Lecture 21. General characteristics of the circulatory system. Physiological properties of the heart muscle

Lecture Outline

- **Cardiovascular System Function**
- Functional Anatomy of the Heart
- Myocardial Physiology
- **External manifestations of cardiac activity**
- ECG
- Cardiac Cycle
- Cardiac Output Controls & Blood Pressure

Cardiovascular System Function

- Functional components of the cardiovascular system:
  - Heart
  - Blood Vessels
  - Blood
- General functions these provide
  - Transportation
    - Everything transported by the blood
  - Regulation
    - Of the cardiovascular system
      - Intrinsic v extrinsic
  - Protection
    - Against blood loss
  - Production/Synthesis

Cardiovascular System Function

- To create the “pump” we have to examine the Functional Anatomy
  - Cardiac muscle
  - Chambers
  - Valves
  - Intrinsic Conduction System

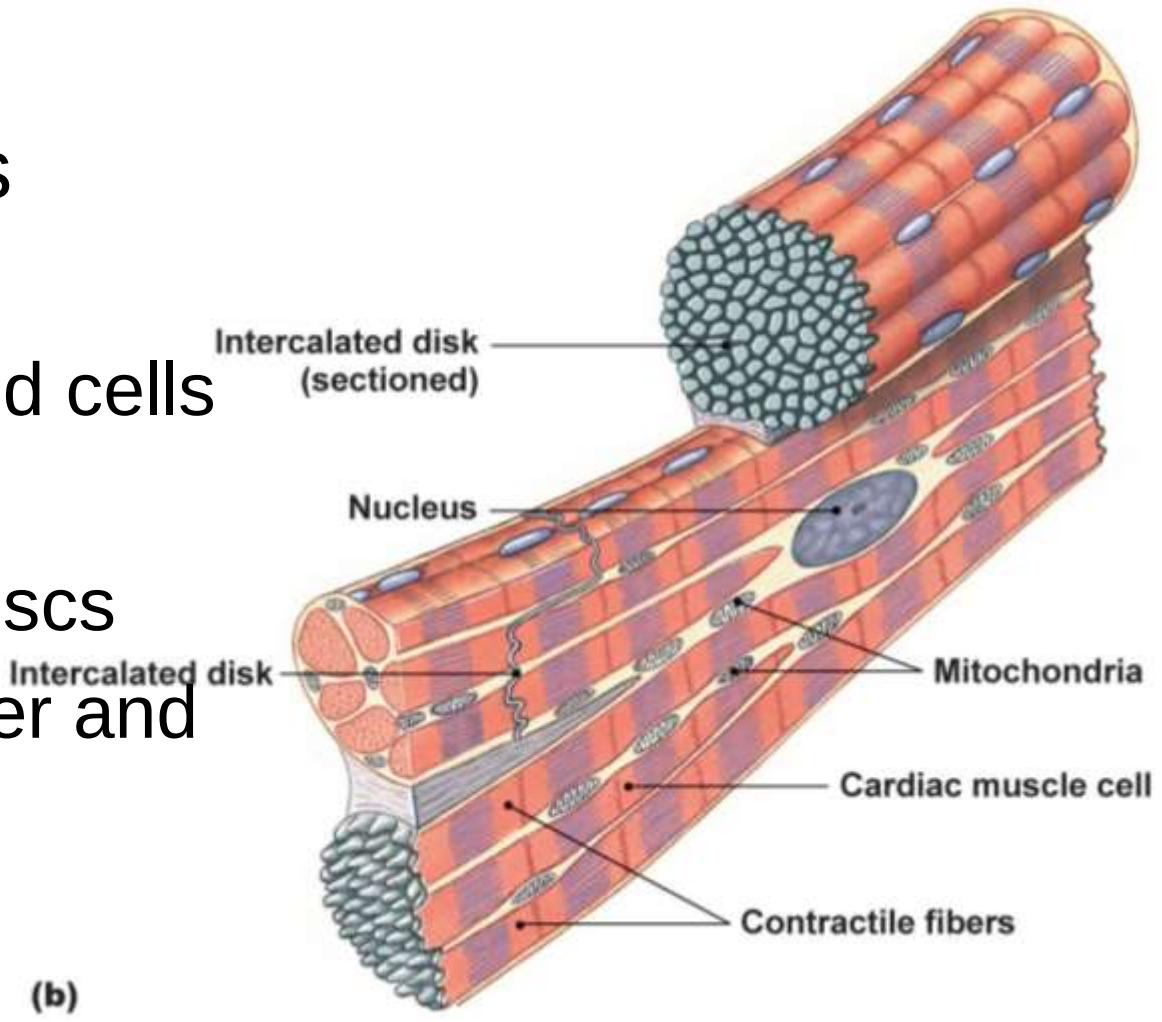
Lecture Outline

- Cardiovascular System Function
- **Functional Anatomy of the Heart**
- Myocardial Physiology
- Cardiac Cycle
- Cardiac Output Controls & Blood Pressure

Functional Anatomy of the Heart

Cardiac Muscle

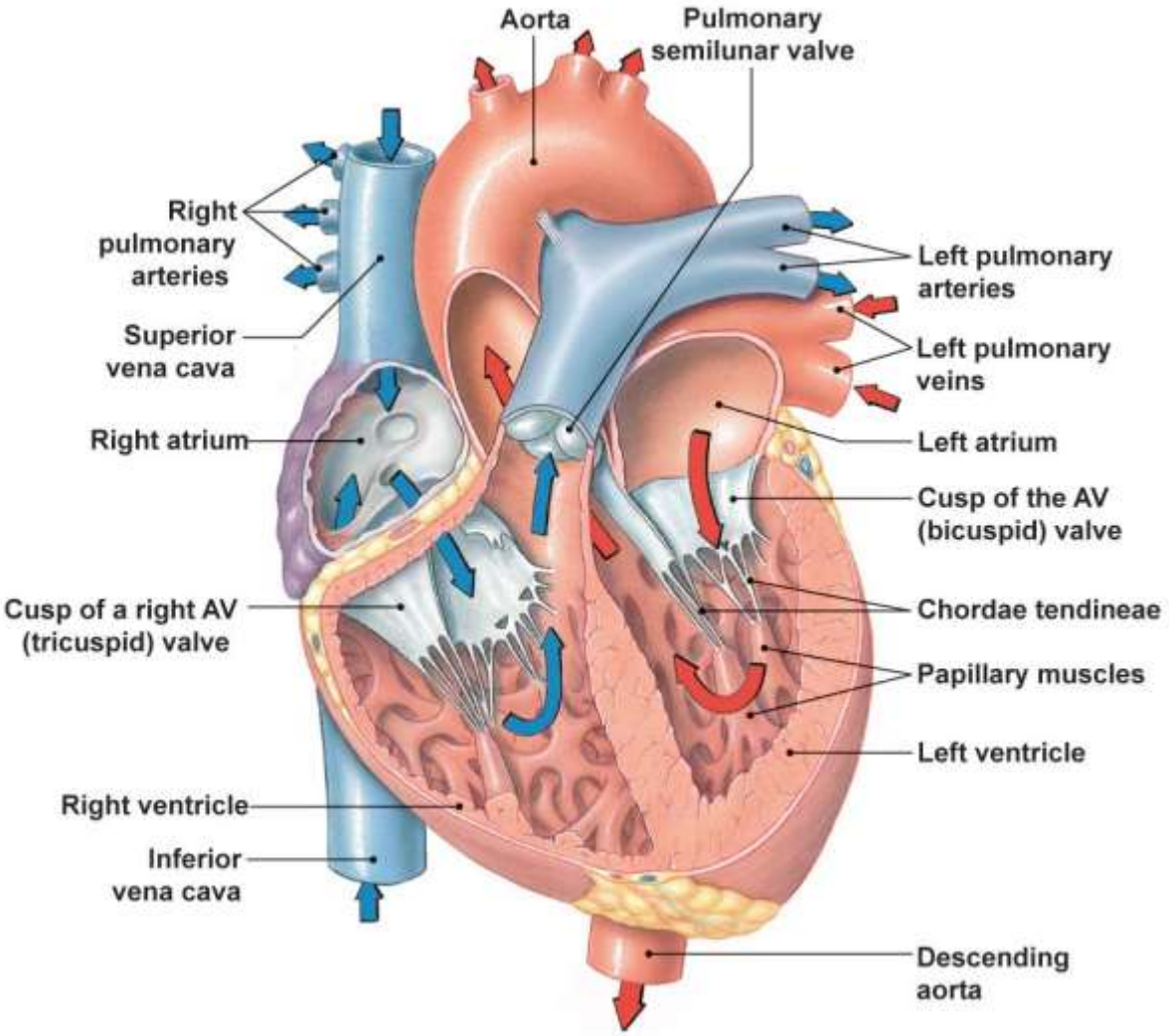
- Characteristics
  - Striated
  - Short branched cells
  - Uninucleate
  - Intercalated discs
  - T-tubules larger and over z-discs



