic force due to interstitial-fluid protein concentration

$Flow = \frac{\Delta P}{R}$



Forces out: $P_c + \pi_{IF}$

Forces In: $P_{IF} + \pi_p$

Net Filtration Pressure = Out - In = $(P_c + \pi_{IF}) - (P_{IF} + \pi_p)$

(+) things leave cap

(-) things enter cap

Comparison of Action Potentials in Cardiac and Skeletal Muscle — Table 14.3

	Skeletal Muscle	Contractile Myocardium	Autorhythmic Myocardium
Membrane potential	Stable at -90mV	Stable at –90 mv	Unstable pacemaker potential; usually starts at –60 mV
Events leading to threshold potential	Net Na^+ entry through ACh-operated channels	Depolarization enters via gap junctions	Net Na^+ entry through I_f channels; reinforced by Ca^{2+} entry
Rising phase of action potential	Na^+ entry	Na^+ entry	Ca^{2+} entry
Repolarization phase	Rapid; caused by K^+ efflux	Extended plateau caused by Ca^{2+} entry; rapid phase caused by K^+ efflux	Rapid; caused by K^+ efflux
Hyperpolarization	Due to excessive K^+ efflux at high K^+ permeability. When K^+ channels close; leak of K^+ and Na^+ restores potential to resting state	None; resting potential is –90 mV, the equilibrium potential for K^+	Normally none; when repolarization hits –60 mV, the I_f channels open again. ACh can hyperpolarize the cell.
Duration of action potential	Short: 1–2 msec	Extended: 200+ msec	Variable; generally 150 + msec
Refractory period	Generally brief	Long because resetting of Na^+ channel gates delayed until end of action potential	Not significant in normal function

Blood Flow due to differences in pressure

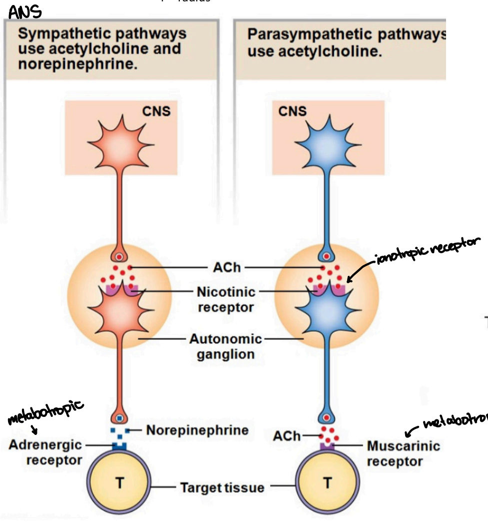
- as blood flows through blood vessels pressure goes down bc of constant friction against walls of blood vessels
- absolute pressure is irrelevant, liquid will flow through a tube if there is a positive pressure gradient

