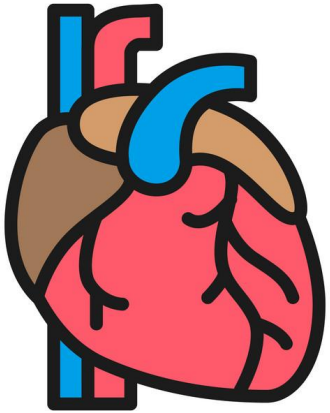
Revised & Reviewed by: Abdulaziz & Bahammam
Faye Wael Sendi

MED441
KING SAUD UNIVERSITY



Contractile mechanism in cardiac muscle

Color Index:
- Main text
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- Girls Slides
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Editing File

Objectives

- Define cardiac muscle contractility & types of its contraction
- Understand the physiology of cardiac muscle
- Understand the phases of cardiac action potential and the ionic bases
- Identify the refractory period of cardiac muscle
- Discuss the role of ca++ in the regulation of cardiac muscle function
- Describe the mechanism of excitation contraction coupling
- Discuss factors affecting cardiac contractility

Before studying we recommend watching the following videos

Video

properties of Cardiac muscles

Video

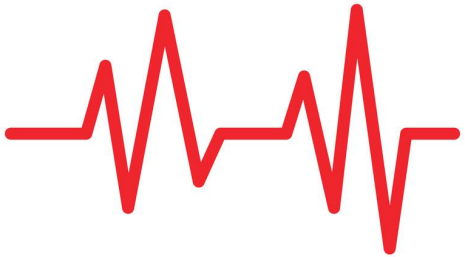
AP of cardiac muscle

Primary function of cardiovascular system:

Video

- Deliver blood to tissues
  - Providing essential nutrients to cells for metabolism
  - Removing waste products.

- The heart muscle is remarkable. At an average heart rate of 70 beats/min , the heart needs to contract and relax more than 100 000 times a day without stopping or tiring.



TYPES OF CARDIAC MUSCLE CELLS

CARDIAC MUSCLE CELLS

Contractile cells

- 99% of cardiac muscle cells
Perform **mechanical work** of pumping

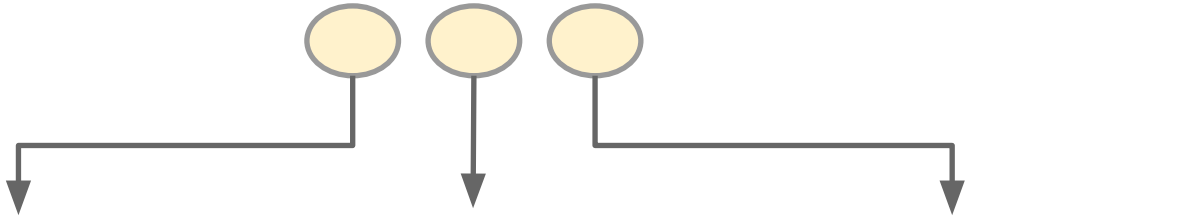
Autorhythmic cells

- Specialized for **initiating** and **conducting** action potentials responsible for contraction of myocytes
- Do not contract
-Automatic rhythmical electrical discharge in form of APs (SA node)

PHYSIOLOGY OF CARDIAC MUSCLE

Atrial and ventricular are very similar (both of them are contractile) and only have microscopic difference

The heart has 3 types of muscles



Atrial | **Ventricular** | **Excitatory and conductive**

★ **Cardiac muscle** cells are found only in the heart, are specialized to pump blood powerfully and efficiently throughout our entire lifetime.

★ **Contractility :** describes the relative ability of the heart to eject a stroke volume (pump blood)

★ Specialized excitatory and conductive fibers Types :

- **Automatic** rhythmical electrical discharge in form of APs (SA node)
- **Conduction** of APs through heart (conductive fibers)

CARDIAC MUSCLE PROPERTIES

- The cardiac muscle cells are responsible for electrical stimulation which leads to mechanical function.
- The electro-physiologic properties of cardiac muscles are:

Automaticity: Ability to spontaneously generate an electrical impulse.

Excitability: Ability to respond to an electrical impulse.