Functional Anatomy of the Heart

Chambers

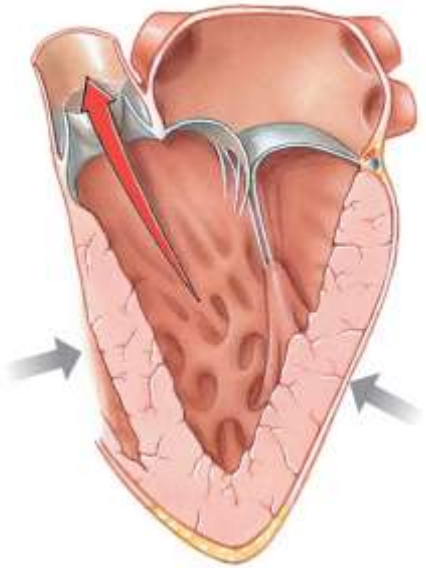
- 4 chambers
  - 2 Atria
  - 2 Ventricles
- 2 systems
  - Pulmonary
  - Systemic

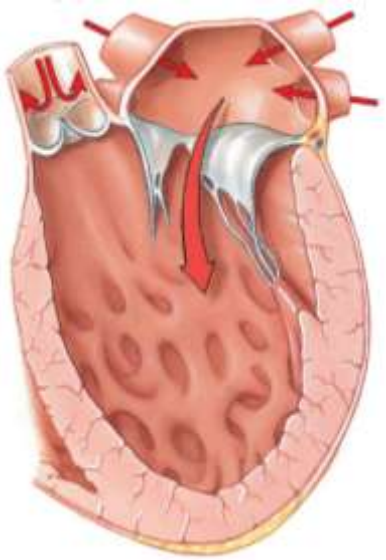


Functional Anatomy of the Heart

Valves

- Function is to prevent backflow
  - Atrioventricular Valves
    - Prevent backflow to the atria
    - Prolapse is prevented by the chordae tendinae
      - Tensioned by the papillary muscles
  - Semilunar Valves
    - Prevent backflow into ventricles

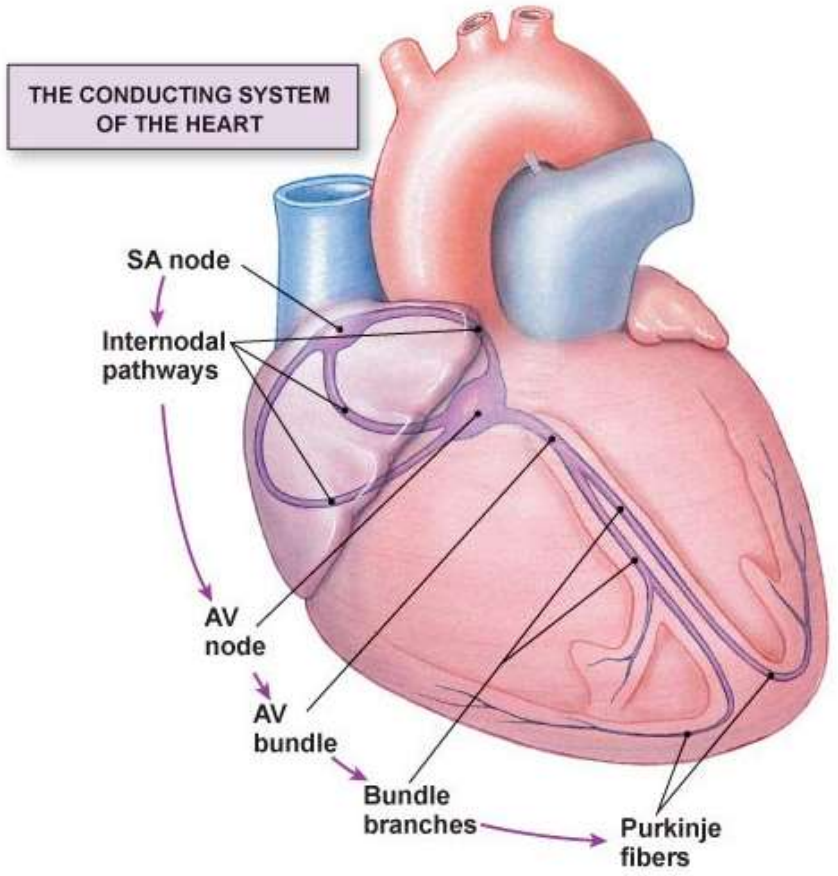




Functional Anatomy of the Heart

Intrinsic Conduction System

- Consists of "pacemaker" cells and conduction pathways
  - Coordinate the contraction of the atria and ventricles



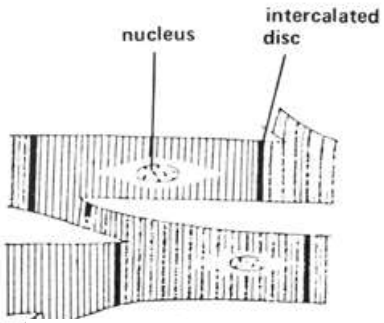
Lecture Outline

- Cardiovascular System Function
- Functional Anatomy of the Heart
- **Myocardial Physiology**
  - **Autorhythmic Cells (Pacemaker cells)**
  - **Contractile cells**
- Cardiac Cycle
- Cardiac Output Controls & Blood Pressure

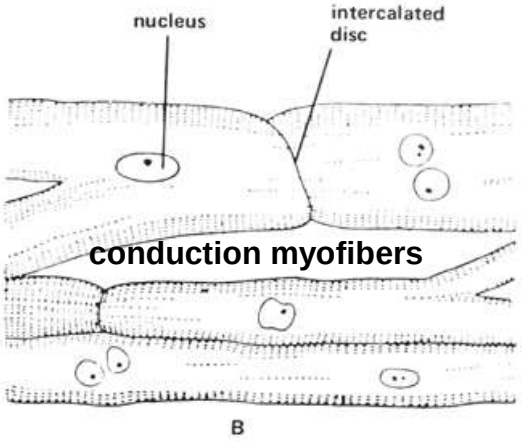
Myocardial Physiology

Autorhythmic Cells (Pacemaker Cells)

- Characteristics of Pacemaker Cells
  - Smaller than contractile cells
  - Don't contain many myofibrils
  - No organized sarcomere structure
    - do not contribute to the contractile force of the heart



normal contractile myocardial cell



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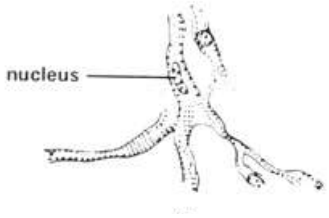
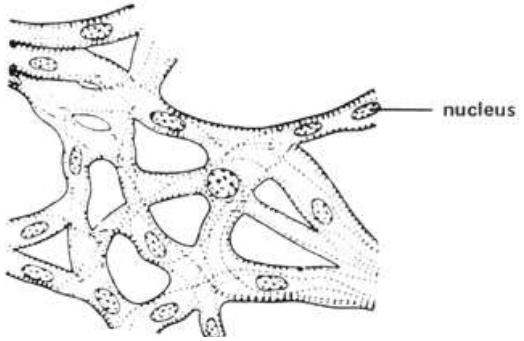


