

- **Thoracic duct**
 - The thoracic duct lies behind the esophagus and between the thoracic aorta and azygos vein.
 - It arises from the cisterna chyli in the abdomen at vertebral level L1 through L2 and enters the thorax through the aortic hiatus of the diaphragm.
- **Azygos system of veins**
 - The posterior thoracic and abdominal walls are drained by the azygos system of veins
 - The azygos vein usually communicates with the inferior vena cava in the abdomen
 - the hemiazygos vein often communicates with the left renal vein.
 - These veins ascend to the thorax through the aortic orifice of the diaphragm.

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- Sympathetic trunks
 - The sympathetic trunks are located paravertebrally, just outside the posterior mediastinum.
- **Superior Mediastinum**
- **Thymus**
 - The thymus usually atrophies in the adult. The remains of the thymus may be found as a fatty mass.
- **Superior vena cava**
 - The superior vena cava is formed behind the right first costal cartilage by the union of the right and left brachiocephalic veins
 - It returns blood from the head, neck, and upper extremities to the right atrium of the heart.

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- **Arch of aorta**
 - The aortic arch begins and ends at the level of the sternal angle.
 - There are three branches: the brachiocephalic trunk, the left common carotid artery, and the left subclavian artery.
- **Vagus**
 - Right and left vagus nerves contribute to the pulmonary and cardiac plexuses.
 - In the neck, the right vagus nerve gives rise to the right recurrent laryngeal nerve, which passes under the right subclavian artery to ascend in the groove between the esophagus and the trachea to reach the larynx. Note: The right recurrent laryngeal nerve is not in the thorax.
 - The left vagus nerve gives rise to the left recurrent laryngeal nerve, which passes under the aortic arch and ligamentum arteriosum to ascend to the larynx (Left recurrent laryngeal nerve has a course in the thorax)

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- **Trachea**
 - The trachea extends from below the cricoid cartilage (vertebral level C6) to its bifurcation (behind the sternal angle) to form the primary bronchi.
 - At the bifurcation is a ridge called the carina whose mucosa is very sensitive to external stimuli.
- **Esophagus**
 - The esophagus extends from the cricoid cartilage (vertebral level C6) and passes through the esophageal hiatus of the diaphragm (T10).
 - It lies posterior to the trachea.
- **Thoracic duct**
 - The thoracic duct is the largest lymphatic channel in the body.
 - It returns lymph to the venous circulation at the junction of the left internal jugular vein and the left subclavian vein.

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Blood vessels

Arteries & Arterioles

- Arteries & Arterioles are the blood vessels which carries blood away from the heart
- Their walls have 3 layers
 1. Tunica Intima (Inner layer of endothelium)
 2. Tunica Media (Middle layer of smooth muscle & elastic tissue)
 3. Tunica Externa (Outer layer of fibrous tissue)
- Arteries have thicker walls than veins
- **Anastomoses** are arteries that form a link between main arteries supplying an area. They provide the alternative pathway for the flow of blood if one vessel become obstructed.
- **End-arteries** are the arteries with No Anastomoses

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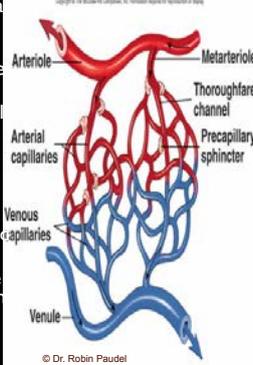
Veins & Venules

- The veins are those blood vessels which carries blood towards the Heart
- Walls of the veins are thinner than the arteries but has the same 3 layers
 1. Tunica Intima
 2. Tunica Media
 3. Tunica Externa
- Has less smooth muscle and the elastic tissue in tunica media than the arteries.
- Some veins (esp. veins of legs) have valves that prevents backflow of blood
- These valves are formed by a fold of tunica intima and supported by connective tissue
- Smallest veins are called venules

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Capillaries

- The smallest arterioles break up into a number of minute vessels known as Capillaries
- Their wall have a single layer of endothelial cells through which water and other small molecules can pass
- Blood cells and other larger molecular substances (like plasma proteins) do not normally pass through the capillary wall
- These capillaries form a complex network of tiny thread like vessels which link the smallest arterioles and smallest venules
- Capillary bed is the site of exchange of substances between the blood and the tissue fluids