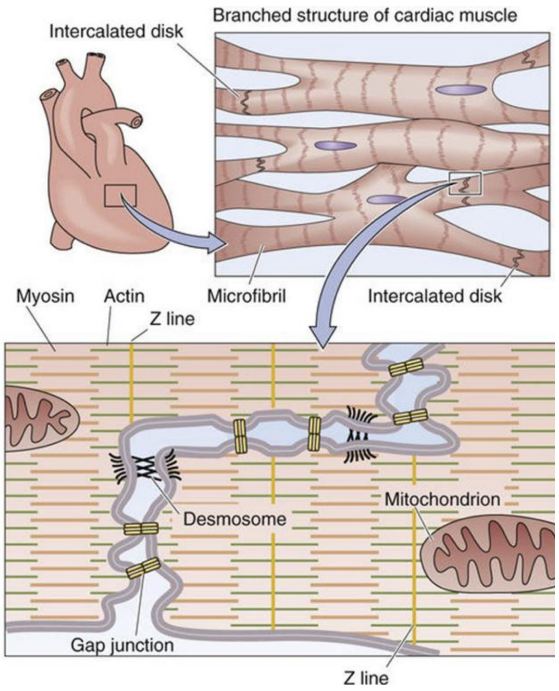
Conductivity: Allow transmission of electrical impulse to another cardiac cell.

Contractility: Ability to contract after electrical impulse response

Rhythmicity: Ability to send electrical impulses in a regularly manner.

PHYSIOLOGIC ANATOMY OF CARDIAC MUSCLE

- Striated , Involuntary and intrinsically controlled.
- Functional unit is called **Sarcomere**
- Branched and connected at **intercalated discs.**
- Discs contain **Gap Junctions**
- Nuclei are **centrally and singly** located
- **Abundant** Mitochondria (needs lots of energy)
- **SR** (sarcoplasmic reticulum) is less than in skeletal muscle, but greater than in smooth muscle
- **Sarcolemma**: Has specialized ion channels that skeletal muscle does not (voltage-gated Ca2+ channels)
- Fibers are **not anchored** at ends which allows for greater sarcomere shortening and lengthening
- *(Cardiac muscles has less Ca+ in the SR so it needs longer T-Tubules to increase the surface area in which it can get Ca+ from Extracellular fluids)*