SA node cell



AV node cells

Myocardial Physiology

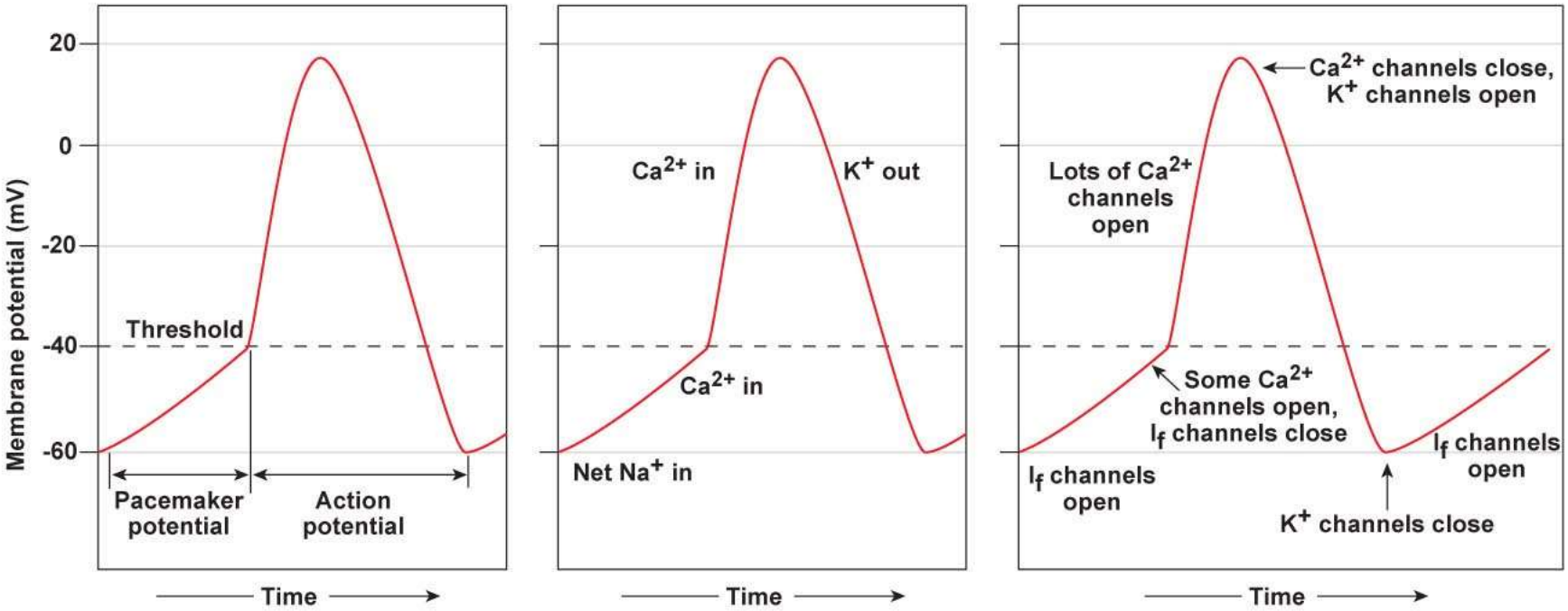
Autorhythmic Cells (Pacemaker Cells)

- Characteristics of Pacemaker Cells
  - Unstable membrane potential
    - "bottoms out" at -60mV
    - "drifts upward" to -40mV, forming a pacemaker potential
  - Myogenic
    - The upward "drift" allows the membrane to reach threshold potential (-40mV) by itself
    - This is due to
      1. Slow leakage of K^+ out & faster leakage Na^+ in
         - » Causes slow depolarization
         - » Occurs through I_f channels (f=funny) that open at negative membrane potentials and start closing as membrane approaches threshold potential
      2. Ca^{2+} channels opening as membrane approaches threshold
         - » At threshold additional Ca^{2+} ion channels open causing more rapid depolarization
         - » These deactivate shortly after and
      3. Slow K^+ channels open as membrane depolarizes causing an efflux of K^+ and a repolarization of membrane

Myocardial Physiology

Autorhythmic Cells (Pacemaker Cells)

- Characteristics of Pacemaker Cells



(a) The pacemaker potential gradually becomes less negative until it reaches threshold, triggering an action potential.

(b) Ion movements during an action and pacemaker potential

(c) State of various ion channels

Myocardial Physiology

Autorhythmic Cells (Pacemaker Cells)

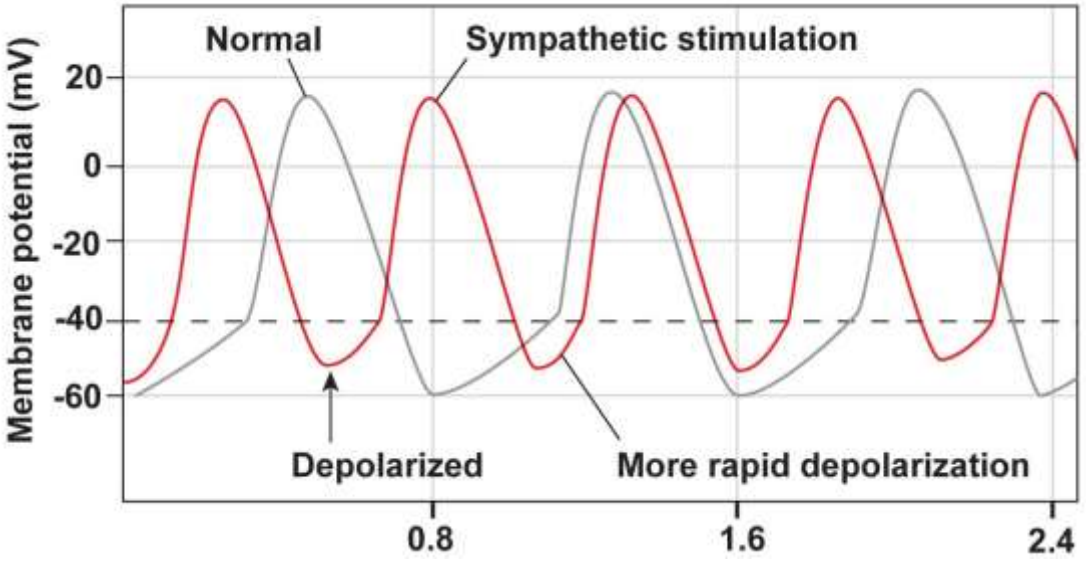
- Altering Activity of Pacemaker Cells
  - Sympathetic activity
    - NE and E increase I_f channel activity
      - Binds to β_1 adrenergic receptors which activate cAMP and increase I_f channel open time
      - Causes more rapid pacemaker potential and faster rate of action potentials

Sympathetic Activity Summary:

increased chronotropic effects
↑heart rate

increased dromotropic effects
↑conduction of APs

increased inotropic effects
↑contractility



Myocardial Physiology

Autorhythmic Cells (Pacemaker Cells)

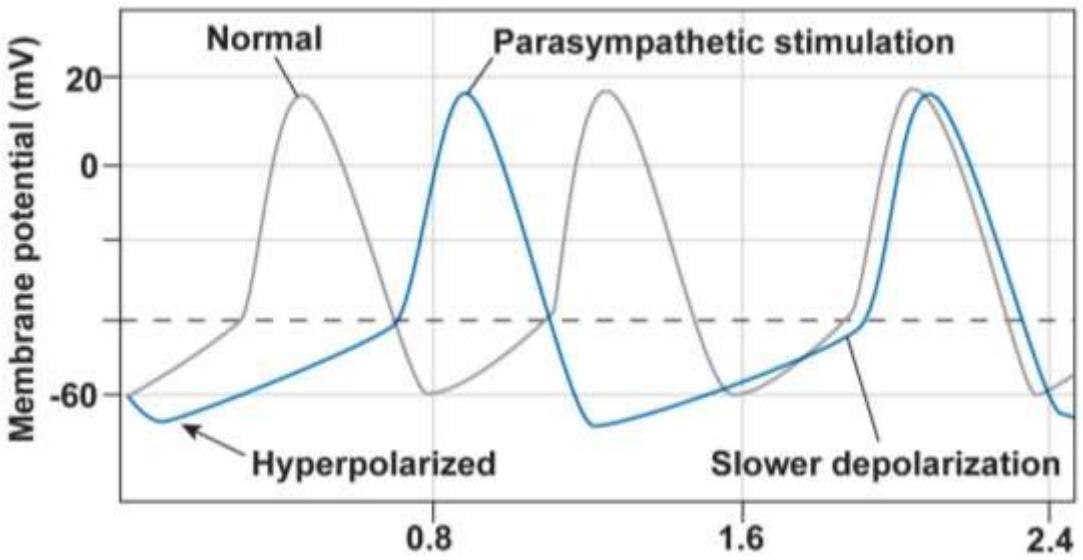
- Altering Activity of Pacemaker Cells
  - Parasympathetic activity
    - ACh binds to muscarinic receptors
      - Increases K^+ permeability and decreases Ca^{2+} permeability = hyperpolarizing the membrane
        - » Longer time to threshold = slower rate of action potentials