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HEART

- Is a cone shaped hollow muscular organ
- Heart lies in the thoracic cavity in the mediastinum between the lungs
- Lies obliquely, a little more on the left than the right
- The size of the heart is nearly about the size of the fist of that person
- Weight of heart
 - Male ~300gms
 - Female ~250gms
- Has a
 - Apex (pointing downwards, forward towards the left)
 - Base (on the poster surface at the level of 2nd rib)



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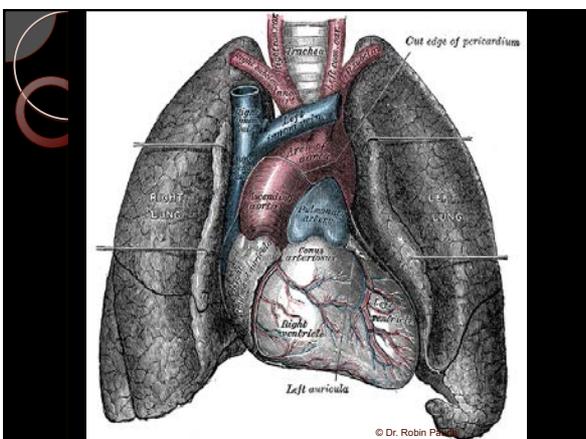
HEART

- **Borders of the Heart**
 - The right border is formed by the right atrium
 - The left ventricle and the auricle of the left atrium form the left border.
 - The superior border is formed by the right and left auricles plus the *conus arteriosus* of the right ventricle.
 - The apex is the tip of the left ventricle.

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- **Surfaces of the Heart:**
 - The base is opposite the apex, formed mainly by the surface where the pulmonary veins enter the heart (left atrium) and by part of the right atrium.
 - The anterior wall is formed primarily by the right ventricle
 - The posterior wall is formed by the left atrium.
 - The diaphragmatic wall is formed primarily by the left ventricle.

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Surface Projections

- Surface projections of the heart may be traced on the anterior chest wall
- The right border extends from the margin of the third right costal cartilage to the sixth right costal cartilage just to the right of the sternum.
- The inferior border extends from the sixth right costal cartilage to the fifth left intercostal space at the midclavicular line.
- The left border extends from the fifth left intercostal space to the second left costal cartilage.
- The superior border extends from the inferior margin of the second left costal cartilage to the superior margin of the third right costal cartilage.

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Wall of heart

- The wall of heart has 3 layers
 - Pericardium
 - Fibrous pericardium
 - Serous pericardium
 - Parietal layer
 - Visceral layer
 - Myocardium

(is composed of Cardiac muscles)
 - Endocardium

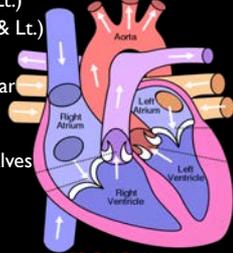
(inner most layer)



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Interior of Heart

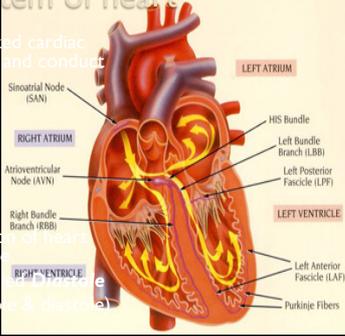
- Divided into right & left side by the septum
- Has four chambers**
 - Two Atrium (Rt & Lt.)
 - Two Ventricles (Rt & Lt.)
- Has four valves**
 - Two atrio-ventricular
 - Tricuspid valve
 - Mitral valve
 - Two semi lunar valves
 - Aortic valve
 - Pulmonary valve



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Conducting system of heart

- It is made up of specialized cardiac muscle cells that initiate and conduct the cardiac impulse
- It contains
 - SA node
 - AV node
 - Bundle of His
 - Rt. & Lt. bundle branch
 - Purkinje fibers
- The period of contraction of heart chamber is called **Systole**
- And the relaxation is called **Diastole**
- One cardiac cycle (systole & diastole) takes 0.8 sec
 - Arterial systole -- 0.1sec
 - Ventricular systole-- 0.3sec
 - Complete cardiac diastole 0.5sec