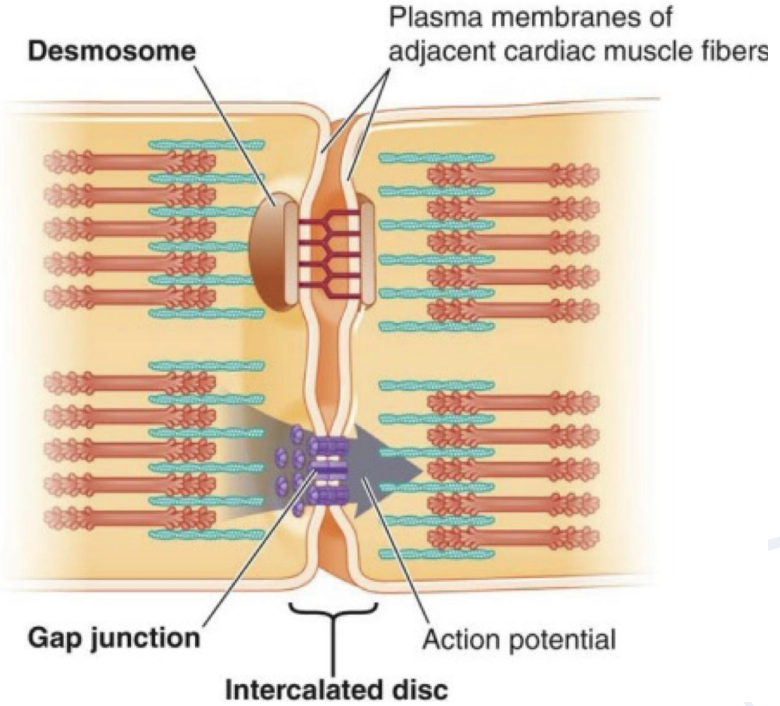
FEATURES OF DIFFERENT TYPES OF MUSCLE

Skeletal muscle	Cardiac muscle	Smooth muscle
Striated	Striated	non-Striated
Actin and myosin form sarcomeres	Actin and myosin form sarcomeres	Actin and myosin not organized into sarcomeres
Sarcolemma lacks junctional complexes between fibers	Junctional complexes between fibers including gap junctions	Gap junctions
Each fiber is innervated	Electrical syncytium	Electrical syncytium
Troponin to bind calcium	Troponin to bind calcium	Calmodulin to bind calcium
High ATPase activity (fast muscle)	Intermediate ATPase activity	Low ATPase activity (slow muscle)
Extensive sarcoplasmic reticulum	Intermediate sarcoplasmic reticulum	Limited sarcoplasmic reticulum
T tubules form triadic contacts with reticulum at A-I junctions	T tubules form dyadic contact with reticulum near Z lines	Lack T tubules, SR controlled by second messengers
Membrane lacks Ca+2 channels	Voltage gated Ca+2 channels	Voltage gated Ca+2 channels

CARDIAC MUSCLE AS A SYNCYTIUM

Intercalated discs:

- **Dark** areas cross cardiac muscle
- Are cell membranes that separate muscle cells.
- Membranes fuse and form <u>permeable gap junctions which allow:</u>
  - AP pass easily
  - allow free diffusion of ions.
  - Formation of syncytium
  -
- Within intercalated discs –two kinds of membrane junctions:
  - Desmosomes (anchoring)
  - Gap junctions



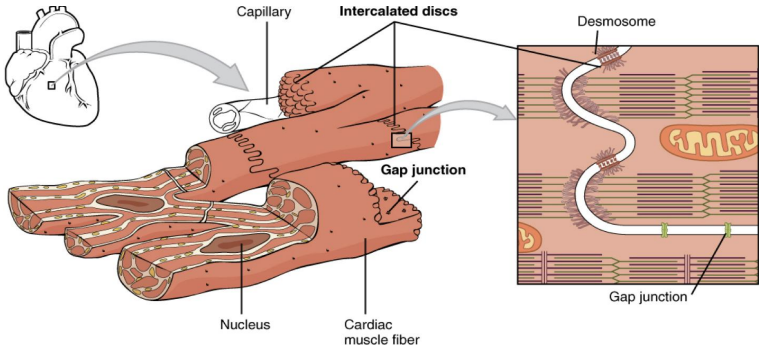
CARDIAC MUSCLE AS A SYNCYTIUM

- ***How do gap junctions within intercalated disks aid contraction of the heart?***

they allow impulses to spread from one cardiac muscle cell to another, allowing sodium, potassium, and calcium ions to flow between adjacent cells, propagating the **action potential**, and ensuring **coordinated contractions**.

intrinsically controlled

Ions move with ease in the intracellular fluid along the *longitudinal axes of the cardiac muscle fibers,* so that action potentials travel easily from one cardiac muscle cell to the nex



- Heart is composed of **two syncytium:**

  1. Atrial

  2. Ventricular

Separated by fibrous tissue which act as an insulater

- What's the importance of this separation?

-Allows atria to **contract** ahead of ventricles

- How do action potentials reach ventricles?

-Action Potentials are conducted by **A-V bundle**.

TYPES OF CONTRACTION

Isometric Contraction:	Isotonic Contraction:
generate force **without changing** the length of the muscle.	generate force by **changing** the length of the muscle