<u>Parasympathetic Activity Summary:</u>

decreased chronotropic effects
↓heart rate

decreased dromotropic effects
↓ conduction of APs

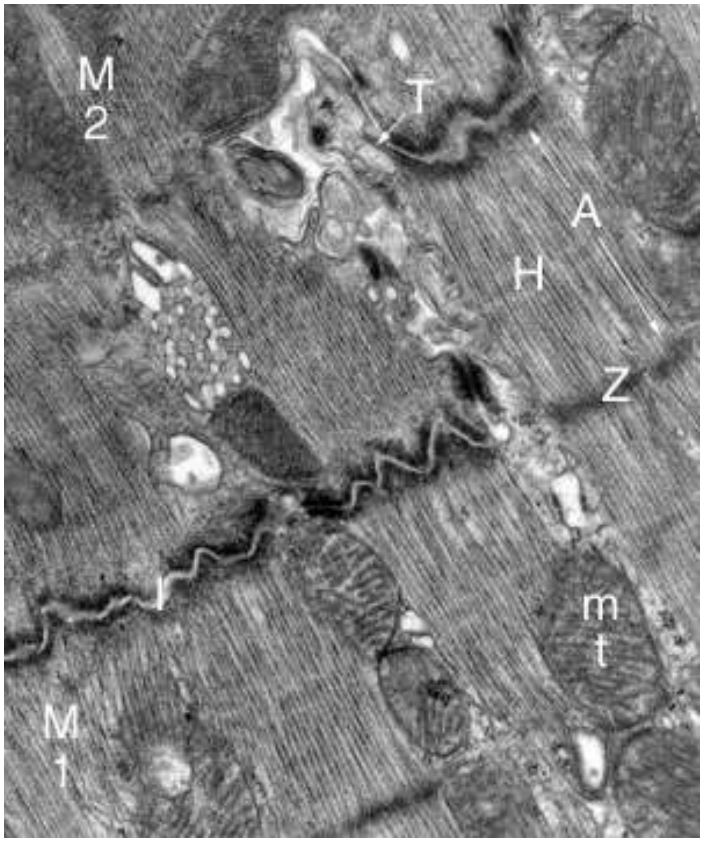
decreased inotropic effects
↓ contractility



Myocardial Physiology

Contractile Cells

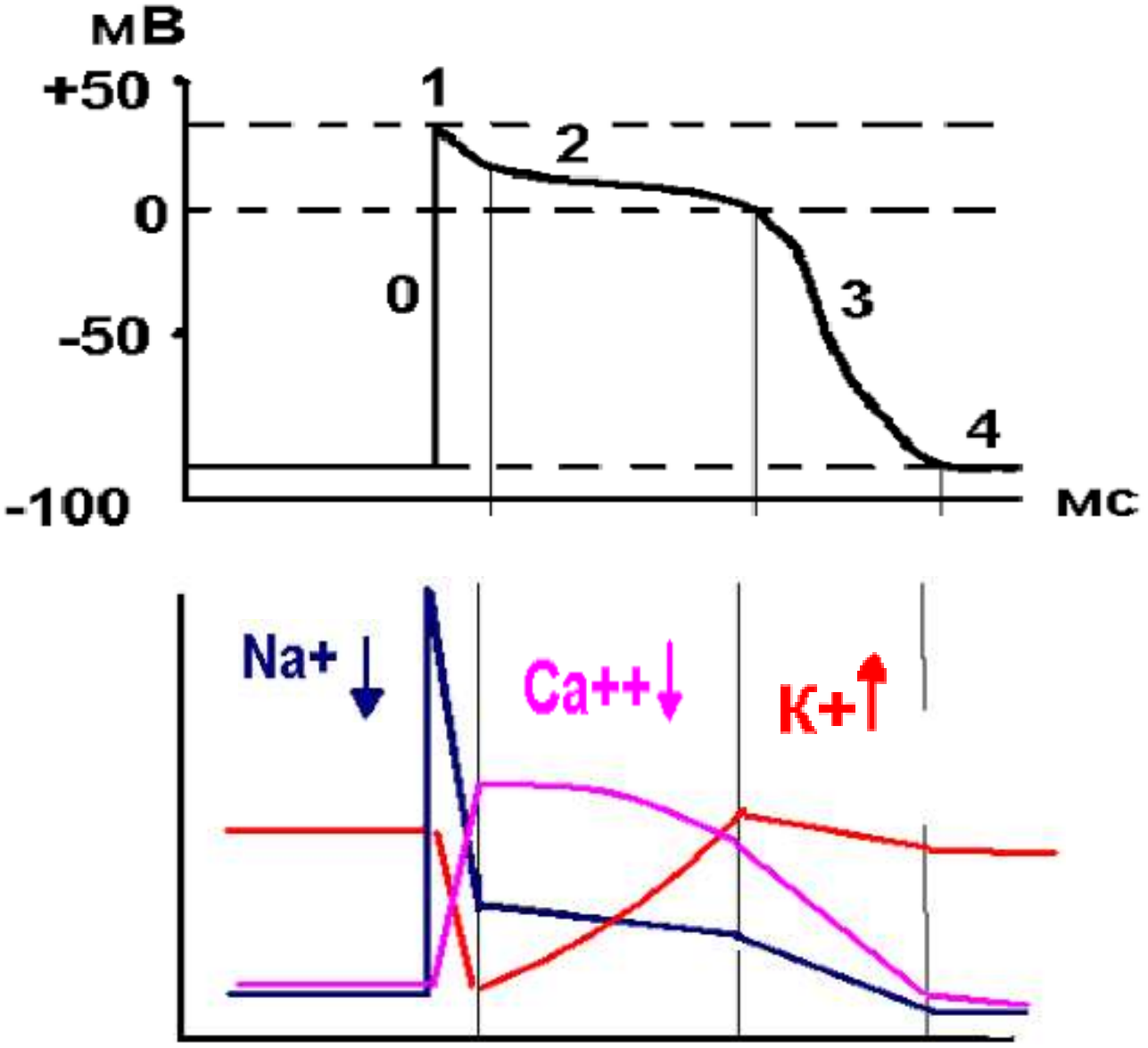
- Special aspects
  - Intercalated discs
    - Highly convoluted and interdigitated junctions
      - Joint adjacent cells with
        - » Desmosomes & fascia adherens
      - Allow for syntical activity
        - » With gap junctions
  - More mitochondria than skeletal muscle
  - Less sarcoplasmic reticulum
    - Ca^{2+} also influxes from ECF reducing storage need
  - Larger t-tubules
    - Internally branching
  - Myocardial contractions are graded!