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- SA node**
 - The SA node initiates the impulse for contraction of heart muscle (and is therefore termed the "pacemaker" of the heart). It is located at the superior end of the crista terminalis, where the superior vena cava enters the right atrium
 - The SA node is supplied by the SA nodal branch of the right coronary artery. Impulse production is speeded up by sympathetic nervous stimulation; it is slowed by parasympathetic (vagal) stimulation.
- AV node**
 - The AV node receives impulses from the SA node. The AV node is located in the interatrial septum near the opening of the coronary sinus. The AV node slows the impulse so that it reaches the ventricles after it has reached the atria.
 - The bundle of His originates in the AV node. It conducts impulses to the right and left ventricles.
 - In the right ventricle, the moderator band (septomarginal trabecula) contains the right bundle branch.
 - Impulses pass from the right and left bundle branches to the papillary muscles and ventricular myocardium.

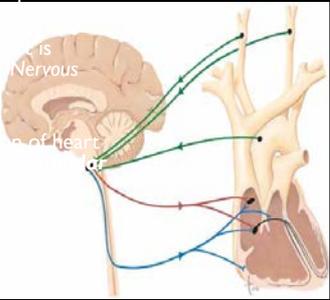
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- There are two bundles of atrial fibres that contain Purkinje type fibres and connect the SA node to the AV node:
 - The anterior internodal tract of **Bachman**
 - Middle : **Wenckebach**
 - Posterior: **Thorel**
 - However, there is controversy regarding whether these fibres are responsible for the conduction from SA node to AV node versus regular myocytes.
- SA node develops from structure from rt. Side
- AV node develops from str. From Lt. side
- Therefore,
 - Rt. Vagus -> SA node ← Rt. Sympathetic fibres
 - Lt. → AV

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Nerve supply to the heart

- In addition to the self impulse generation inside the heart, the heart is supplied by the **Autonomic Nervous system**
- Rate & force of contraction of heart is controlled by the **Cardiac centre** in the Medulla
- Sympathetic stimulation** increases the rate & force of contraction
- While the **Parasympathetic stimulation** decreases the rate & force of contraction



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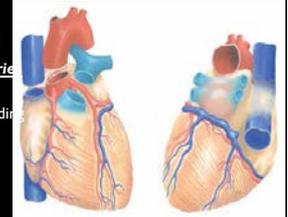
- **Chronotropic** (Heart rate)
- **Dromotropic** (Conduction velocity)
- **Inotropic** (Contractility)
- **Batmotropic** (Excitability)
- **Lusitropic** (Relaxation)

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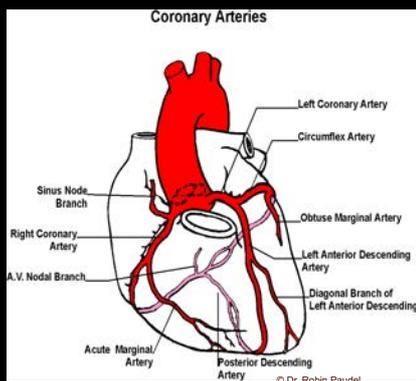
Blood supply of heart

Arterial supply

- The heart receives arterial blood through **Coronary Arteries (Rt. & Lt)**
- Coronary arteries arise from Ascending part of Aorta
- It receives ~5% of the pumped blood



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Right coronary artery

- The right coronary artery arises from the ascending aorta and runs in the coronary (AV) sulcus
- The right coronary artery primarily supplies the
 - right atrium,
 - the right ventricle,
 - the sino-atrial (SA) and
 - AV nodes.
- Important branches are the SA nodal artery, the right marginal artery, and the posterior inter-ventricular artery.

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Left coronary artery

- The left coronary artery arises from the ascending aorta. It divides into two branches,
 - the anterior interventricular (descending) artery and
 - the circumflex artery
- The left coronary artery supplies most of the
 - left ventricle,
 - the left atrium, and
 - the interventricular septum.