EXCITATION-CONTRACTION COUPLING

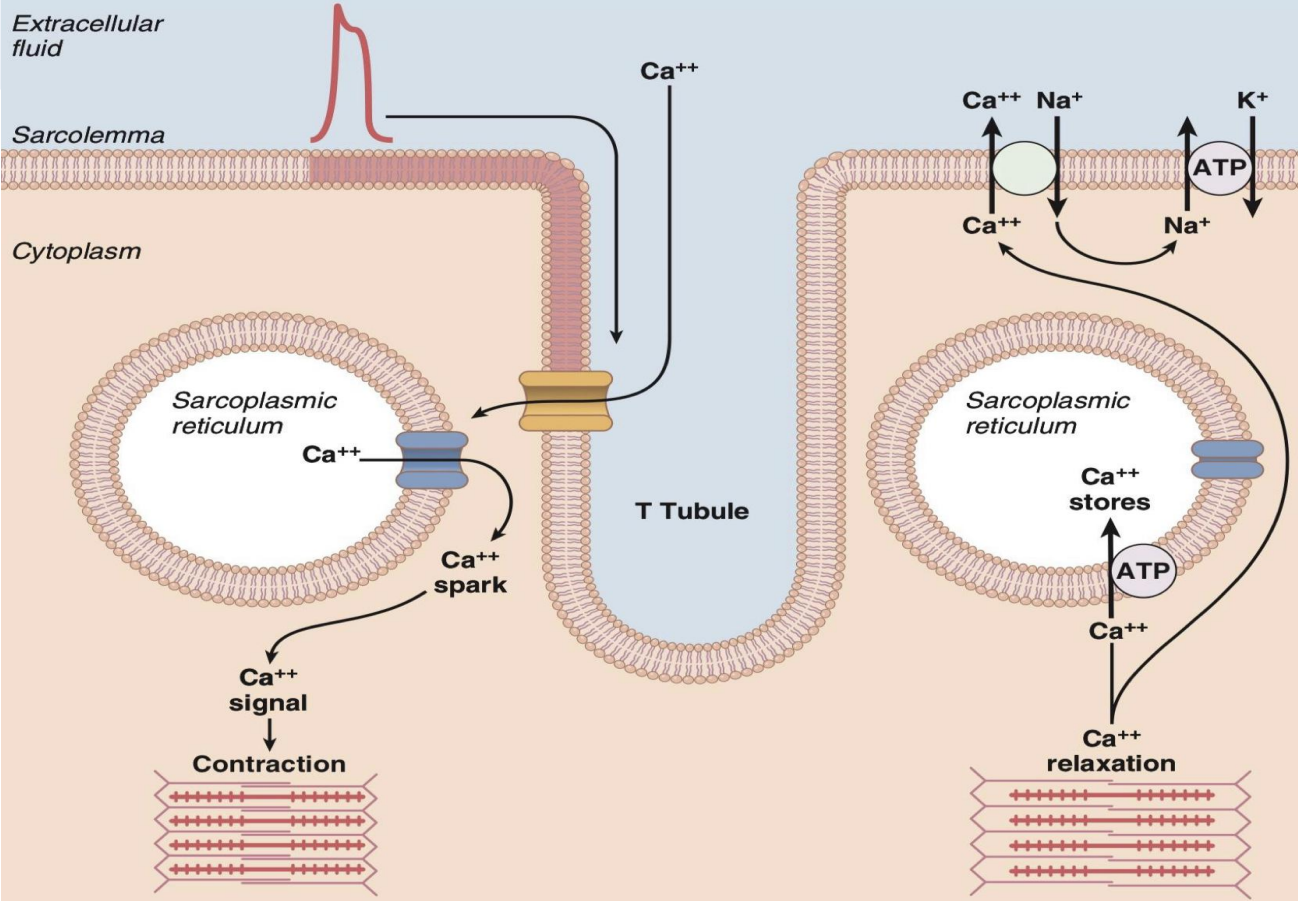
excitation → Increase ca++ → contraction

Excitation of the heart is triggered by **electrical** impulse rather than neurotransmitters.

Contraction of the heart is triggered by elevation of intracellular calcium influx.

Excitation-Contraction Coupling

Extra slide
(Thanks to team 439)



summary

1- Ca++ enter the cell through Ca++ channels on sarcolemma during depolarization(phase 2) and triggers release of Ca++ by terminal cisternae. **=(Ca++ induced Ca++ release)**

2- Ca++ binds to troponin-C inducing a conformational change in the troponin complex. (Ca+ binds to troponin, so troponin releases actin. The free actin can now bind to myosin.)

3- Myosin heads bind to actin, leading to cross-bridge movement(=sliding) (requires ATP hydrolysis) and reduction in sarcomere length. (muscle contraction)

4- Ca++ is re-sequestered(Ca++ reuptake) by sarcoplasmic reticulum by sarco- endoplasmic reticulum calcium ATPase (SERCA) pump.