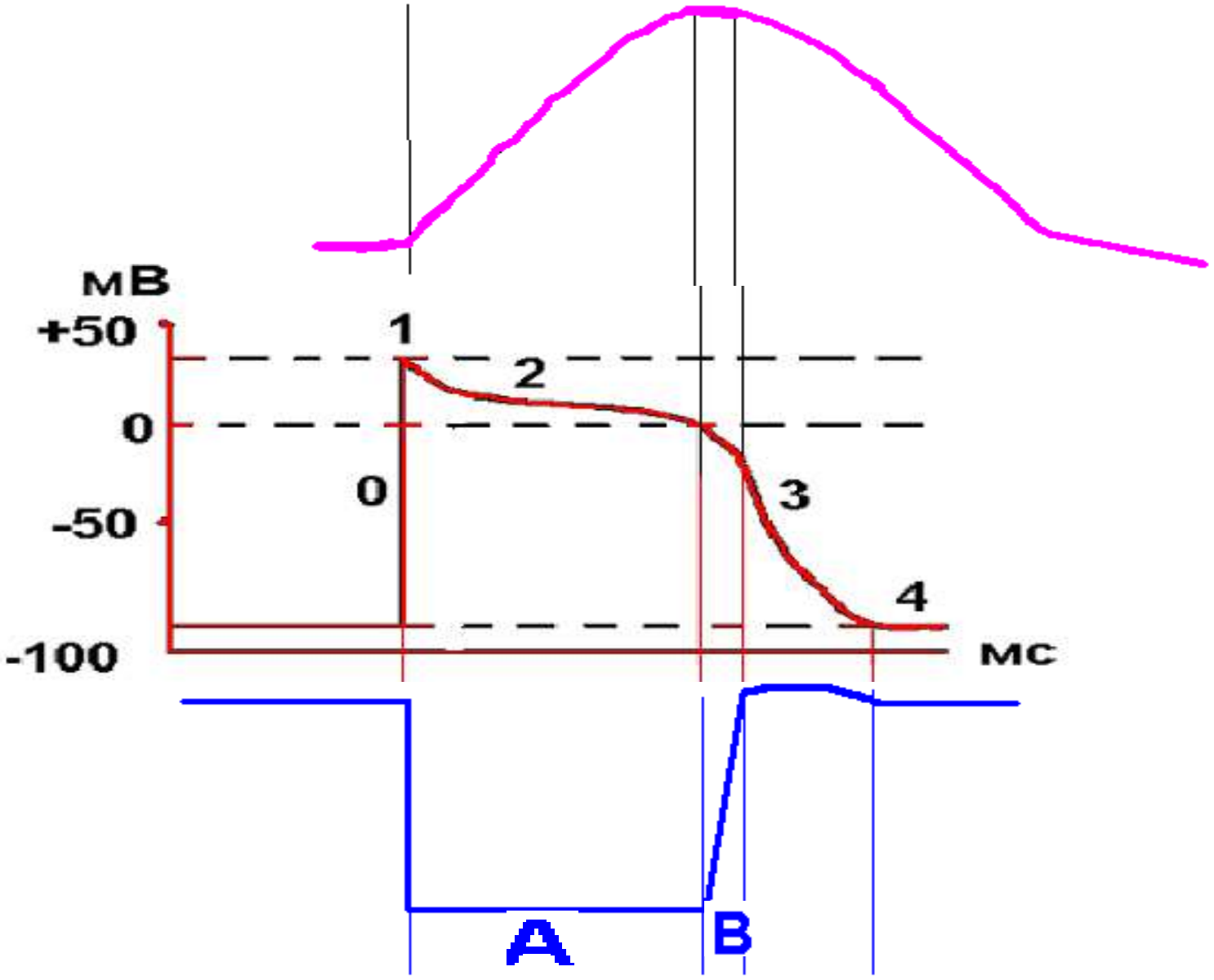


Myocardial Physiology

Contractile Cells

- Special aspects
  - The action potential of a contractile cell
    - Ca^{2+} plays a major role again
    - Action potential is longer in duration than a “normal” action potential due to Ca^{2+} entry
    - Phases
      - 4 – resting membrane potential @ -90mV
      - 0 – depolarization
        - » Due to gap junctions or conduction fiber action
        - » Voltage gated Na^{+} channels open… close at 20mV
      - 1 – temporary repolarization
        - » Open K^{+} channels allow some K^{+} to leave the cell
      - 2 – plateau phase
        - » Voltage gated Ca^{2+} channels are fully open (started during initial depolarization)
      - 3 – repolarization
        - » Ca2+ channels close and K+ permeability increases as slower activated K+ channels open, causing a quick repolarization
  - What is the significance of the plateau phase?


мВ
+50
0
-50
-100
1
2
0
3
4
мс
Na+
Ca++
K+


мВ
+50
0
-50
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1
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4
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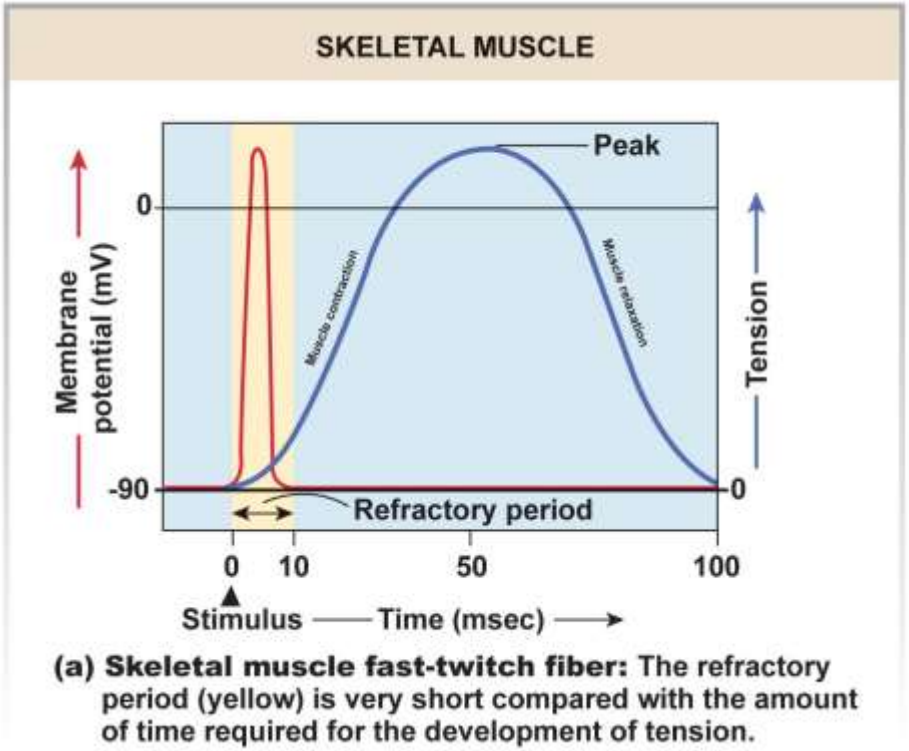
A
B

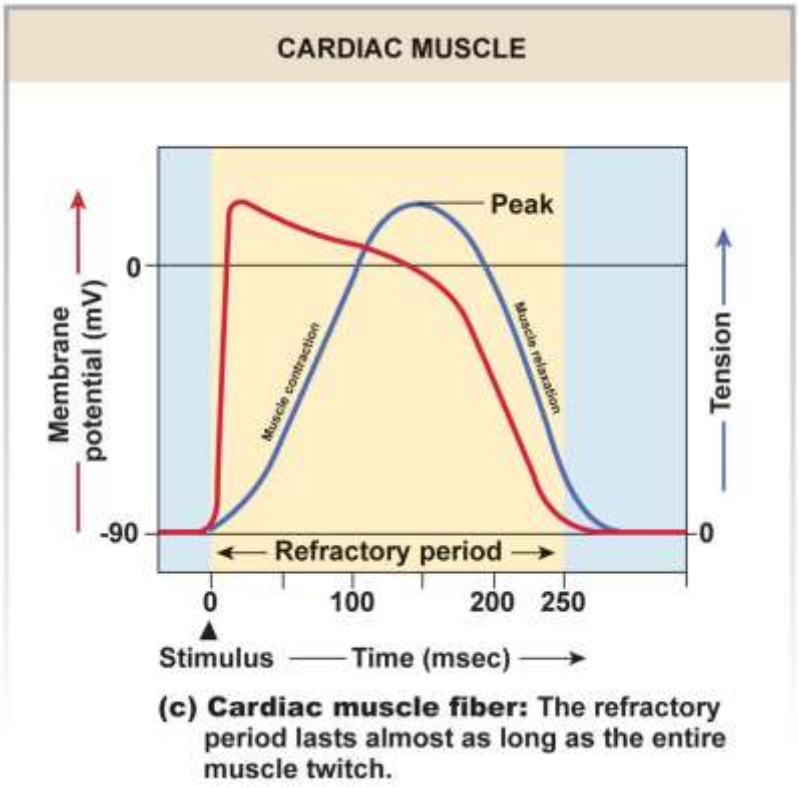
Myocardial Physiology

Contractile Cells

- Skeletal Action Potential vs Contractile Myocardial Action Potential



(a) **Skeletal muscle fast-twitch fiber:** The refractory period (yellow) is very short compared with the amount of time required for the development of tension.