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Venous drainage

- Most of the venous blood from heart is collected by small veins which join to form **Coronary Sinus** and finally drained into Rt. Atrium
- Small amount passes directly into heart chamber through small venous channels

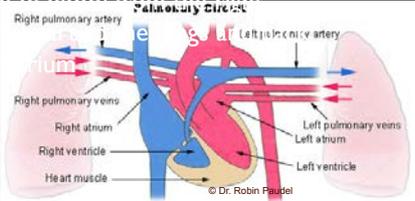
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Circulation of blood

- Circulation of blood can be divided into two parts
 - Pulmonary circulation
 - Systemic Circulation

PULMONARY CIRCULATION

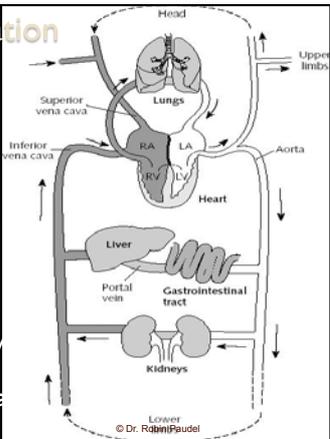
- Circulation of blood from the right ventricle of the heart to the lungs and back to the left atrium



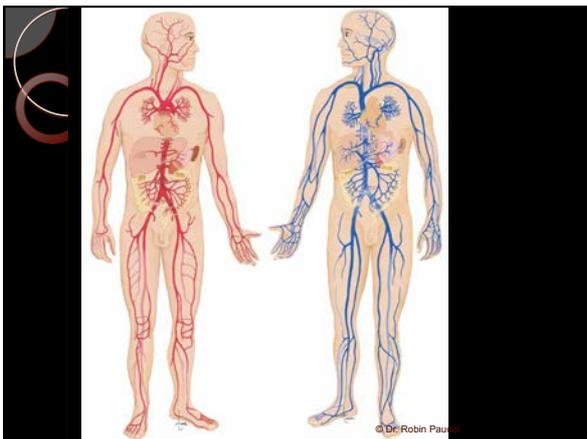
Labels in diagram: Right pulmonary artery, Right pulmonary veins, Right atrium, Right ventricle, Heart muscle, Left pulmonary artery, Left pulmonary veins, Left atrium, Left ventricle. © Dr. Robin Pauzel

Systemic Circulation

- In systemic circulation; the blood pumped out from the left ventricle is carried by the branches of **Aorta** to the whole body and returned back into the Right atrium by the superior & inferior venacava



Labels in diagram: Head, Upper limbs, Superior vena cava, Lungs, RA, LA, Heart, Aorta, Inferior vena cava, Liver, Portal vein, Gastrointestinal tract, Kidneys, Lower limbs. © Dr. Robin Pauzel



CHARACTERISTICS OF A RESTING VENTRICULAR MUSCLE CELL

	Ion conc. Out	Conc. In	Equil. pot.	Permeability
K ⁺	4	135	-94 mV	High
Na ⁺	145	10	+70 mV	Low
Ca ⁺²	2	10 ⁻⁴	+132 mV	low

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MEMBRANE CHANNELS

- **Ungated Potassium Channels**
 - Always open and unless the membrane potential reaches the potassium equilibrium potential (~-94 mV), a potassium flux (efflux) continues through these channels.
- **Voltage-Gated (-Dependent) Sodium Channels**
 - Closed under resting conditions.
 - Membrane depolarization is the signal that causes these channels to quickly open and then close.
 - Because they open and close quickly, they are sometimes referred to as the *fast channels*.
 - These channels have the same characteristics as the voltage-gated sodium channels in the neuron axon.
 - Once closed, they will not respond to a second stimulus until the cell repolarizes.

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- **Voltage-Gated Calcium Channels**
 - Closed under resting conditions.
 - Depolarization is the signal that causes these channels to open, but they open more slowly than the sodium channels.
 - Consequently, they are sometimes called the *slow channels*.
 - Because they allow sodium as well as calcium to pass, the *slow calcium-sodium channel* is also appropriate terminology.
 - The calcium entering the cell through these channels will participate in contraction and will also be involved in the release of additional calcium from the sarcoplasmic reticulum.
 - If the fast channels fail to open, depolarization occurs via the entrance of calcium through these channels.

