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Basic Electrophysiology

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Types of Cardiac Cells

- Myocardial cells
 - Working or mechanical cells
 - Contain contractile filaments
- Pacemaker cells
 - Specialized cells of the electrical conduction system
 - Responsible for the spontaneous generation and conduction of electrical impulses

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Properties of Pacemaker Cells

- Automaticity
 - Ability of cardiac pacemaker cells to spontaneously initiate an electrical impulse without being stimulated from another source (such as a nerve)
- Excitability
 - Ability of cardiac muscle cells to respond to an outside stimulus
- Conductivity
 - Ability of a cardiac cell to receive an electrical stimulus and conduct that impulse to an adjacent cardiac cell

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Properties of Myocardial Cells

- Contractility
 - Ability of cardiac cells to shorten, causing cardiac muscle contraction in response to an electrical stimulus
- Extensibility
 - the ability of the cell to stretch

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Cardiac Action Potential

- All living cells maintain a difference in the concentrations of ions across their cell membranes
- Electrical impulses are the result of brief but rapid flow of ions (charged particles) back and forth across the cell membrane

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Cardiac Action Potential

- The exchange of electrolytes in myocardial cells creates electrical activity
 - Appears on the ECG as waveforms
- Major electrolytes that affect cardiac function:
 - Sodium
 - Potassium
 - Calcium

Cardiac Action Potential

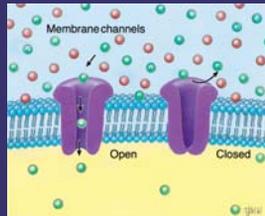
- Differences in ion concentrations across the cell (the ionic gradient) determine the cell's electrical charge
- There is normally a slight excess of:
 - Positive ions outside the membrane
 - Negative ions inside the membrane
- Results in a difference in electrical charge across the membrane called the "membrane potential"

Cardiac Action Potential

- "Threshold" is the membrane potential at which the cell membrane will depolarize and generate an action potential
- Action potential
 - A five-phase cycle that reflects the difference in the concentration of these ions across the cell membrane at any given time

Membrane Channels

- Cell membranes contain membrane channels (pores)
 - Specific ions or other small, water-soluble molecules can cross the cell membrane from outside to inside



Cardiac Action Potential

- A series of events causes the electrical charge inside the cell to change from its resting state (negative) to its depolarized (stimulated) state (positive) and back to its resting state (negative)
 - The cardiac action potential is an illustration of these events in a single cardiac cell during polarization, depolarization, and repolarization

Types of Action Potentials

- Two types of action potentials in the heart
 - Fast
 - Slow
- Classification is based on rate of voltage change during depolarization of cardiac cells

Fast-Response Action Potentials

- Occur in cells of the atria, ventricles, and Purkinje fibers
 - Have voltage-sensitive sodium channels
- Myocardial fibers with a fast-response action potential can conduct impulses at relatively rapid rates

Slow-Response Action Potentials

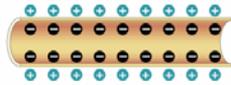
- Normally occur in the SA and AV nodes
 - Can occur abnormally anywhere in the heart, usually secondary to ischemia, injury, or an electrolyte imbalance
- Possess slow calcium and slow sodium channels
- Slower rate of conduction compared to cardiac cells with fast sodium channels

Polarization, Depolarization, and Repolarization

Polarization = Resting

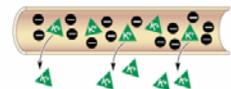
- Polarization
 - Also called the resting membrane potential
 - Resting state during which no electrical activity occurs
 - Inside of the cell is more negative than the outside

Polarization (resting)



Polarization = Resting

Polarization (inside negative)

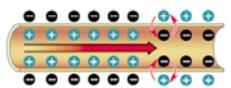


- ▲ Potassium (K⁺)
- Sodium (Na⁺)
- Anions

Depolarization = Stimulation

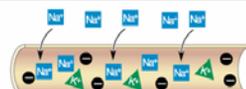
- Inside of the cell becomes more positive due to inward diffusion of Na⁺
- On the ECG:
 - P wave represents atrial depolarization
 - QRS complex represents ventricular depolarization