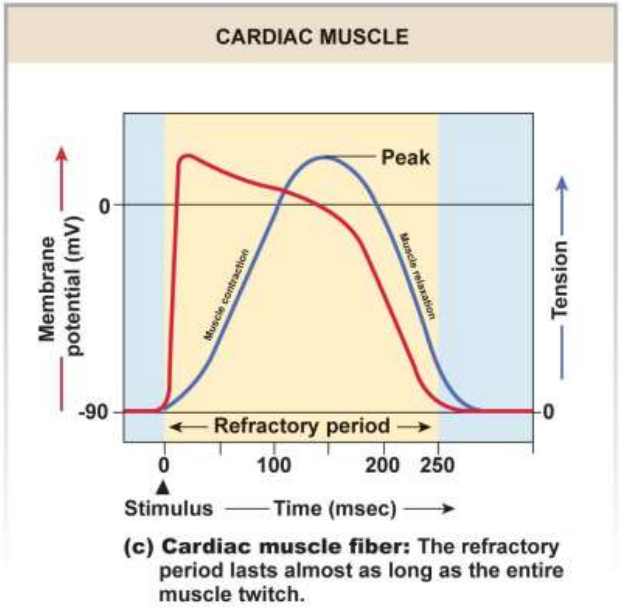


(c) **Cardiac muscle fiber:** The refractory period lasts almost as long as the entire muscle twitch.

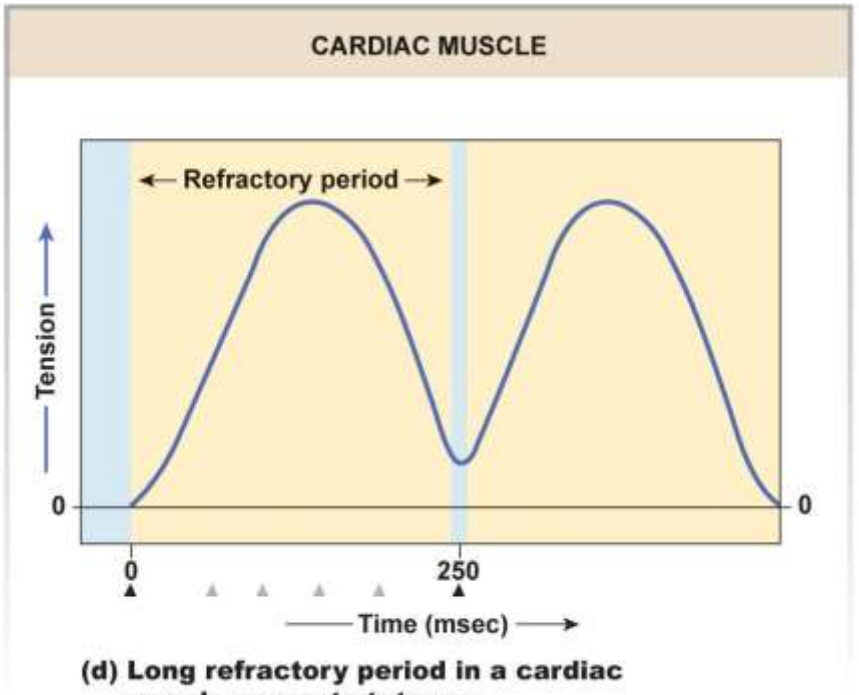
Myocardial Physiology

Contractile Cells

- Plateau phase prevents summation due to the elongated refractory period
- No summation capacity = no tetanus
  - Which would be fatal



(c) **Cardiac muscle fiber:** The refractory period lasts almost as long as the entire muscle twitch.



(d) **Long refractory period in a cardiac muscle prevents tetanus.**

Summary of Action Potentials

Skeletal Muscle vs Cardiac Muscle

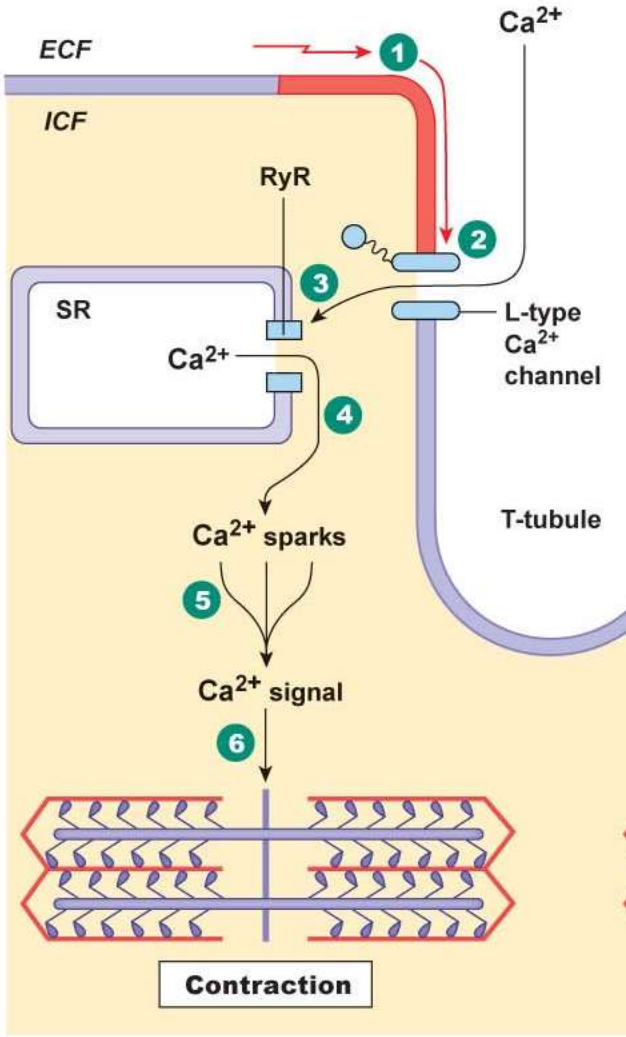
TABLE 14-3 Comparison of Action Potentials in Cardiac and Skeletal Muscle

	SKELETAL MUSCLE	CONTRACTILE MYOCARDIUM	AUTORHYTHMIC MYOCARDIUM
Membrane potential	Stable at −70 mV	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	None

Myocardial Physiology

Contractile Cells

- Initiation
  - Action potential via pacemaker cells to conduction fibers
- Excitation-Contraction Coupling
  1. Starts with CICR (Ca^{2+} induced Ca^{2+} release)
     - AP spreads along sarcolemma
     - T-tubules contain voltage gated L-type Ca^{2+} channels which open upon depolarization
     - Ca^{2+} entrance into myocardial cell and opens RyR (ryanodine receptors) Ca^{2+} release channels
     - Release of Ca^{2+} from SR causes a Ca^{2+} "spark"
     - Multiple sparks form a Ca^{2+} signal