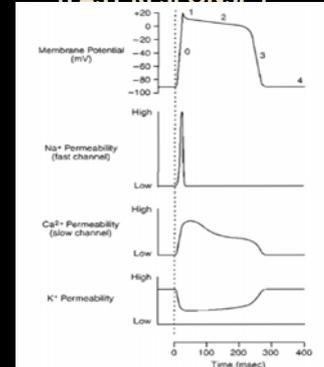
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Voltage-Gated Potassium Channels

- Open under resting conditions.
- Depolarization is the signal to close these channels.
- They will be closing during the depolarization phase and will be closed during the main part of the plateau phase.
- They begin to reopen during the latter part of the plateau phase and continue to reopen during repolarization.
- Thus, potassium conductance is exceptionally high under resting conditions, decreases during depolarization, is at a minimum during the plateau phase, and increases back toward the high resting level during repolarization.

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ACTION POTENTIAL OF A VENTRICULAR FIBER (FAST RESPONSE)



Ionic Basis of the Action Potential

Phase 0

- Fast channels open, increased G_{Na} (conductance of Na)
- Sodium influx then causes depolarization.
- The channels open and close quickly, and they have closed by the time the main part of the plateau phase is entered.
- Phase 1
 - This slight repolarization is due to a potassium current and the closing of the sodium channels.

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Phase 2

- Slow channels are open, G_{Ca} increase permitting a calcium influx.
- Voltage-gated potassium channels are closed; G_K decrease, compared with resting membrane.
- Potassium efflux continues through the ungated potassium channels.
- If voltage-gated potassium channels did not close during depolarization, early repolarization would occur, preventing the full development of the plateau phase.
- The development of the plateau phase is dependent on the closing of voltage-gated potassium channels.

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Phase 3

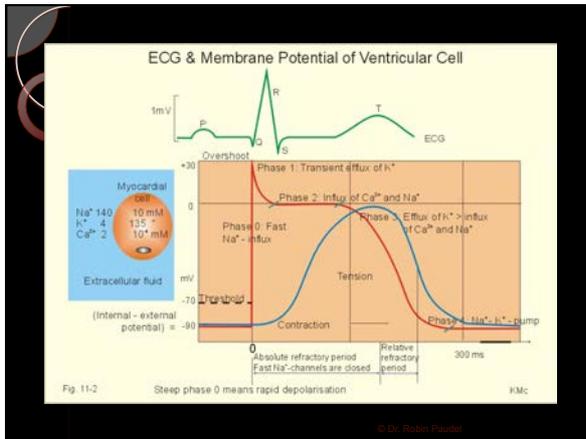
- Calcium or slow channels close, G_{Ca} decrease; this eliminates any influx through these channels.
- Voltage-gated potassium channels are reopening, G_K increase.
- Because we are a long way from the potassium equilibrium potential and conductance to potassium is increasing, a large potassium efflux begins, and the cell quickly repolarizes.
- If the voltage-gated potassium channels did not reopen, the cell would still repolarize, but more slowly, through the ungated potassium channels.

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Phase 4

- G_K is high
- Voltage gated and ungated potassium channels remain open.

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ACTION POTENTIAL CHARACTERISTICS OF SPECIALIZED CELL

- SA node
- AV node
- Purkinje fibres
- They have unstable phase 4

General properties.

They all have pacemaker potential or pre-potential. Unlike regular contracting myocyte cells, there is not a stable membrane potential during phase 4; rather, there is a slow gradual depolarization toward threshold. Once threshold is reached, an action potential is generated. Although the concept is still somewhat controversial, it is generally held that phase 4 is associated with a decreasing potassium conductance, which increases excitability.

- **Phase 0**
 - Phase 0 is mainly a slow channel or calcium spike rather than a fast channel or sodium spike.
- **Phase 3**
 - As is the case with other action potentials, phase 3 is due to a rapid potassium efflux
 - (Gk increases).
- **No Phase 1 and 2**

Effect of Sympathetics

- The slope of the prepotential increases, threshold is reached sooner, and the intrinsic firing rate increases (via increased calcium conductance of nodal fibers).

Facilitates opening of calcium channels

Effect of Para-Sympathetics

- The slope of the prepotential decreases, threshold is reached slower, and the intrinsic firing rate decreases
- Hyperpolarize the cell via increasing potassium conductance.
- Vagal fibres cause membrane hyper-polarisation.