Depolarization (stimulated)



Depolarization = Stimulation

Depolarization (inside positive)



- ▲ Potassium (K⁺)
- Sodium (Na⁺)
- Anions

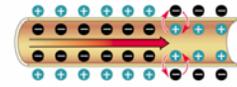
Depolarization

- Depolarization is not the same as contraction
 - Depolarization is an electrical event expected to result in contraction (a mechanical event)
- It is possible to view electrical activity on the cardiac monitor, yet evaluation of the patient reveals no palpable pulse
 - Pulseless electrical activity (PEA)

Repolarization = Resting

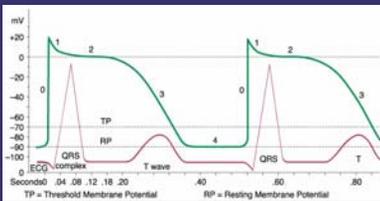
- Outward diffusion of K⁺
 - Membrane potential returns to its negative resting level
- On the ECG:
 - ST segment represents early ventricular repolarization
 - T wave presents ventricular repolarization

Repolarization (resting)



Phases of the Action Potential

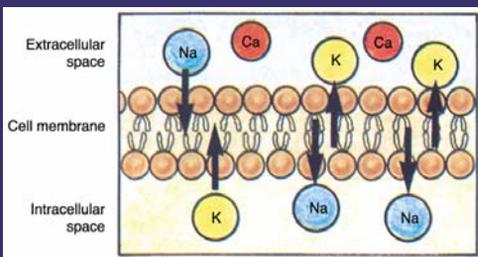
- Action potential of a cardiac cell consists of five phases
- Reflects rapid sequence of voltage changes across cell membrane during electrical cardiac cycle



Phase 0 – Depolarization

- Begins when the cell receives an impulse
 - Sodium moves rapidly into cell
 - Potassium leaves cell
 - Calcium moves slowly into cell
- Cell depolarizes and cardiac contraction begins
- Responsible for QRS complex on the ECG

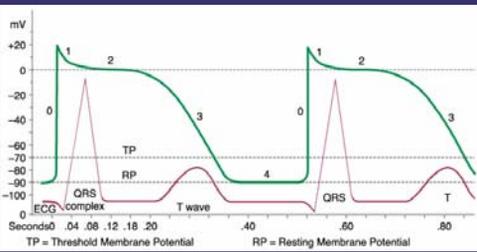
Phase 0 – Depolarization



Phase 1 – Early Repolarization

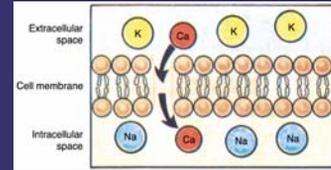
- Phase 1 is an early, brief period of limited repolarization
 - Fast Na⁺ channels partially close
 - Transient outward movement of K⁺ through K⁺ channels
 - Results in a decrease in positive electrical charges within the cell

Phase 1 – Early Repolarization



Phase 2 – Plateau Phase

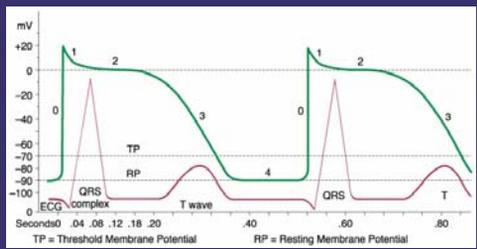
- Repolarization continues relatively slowly
 - Caused by slow inward movement of Ca^{++} and slow outward movement of K^+ from the cell
- Responsible for ST segment on ECG



Phase 3

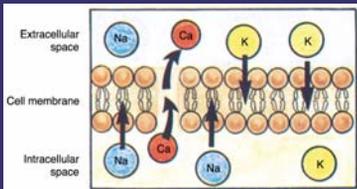
- Phase of late and rapid repolarization
 - K^+ flows quickly out of the cell
 - Slow channels close, stopping influx of Ca^{++} and Na^+
 - Cell becomes progressively more electrically negative and more sensitive to external stimuli
- Corresponds with T wave on the ECG