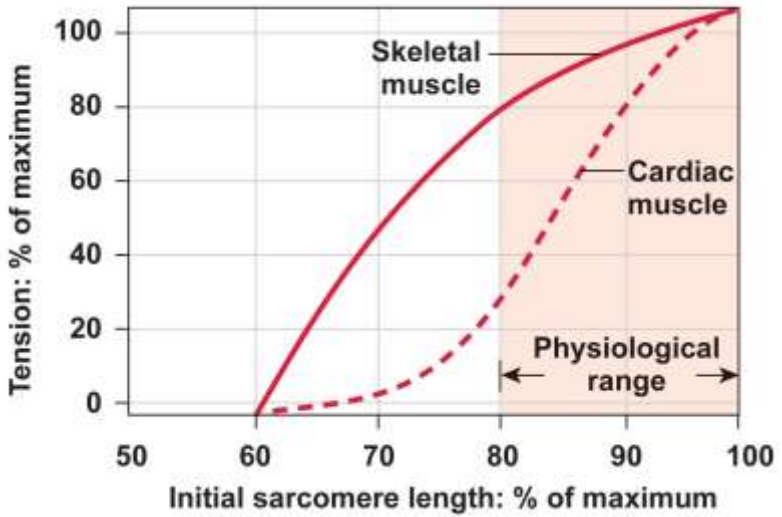


Spark Gif

Myocardial Physiology

Contractile Cells

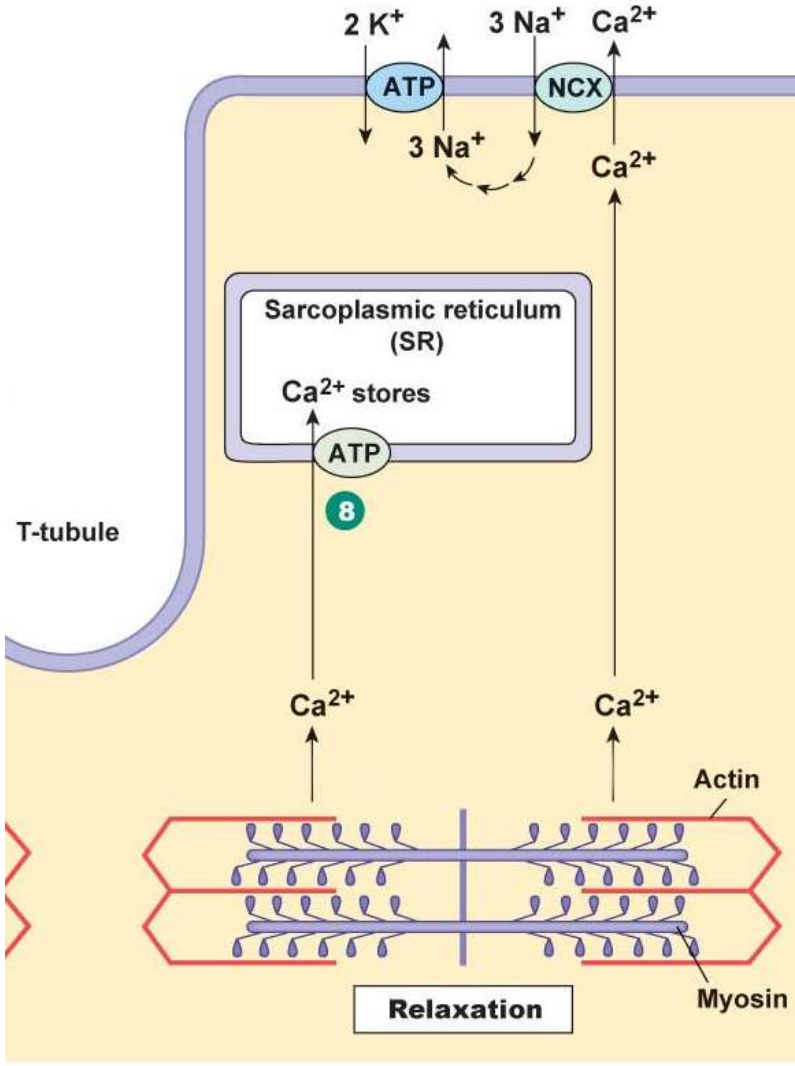
- Excitation-Contraction Coupling cont…
  2. Ca^{2+} signal (Ca^{2+} from SR and ECF) binds to troponin to initiate myosin head attachment to actin
- Contraction
  - Same as skeletal muscle, but…
  - Strength of contraction varies
    - Sarcomeres are not “all or none” as it is in skeletal muscle
      - The response is graded!
        - » Low levels of cytosolic Ca^{2+} will not activate as many myosin/actin interactions and the opposite is true
    - Length tension relationships exist
      - Strongest contraction generated when stretched between 80 & 100% of maximum (physiological range)
      - What causes stretching?
        - » The filling of chambers with blood



Myocardial Physiology

Contractile Cells

- Relaxation
  - Ca^{2+} is transported back into the SR and
  - Ca^{2+} is transported out of the cell by a facilitated Na^{+}/Ca^{2+} exchanger (NCX)
  - As ICF Ca^{2+} levels drop, interactions between myosin/actin are stopped
  - Sarcomere lengthens

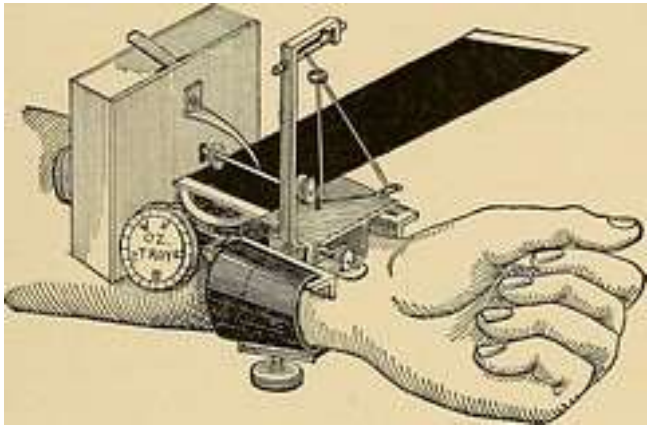


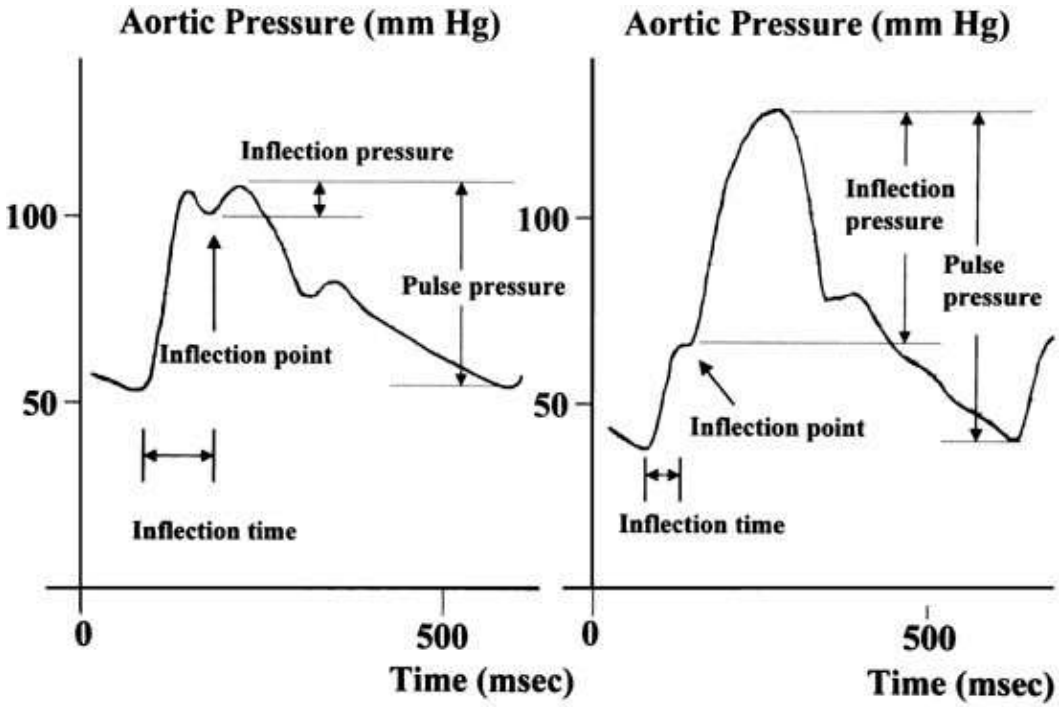
External manifestations of cardiac activity