Automaticity

- SA nodal cells: Highest intrinsic rate, primary pacemaker of the heart (100-120/min)
- AV nodal cell: Second highest intrinsic rate, secondary pacemaker of the heart (40-60/min)
- Purkinje cells: Slowest intrinsic rate (30-40/min)

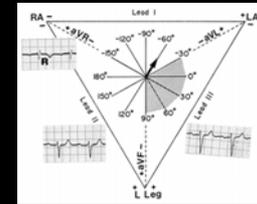
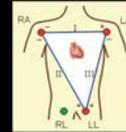
• Then why is the normal heart rate less than SA nodal rate???

ECG

- P wave: Atrial depolarization
- QRS complex: Ventricular depolarization
- T wave: Ventricular repolarization
- PR interval: From the beginning of the P wave to the beginning of the QRS complex (120-210 msec); mostly due to conduction delay in the AV node
- QT interval: From the beginning of the QRS complex to the end of the T wave
- **Common Conventions**
 - Paper speed: 25 mm/sec
 - Calibration: 1 mV = 1 cm pen deflection
 - A wave of depolarization approaching a positive electrode leads to an upward deflection of the pen.
- **Ventricular Depolarization**
 - Proceeds from endocardium to epicardium
- **Ventricular Repolarization**
 - Proceeds from epicardium to endocardium

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Einthoven's Triangle



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Einthoven's law: I + III = II

Mean Electrical Axis

- The mean electrical axis of the ventricles describes the net direction of current movement during ventricular depolarization.
- It is affected by a number of factors, including the position of the heart, heart mass, and conduction time.
- It can be calculated by summing the depolarization during the QRS complex in any two leads.
- Can we tetanize cardiac muscle?

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SYSTOLIC PERFORMANCE OF THE VENTRICLE

- Overall force generated by the ventricular muscle during systole is determined by the number of cross-bridges cycling during contraction.
- The greater the number of cross-bridges cycling, the greater the force of contraction.
- The number of cross-bridges cycling is determined by two independent variables:
 - the amount of preload on the muscle and the level of contractility.
- These two factors are summed together to determine the overall force of ventricular contraction.
- They are not completely independent.

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Preload

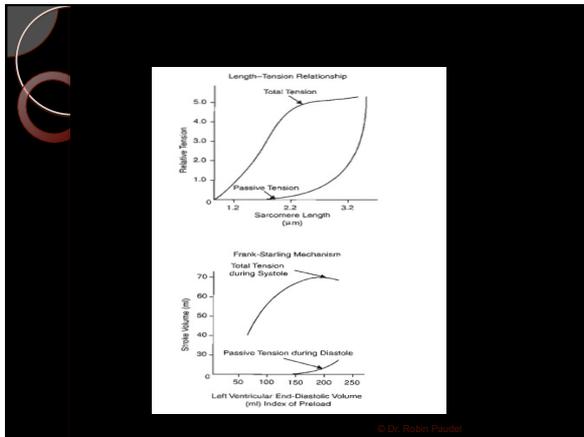
- Preload is the load on the muscle in the relaxed state
- Load or prestretch on **ventricular** muscle at the end of diastole.
- The best indices of preload on ventricular muscle are those measured directly in the ventricles.
- Indices of left ventricular preload:
 - Left ventricular end-diastolic volume (LVEDV)
 - Left ventricular end-diastolic pressure (LVEDP)
- Less reliable indices of left ventricular preload are those measured in the venous system. The farther from the ventricle, the less reliable the index.
 - Left atrial pressure
 - Pulmonary venous pressure
 - Pulmonary wedge pressure
- Even though pulmonary wedge pressure, measured via a Swan-Ganz catheter, is the least reliable index of those listed, its easy measurement in the clinical situation makes it the one most often utilized.

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The Preload Factor in Systolic Performance (Frank-Starling Mechanism)

- The preload effect can be explained on the basis of a change in sarcomere length.
 - The resting length of skeletal muscle *in vivo* is at a sarcomere length close to the optimum for maximal cross-bridge linking between actin and myosin during contraction (L_0).
- Heart muscle at the end of diastole is below this point. Thus, in a normal heart, increased preload increases sarcomere length toward the optimum actin-myosin overlap. This results in more cross-linking and a more forceful contraction during systole.