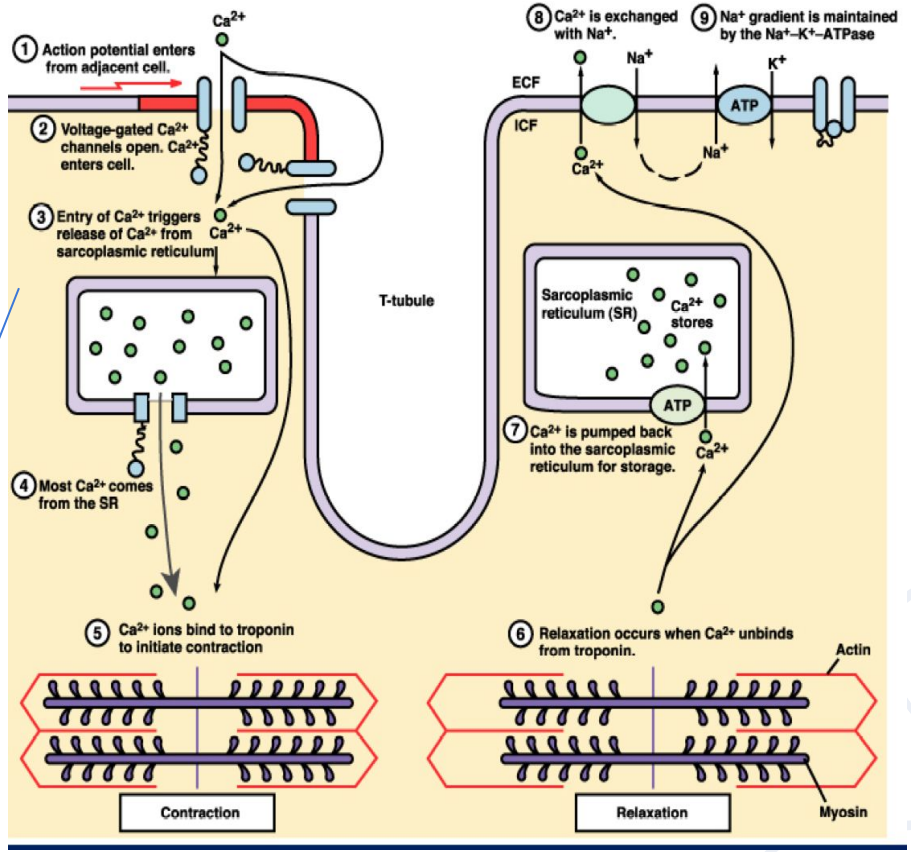
5- Ca++ is removed from troponin-C and myosin unbinds from actin (requires ATP hydrolysis); this allows the sarcomere to resume its original, relaxed length. (muscle relaxation)

EXCITATION-CONTRACTION COUPLING IN CARDIAC MUSCLE

- Cardiac muscle fibers contract via excitation-contraction coupling, using a mechanism unique to cardiac muscle called calcium -induced calcium release.

- Calcium-induced calcium release involves the conduction of calcium ions into the cardiomyocyte, triggering further release of ions into the cytoplasm.

Entry of extracellular calcium ions causes the release of calcium from the sarcoplasmic reticulum (calcium-induced calcium release), source of about 95% of calcium in cytosol.



EXCITATION-CONTRACTION COUPLING

1-AP is initiated in cell membrane, and depolarization spreads to interior of cell via T tubules.

2-Entry of Ca ++ triggers release of more Ca2+ from SR through ryanodine receptors. (Ca+ induced Ca+ release)

3 and 4. Ca ++ release from the SR Increases intracellular Ca++ which binds to troponin C, tropomyosin is moved out of the way, and interaction of actin and myosin occurs.

5-Relaxation occurs when Ca++ is reaccumulated in SR by Ca ++ ATPase (SERCA, sarco-endoplasmic reticulum calcium-ATPase).