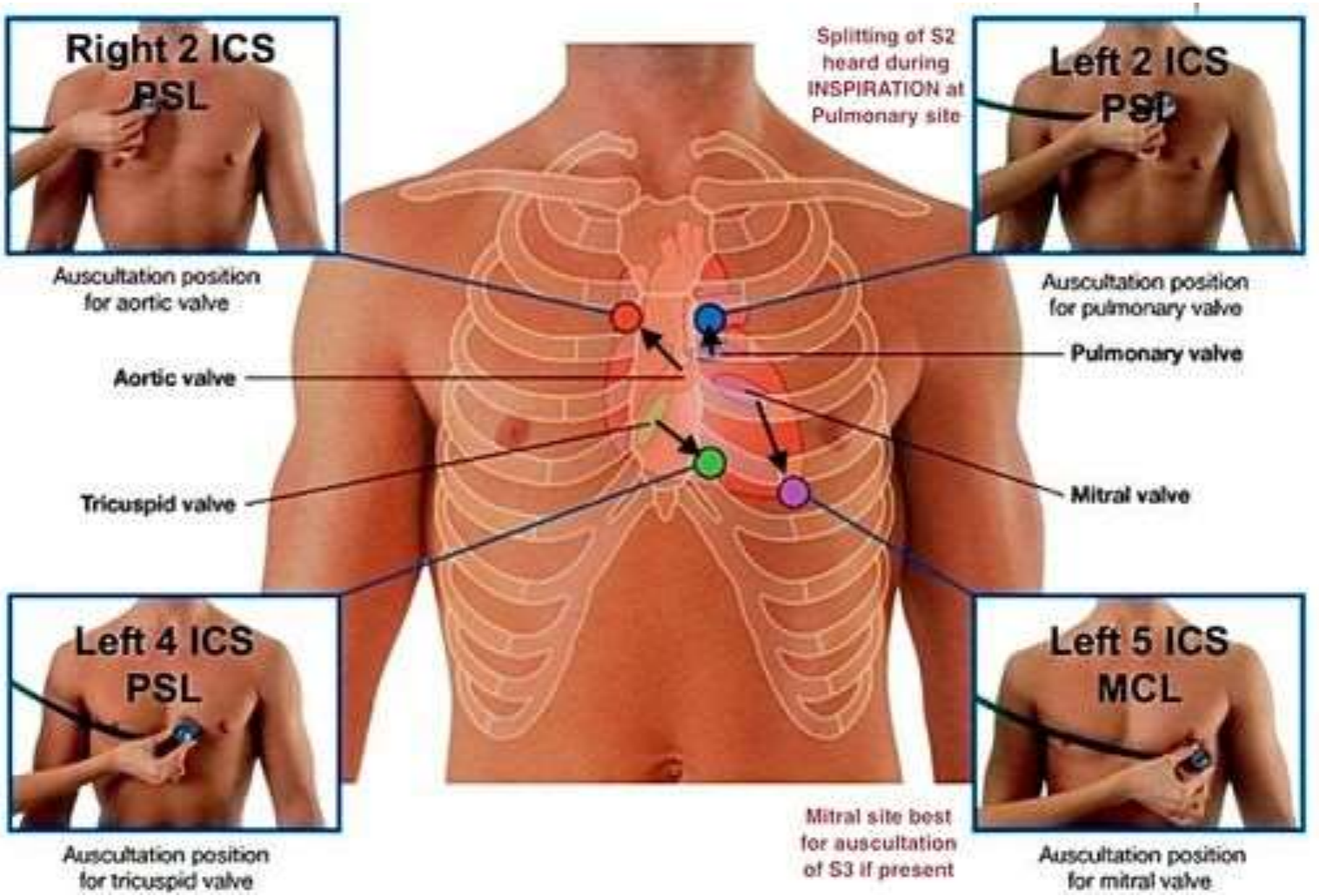
- **The apex beat**
- **The apex beat can be investigated, using such methods: visual, palpatory, and by recording of apexcardiogram**
- **Puls**
- **Heart sound**
- **ECG**

Sphygmography

- Pulse is a shock wave caused by systolic ejection and propagates along the vessel wall.
- Pulse wave registration method is sphygmography





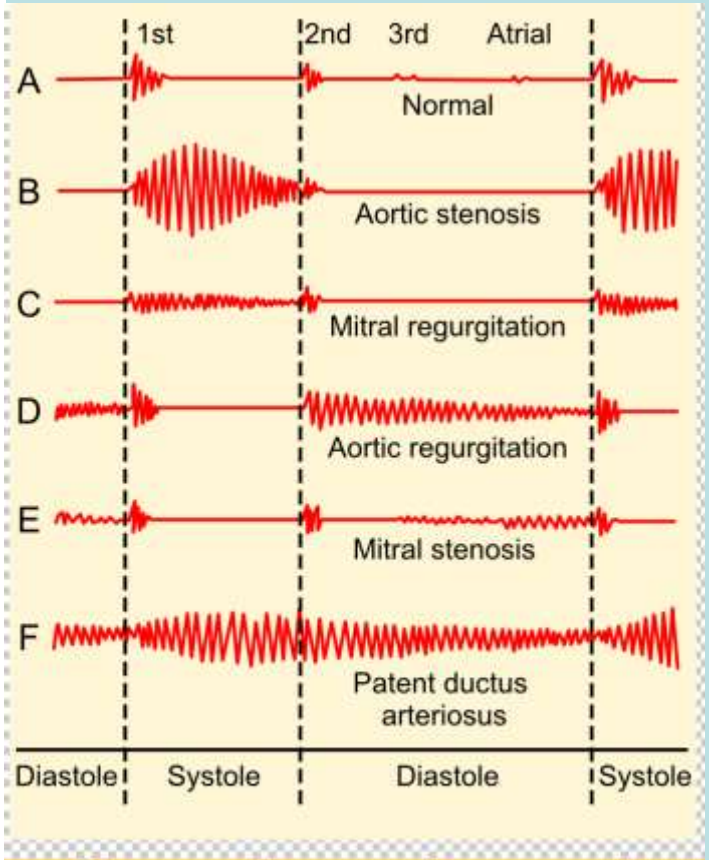


The heart sounds auscultation

The heart sounds auscultation

- The region of the apex beat – **the left fifth intercostal space**, one centimetre medially of the midclavicular line (mitral area) is the best region for the first sound auscultation. The lower end of the sternum (tricuspid area) is the place for auscultation of the first sound component, formed by the tricuspid valve. Thus, as a result of first sound auscultation we can estimate condition of the atrio-ventricular valves.
- The best place for the auscultation of the second sound **over the second intercostal space** to the right of the sternum (for aortic valve) and to the left of the sternum (for the pulmonary valve). Auscultation of the second sound gives as opportunity to estimate the semilunar valves condition.
-

Heart sounds



Phonocardiograms from normal and abnormal heart sounds

Phonocardiogram is a special device , designed to detect sounds with low frequency and amplifying them to be recorded by a special apparatus.

The 1rst (S_1) heart tone ("lub") defines as 'systolic'. It occurs as the ventricle contracts and ventricular pressure rises above atrial pressure, causing the atrioventricular valves to close. A soft and low pitch sound.. There are four components which participated in the first heart tone origination: muscular, atrial, valvular (normally mitral proceeds tricuspid) and vascular components.

The 2rst (S_2) heart tone (dub). defines as 'diastolic' A sharp and high pitch sound .caused by closure of semilunar valves. It has only two components: valvular (aortic proceeds pulmonary) and vascular components

The 3 heart sound (S_3) (diastolic) results from vibrations during the rapid phase of ventricular filling and is associated with ventricular filling that is too rapid. Although it may be heard in normal children and adolescents, its appearance in a patient older than age 35 usually signals the presence of a cardiac abnormality. We can hear it (as a S_4) in norm on phonocardiography only.

The fourth heart sound (S_4) (presystolic) may be heard during atrial systole It is caused by blood movement resulting from atrial contraction and, like S3, is more common in patients with abnormal hearts.