Phase 3



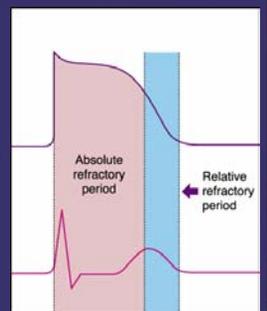
Phase 4 – Return to Resting State

- Phase 4 is the resting membrane potential (return to resting state)
 - Heart is "polarized" during this phase (ready for discharge)
- Cell will remain in this state until reactivated by another stimulus



Refractory Periods

- Refractoriness
 - The extent to which a cell is able to respond to a stimulus
- Absolute refractory period
 - Onset of QRS complex to approximately peak of T wave
 - Cardiac cells cannot be stimulated to conduct an electrical impulse, no matter how strong the stimulus



Refractory Periods

- Relative refractory period
 - Corresponds with the downslope of the T wave
 - Cardiac cells can be stimulated to depolarize if the stimulus is strong enough
- Supernormal period
 - Corresponds with the end of the T wave
 - A weaker than normal stimulus can cause depolarization of cardiac cells

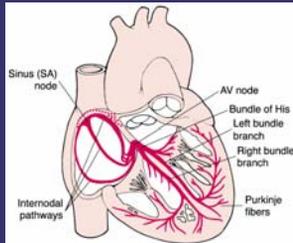


The Conduction System

- Conduction system
 - Specialized electrical (pacemaker) cells in the heart arranged in a system of pathways
- Normally, the pacemaker site with the fastest firing rate controls the heart

Sinoatrial (SA) Node

- Located at the junction of the superior vena cava and the right atrium
- Initiates electrical impulses at a rate of 60 to 100 beats/min
- Normally the primary pacemaker of the heart



Atria

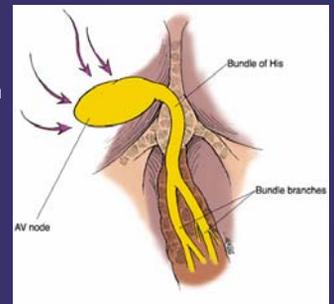
- Fibers of SA node connect directly with fibers of atria
- Impulse leaves SA node and is spread from cell to cell across the atrial muscle

Internodal Pathways

- Conduction through the AV node begins before atrial depolarization is completed
- Impulse is spread to AV node via internodal pathways
 - Pathways merge gradually with cells of AV node

AV Junction

- Area of specialized conduction tissue
 - Provides electrical links between atrium and ventricle



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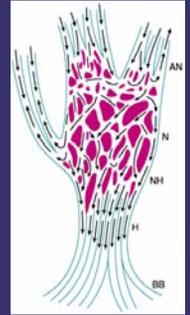
AV Node

- Located in the posterior septal wall of the right atrium
 - Supplied by right coronary artery in most individuals
- As the impulse from the atria enters the AV node, there is a delay in conduction of the impulse to the ventricles
 - Allows time for atria to empty contents into ventricles

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AV Node

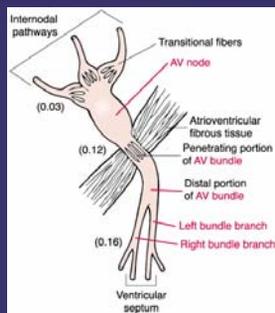
- Divided into three functional regions according to their action potentials and responses to electrical and chemical stimulation
 - Atrionodal (AN) or upper junctional region
 - Nodal (N) region
 - Nodal-His (NH)



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AV Node

- The primary delay in the passage of the electrical impulse from the atria to the ventricles occurs in the AN and N areas of the AV node



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Bundle of His

- Also called the "common bundle" or the "AV bundle"
- Normally the only electrical connection between the atria and the ventricles
 - Connects AV node with bundle branches
 - Has pacemaker cells capable of discharging at an intrinsic rate of 40 to 60 beats/min
 - Conducts impulse to right and left bundle branches