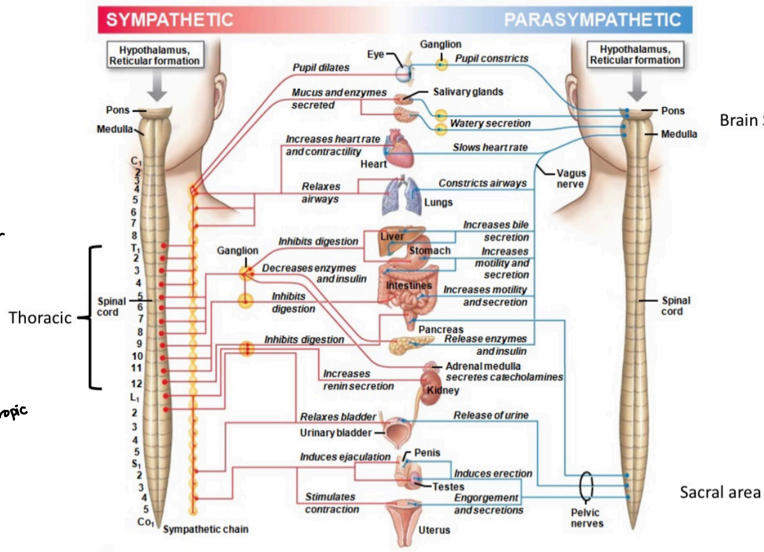
$$R = \frac{8L\eta}{\pi r^4}$$

- L= length
- η=blood viscosity,
- r = radius

- flow rate= vol/min while velocity=distance/min
- velocity as a fan of cross sectional area—velocity of flow through the capillary bends is slow bc their total cross sectional area is larger, capillaries have the lowest velocity

ANS





Sympathetic
↳ ganglia (short) → long
Parasympathetic
↳ nuclear system of ganglia
↳ long → short

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Blood Pressure

MAP=COx PR= 2/3DP + 1/3 SP

- baroreceptors monitor arterial pressure to ensure adequate perfusion of the brain and heart
- arterioles=most important vessel for regulation of peripheral resistance and thus MAP

- pulses pressure=systolic P-diastolic P
- ventricles produce driving force for blood flow
- resistance to flow regulated by local and reflex control mechanisms
  - act on arteriolar smooth muscle to help match tissue perfusion to tissue needs

Mean Arterial Pressure
Systolic P ⟶ Pressure as blood leaves LV during systole ~250ms
Diastolic P ⟶ Pressure of blood leaving ventricle in aorta during diastole ~550ms

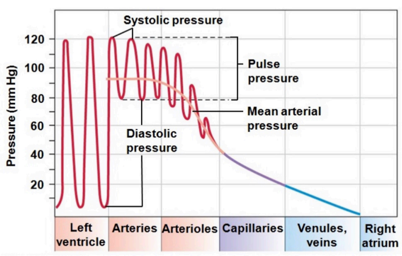
MAP = HR×SV × TPR (total peripheral resistance)
TPR ↳ resistance of blood vessels ↳ $F = \frac{\Delta P}{R}$
HR×SV = CO (cardiac output) ↳ amt of blood that leaves heart in 1min 70bpm (70mL/b) = 4.9L/min *normal = 2.5L/min

CO: HR ↓ # times heart beats/min; SV (stroke vol.) ↓ amt of blood leaving ventricle in one single heart beat
SV ↓ depends on Preload & Afterload
EDV − ESV = SV
EDV - end diastolic volume ↓ amt of blood in heart prior to contraction
ESV - end systolic vol. ↓ amt of blood left in heart after systole
* heart pump ~60% of blood ~70mL

* Ejection Fraction
↳ % of blood that was in ventricles that was ejected
$EF = \frac{SV}{EDV} \cdot 100$

Systemic Pressures

- Pressure waves created by ventricular contraction travel into blood vessels
  - pressure in arterial side of circulation cycles but the pressure waves diminish in amplitude with distance and disappear at the capillaries