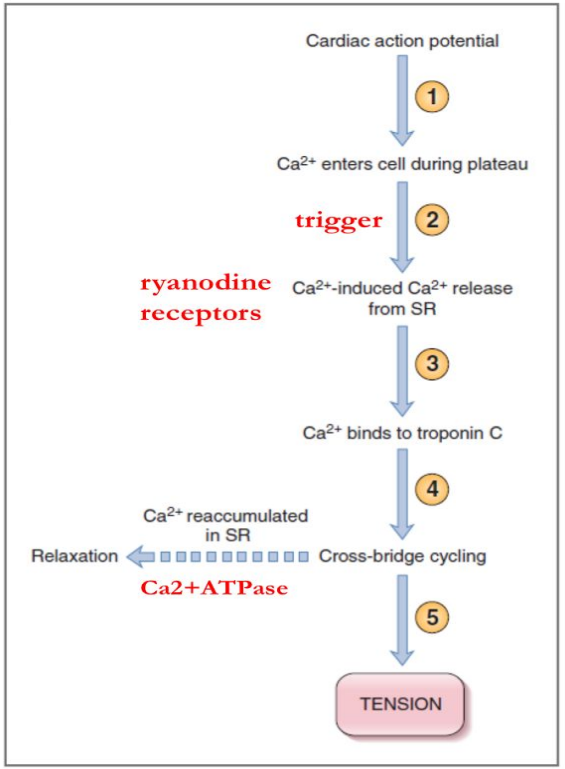


Figure 4–18 **Excitation-contraction coupling in myocardial cells.** See the text for an explanation of the circled numbers. SR, Sarcoplasmic reticulum.

EXCITATION-CONTRACTION COUPLING

Only female slides

What's the importance of Ca+2 from T tubules?

Without Ca+2 from T tubules, strength of cardiac muscle contraction would be reduced considerably because:

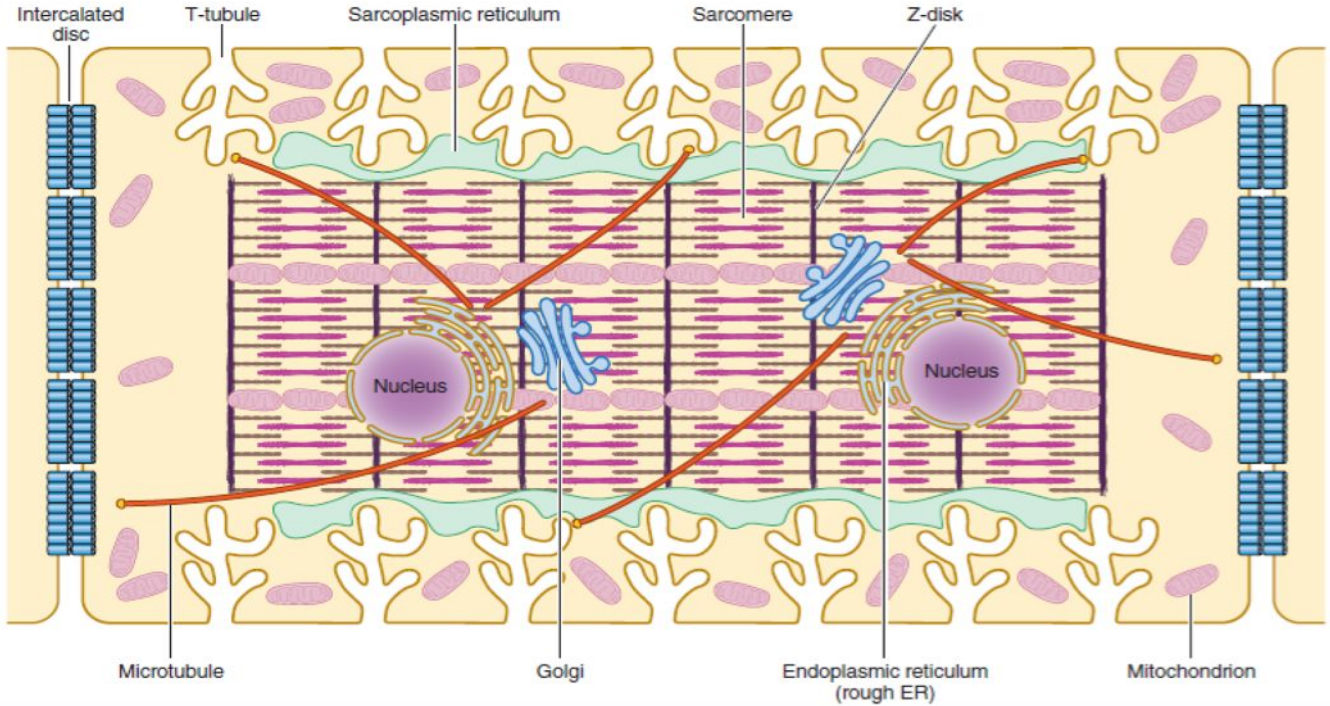
- the SR is ***less*** well developed than that of skeletal muscle and does not store enough Ca+2 to provide full contraction.