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Right & Left Bundle Branches

- Right bundle branch
 - Innervates the right ventricle
- Left bundle branch
 - Spreads the electrical impulse to the interventricular septum and left ventricle
 - Divides into three divisions (fascicles)
 - Anterior fascicle
 - Posterior fascicle
 - Septal fascicle

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Purkinje Fibers

- Elaborate web of fibers that penetrate about 1/3 of the way into the ventricular muscle mass
 - Become continuous with cardiac muscle fibers
- Receive impulse from bundle branches and relay it to ventricular myocardium
- Intrinsic pacemaker ability of 20 to 40 beats/min

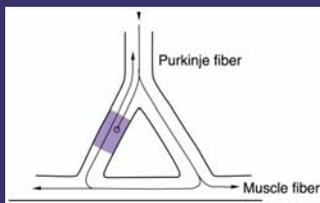
Causes of Dysrhythmias

Enhanced Automaticity

- An abnormal condition in which:
 - Cardiac cells not normally associated with the property of automaticity begin to depolarize spontaneously *or*
 - Escape pacemaker sites increase their firing rate beyond that considered normal

Reentry

- Propagation of an impulse through tissue already activated by that same impulse

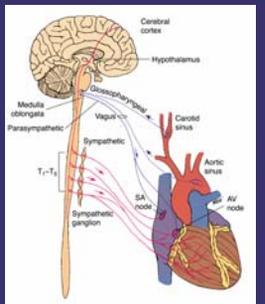


Escape Beats or Rhythms

- Escape: term used when the SA node slows down or fails to initiate depolarization and a lower site spontaneously produces electrical impulses, assuming responsibility for pacing the heart
- "Protective" mechanisms
 - Maintain cardiac output
 - Originate in the AV junction or the ventricles

Heart Rate

- Autonomic nervous system (ANS) influences:
 - Heart rate
 - Conductivity
 - Contractility



Baroreceptors

- Also called "pressoreceptors"
 - Specialized nerve tissue
 - Found in internal carotid arteries / aortic arch
 - Detect changes in blood pressure

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Chemoreceptors

- Located in internal carotid arteries and aortic arch
- Detect and respond to changes in:
 - Oxygen content of the blood
 - pH
 - Carbon dioxide tension

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Parasympathetic Stimulation

- Major parasympathetic nerves are the two vagus nerves
 - One on each side of the body
- Vagus nerve innervates heart at SA and AV nodes
 - Primary postganglionic neurotransmitter = acetylcholine

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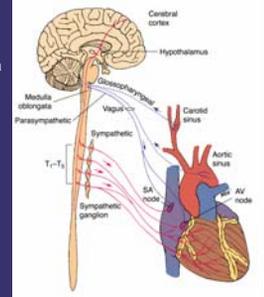
Parasympathetic Stimulation

- Effects of acetylcholine
 - Slowing of rate of discharge of SA node
 - Slowing of rate of conduction through AV node

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Sympathetic Stimulation

- Impulses sent from accelerator center in medulla travel along sympathetic fibers
- Primary postganglionic neurotransmitter = norepinephrine



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Receptor Sites

- Alpha
 - Vascular smooth muscle
- Beta-1
 - Heart
- Beta-2
 - Bronchial smooth muscle
 - Skeletal blood vessels
- Dopaminergic
 - Coronary arteries, renal, mesenteric, and visceral blood vessels

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Effects of Norepinephrine on Receptor Sites

- Alpha
 - No effect on heart
 - Peripheral vasoconstriction
- Beta-1
 - Increased heart rate
 - Increased conductivity
 - Increased contractility

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Chronotropic Effect

- Refers to a change in heart rate
 - A positive chronotropic effect refers to an increase in heart rate
 - A negative chronotropic effect refers to a decrease in heart rate

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Inotropic Effect

- Refers to a change in myocardial contractility
 - A positive inotropic effect results in an increase in myocardial contractility
 - A negative inotropic effect results in a decrease in myocardial contractility