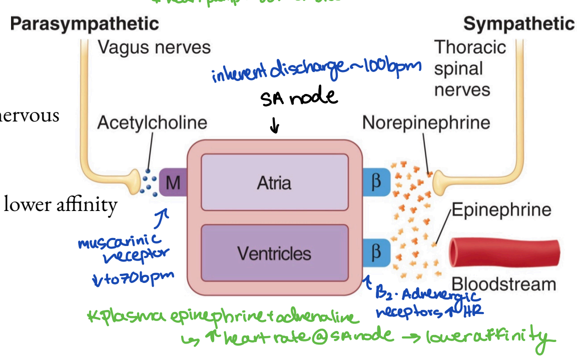


Regulating Cardiac Output

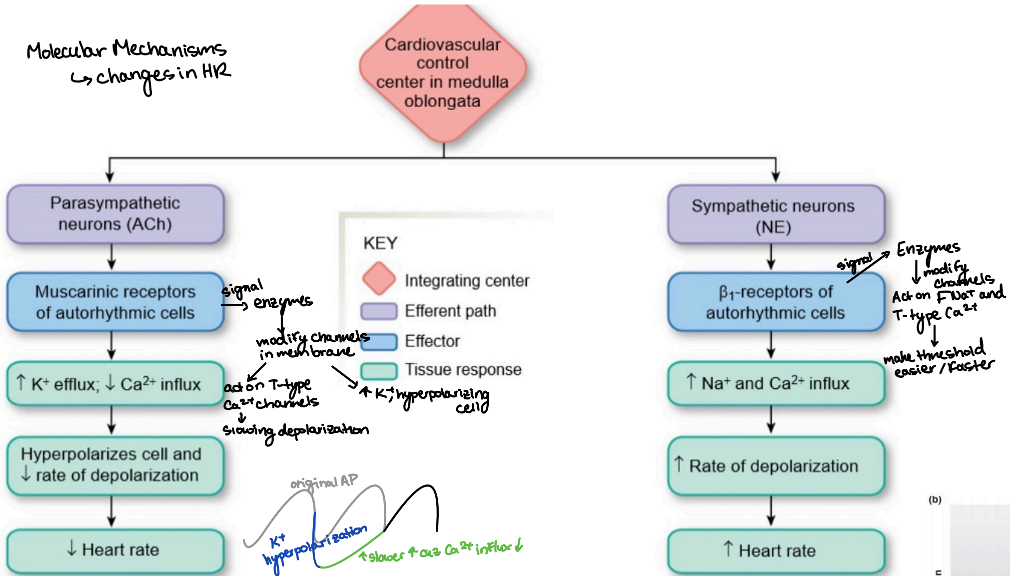
- heart rate(ANS)
- Stroke volume(preload, ANS, and afterload)

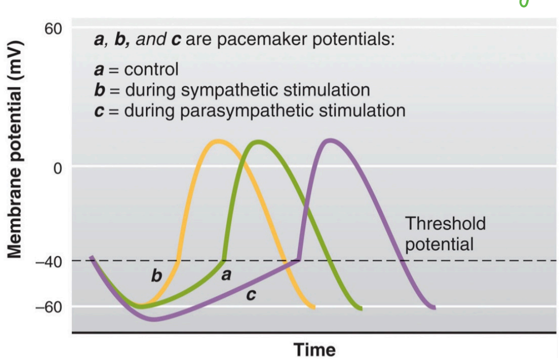
Innervation of heart

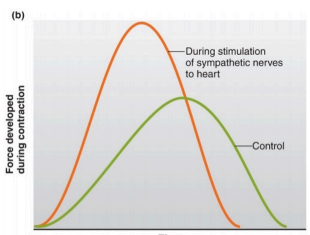
- receptors metabotropic(adrenergic and muscarinic receptors)
- ventricles dont get any significant influence from parasympathetic nervous system,
  - sympathetic system able to moderate strength of contraction
- epinephrine and adrenaline can impact the same receptors but with lower affinity



Molecular Mechanisms
↳ changes in HR







MAP = HR × SV × TPR ⊕ SNS
⊖ PNS ⊕⊕ SNS ⊕ ↑EDV (preload) ↓ venous return

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Stroke Volume:

preload—myocardial stretch before contraction. represents load on the heart, depends on EDV

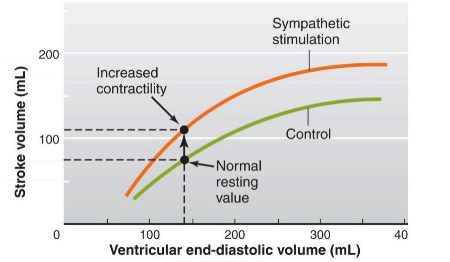
- more blood more muscle fibers stretch allowing them to generate more force

afterload—combined load of EDV and atrial resistance during ventricle contraction