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The Contractility Factor in Systolic Performance (Inotropic State)

- An acceptable definition of *contractility* would be a *change in performance at a given preload*.
 - In other words, if a change in performance cannot be explained on the basis of preload, there must have been a change in contractility.
 - Stated another way, contractility is a change in the force of contraction at any given sarcomere length.
 - Acute changes in contractility are due to changes in the intracellular dynamics of calcium.
 - Drugs that increase contractility usually provide more calcium and at a faster rate to the contractile machinery. More calcium increases the availability of crosslink sites on the actin, increasing crosslinking and the force of contraction during systole.
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Afterload

- As in skeletal muscle, afterload is the load on the muscle during contraction.
 - With left ventricular muscle, it represents the force that the muscle must generate to eject the blood into the aorta.
 - Acceptable indices of afterload on the left ventricle are the following:
 - Mean aortic pressure
 - Hypertension: increased afterload
 - Hypotension: decreased afterload
 - Peak left ventricular pressure
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The Influence of Afterload on Ventricular Ejection

- The ability of the heart to eject a stroke volume depends on preload and contractility.
 - How large a stroke volume is actually ejected also depends on afterload.
 - An acute increase in afterload reduces the volume of blood ejected.
 - The blood not ejected remains in the left ventricle and increases preload in the next cycle.
 - The increased preload and increased force of contraction restore stroke volume.
 - *more complex than outlined here*
 - Chronic exposure of the ventricle to an increased afterload (e.g., hypertension) causes it to hypertrophy. Hypertrophy increases the force of contraction at a given preload and helps maintain stroke volume.
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Ventricular Volumes

- End-diastolic volume (EDV): Volume of blood in the ventricle at the end of diastole
 - End-systolic volume (ESV): Volume of blood in the ventricle at the end of systole
 - Stroke volume (SV): Volume of blood ejected by the ventricle *per beat*
 - $SV = EDV - ESV$
 - End-diastolic reserve volume (EDRV): Difference between the EDV and the maximal ventricular volume
 - Residual volume (RV): Volume of blood in the ventricle after maximal contraction
 - End-systolic reserve volume (ESRV): Difference between the ESV and RV
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Control of Heart Rate

- Intrinsic heart rate in the human is approximately 110 beats/min.
 - Neural Influences
 - Parasympathetic nerves: Right vagus predominates at SA node; left vagus at AV node slows AV conduction time.
 - Sympathetic nerves: Stimulation causes tachycardia; additional effect on contractility; augments increase in cardiac output.
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Bainbridge Reflex

- Receptors: stretch receptors in the right atrium
- Afferents: Vagus
- Efferents: Vagus
- Mechanism: Stretch of the right atrium leads to an increase in heart rate

Respiratory Arrhythmia

- Tachycardia associated with increase in venous return to the right heart during inspiration is responsible for respiratory arrhythmia.

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The Baroreceptor Reflex and the Control of Blood Pressure

- Baroreceptor reflex:** short-term regulation of blood pressure
- The main receptors of the system are located in the carotid sinus.
- Receptors monitor the stretch of the vessel wall as an index of arterial blood pressure. The afferents are always active, with impulses traveling centrally. This is necessary if both increases and decreases in blood pressure are to be detected. A rise in afferent activity signals an increase in blood pressure, and a loss of afferent activity signals a decrease in blood pressure.
- Renin-angiotensin-aldosterone system:** long-term regulation of blood pressure

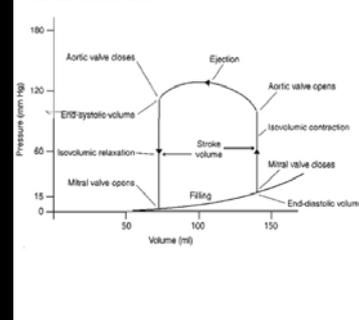
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MAP = CO X TPR

- A lowered blood pressure (MAP) leads to a rise in cardiac output (CO) and total peripheral resistance (TPR).
- A rise in blood pressure leads to a decrease in cardiac output and TPR.

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PRESSURE-VOLUME LOOPS



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