- change sympathetic input to ventricles—affects contractility of ventricles

Frank-Starling Law

- strength of ventricular contraction depends directly on the end of diastolic volume(stretch)
  - EDV—determined by venous return
    - affected by—> skeletal muscle pump, respiratory pump, sympathetic innervation of veins
- relates to how much the myocardium is stretched by incoming blood—> larger stretch=more forceful conrtaction=larger SV
  - increased contractility causes an increased ejection fraction



Effect on Sympathetic System on Contractility

- positive inotropic effects—> increase contractility
- negative inotropic effects—> decrease contractility
  - a chemical that affects contractility is an inotropic agent

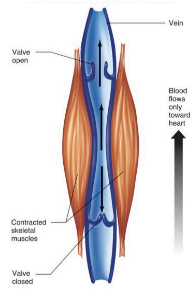
Veins

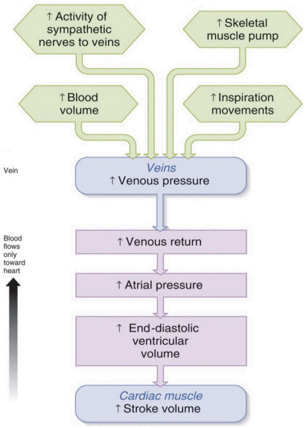
- highly distensible, called capacitance vessels, act as blood reservoirs

Venous Pressure

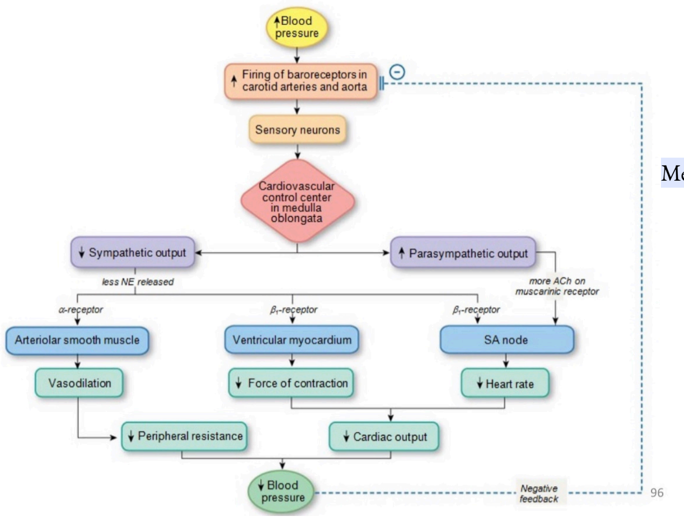
- BP in veins is ~15mmHg, not sufficient to move blood back to heart

1) respiratory pump
   - pressure changes in central cavity due to the pressure changes due to breathing. this helps propel blood back to heart
2) muscular pump
   - when muscle contacts they squeeze the veins. results in blood moving forward and being prevented from backflow by the veins
   - smooth muscle in veins is under SNS control and contract when stimulated increasing venous pressure and venous return





The Baroreceptor Reflex in Action

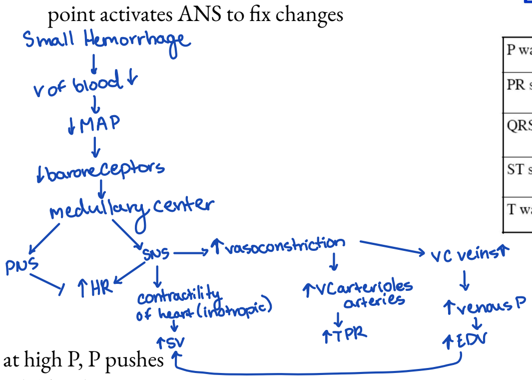


Baro-Receptors—localized in carotid artery and aorta

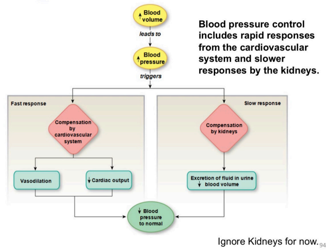
- BR neurons project to the medullary center—> regulates/ monitors bp
- aortic arch—when blood leaves the ventricle, first place it exits, most accurate measure of bp.
- carotid artery—points at which we can measure the amt of blood going to the brain

Medulla—cardiovascular center

- cells fire Ap proportional to wht is being sensed, control center—compares info it receives to set point activates ANS to fix changes



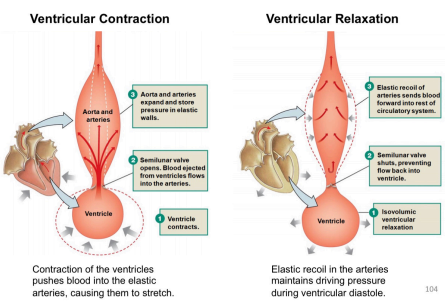
Regulation of Blood Pressure



Electrical Events in the EKGs

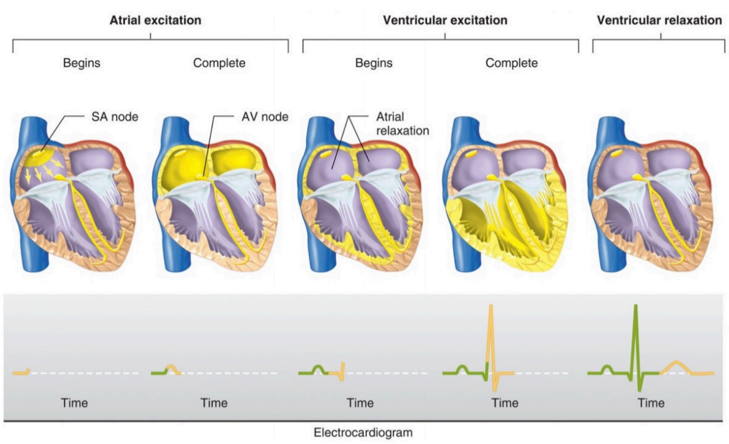
P wave	Atrial cells depolarize
PR segment	Plateau of atrial muscle action potentials also rep. AV node delay
QRS complex	Ventricular cells depolarize and *atrial cells repolarize*
ST segment	Plateau of ventricular muscle action potentials
T wave	Ventricular cells repolarize

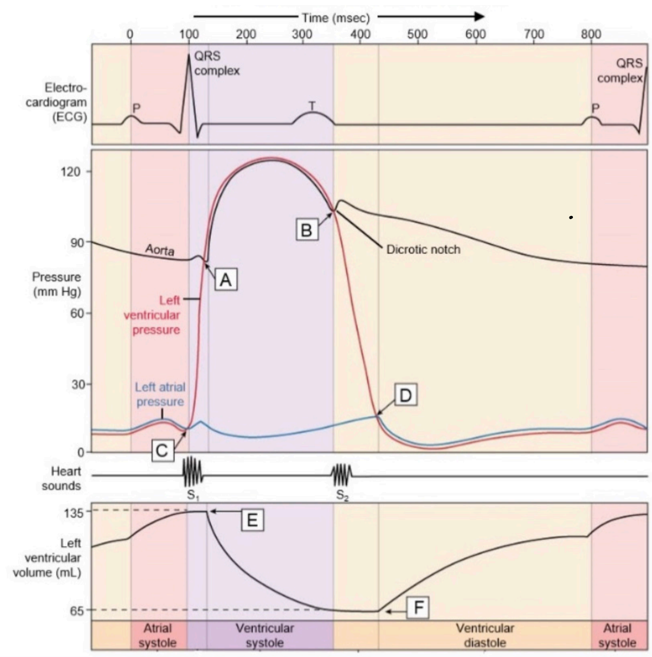
Dicrotic Notch and Arteries as Pressure Reservoirs

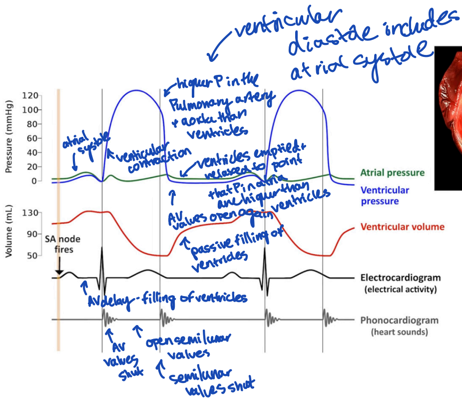


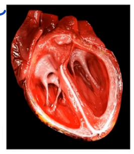
Aorta—elastic artery

- when blood comes out of heart at high P, P pushes walls of aorta which gets filled with blood
- once semilunar valves close aorta slowly comes back to normal size pumping blood back to body

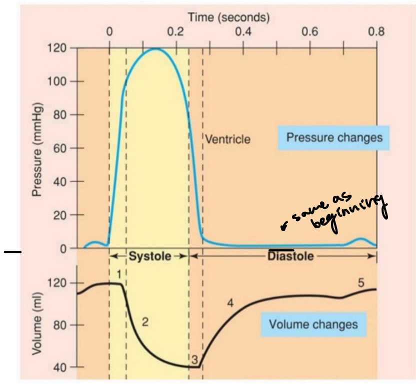








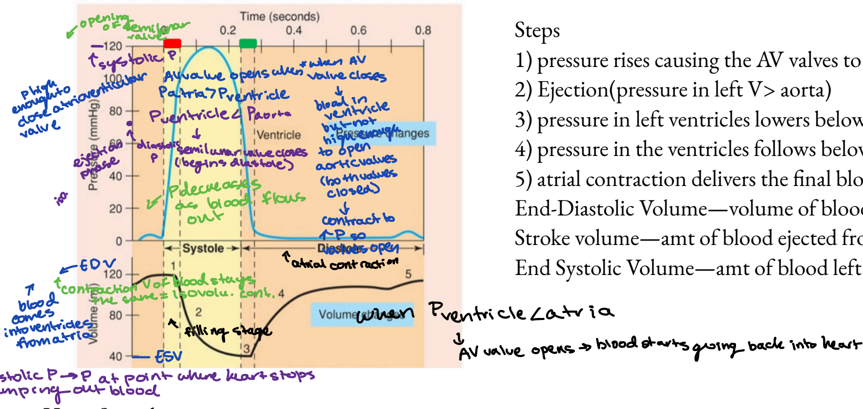
The Cardiac Cycle



Cycle initiates—firing of SA node —> atria depolarization(p wave)—>atrial contraction
Isovolumetric contraction—no blood is ejected, ventricular volume remains unchanged

- cardiac cycle comprises all the events involved with the blood flow through the heart during one heart beat
- systole is the contraction phase
- diastole is the relaxation phase

FOR THE LEFT VENTRICLE



Steps
1) pressure rises causing the AV valves to shut and teh SL valves are still closed(isovolumetric contraction)
2) Ejection(pressure in left V> aorta)
3) pressure in left ventricles lowers below aorta—> SL valve shuts(isometric relaxation)
4) pressure in the ventricles follows below that of the atria—> AV opens(filling)
5) atrial contraction delivers the final blood to the ventricles
End-Diastolic Volume—volume of blood in ventricles at end of diastole
Stroke volume—amt of blood ejected from ventricles during systole
End Systolic Volume—amt of blood left in ventricles at end of systole

Heart Sound

- Ausculation is listening to the heart through the chest wall through a stethoscope
- closing of AV and semilunar valves produces sounds that can be heard through stethoscope
    - lub(1st sound) produced by closing of AV valves
    - dub(2nd sound) produced by closing of semilunar valves