- Therefore, T tubules of cardiac muscle have a diameter 5x as great as skeletal muscle tubules

- Inside T tubules is a large quantity of **mucopoly-saccharides** that are electro-negatively charged and bind an abundant store of Ca+2 keeping Ca+2 available for diffusion to interior of cardiac muscle fiber when a T tubule AP appears.

ILLUSTRATION OF THE INTERNAL STRUCTURES OF AN ADULT VENTRICULAR CARDIOMYOCYTE

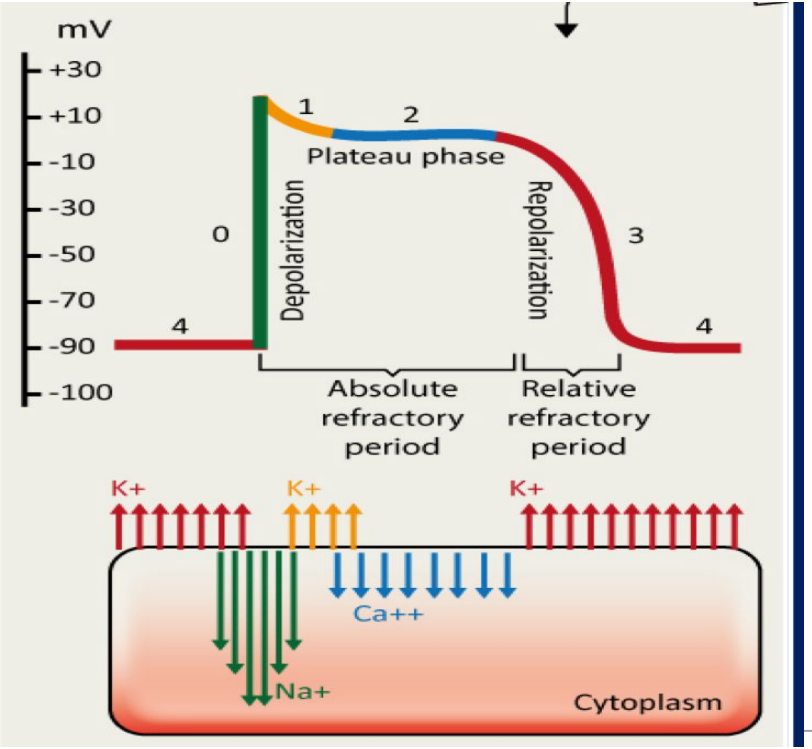
Only female slides



T-tubules, which are enriched with voltage-gated L-type calcium channels, are positioned closely near the sarcoplasmic reticulum, the primary internal calcium store

ACTION POTENTIAL IN CARDIAC MUSCLE (VENTRICLES)

Phase 4	Resting, K+ efflux
Phase 0	Depolarization, influx of Na+ through fast voltage-gated Na+ channels Membrane potential reaches about +20 millivolt before Na+ channel close
Phase 1	fast Na+ channels close. Cell begins to repolarize, and there is K+ efflux through open K+ channels
Phase 2	Plateau =0.2 sec, slow Ca++ channels open causing Ca++ influx which prolonged depolarization and initial repolarization occurs
Phase 3	Rapid Repolarization: Opening of K+ channel and Ca+2 close The closure of calcium ion channels and increased potassium ion permeability, permitting potassium ions to rapidly exit the cell



The presence of Plateau in the action potential causes ventricular contraction to last as much as 15 times as long in cardiac muscle as in skeletal muscle

Plateau

01

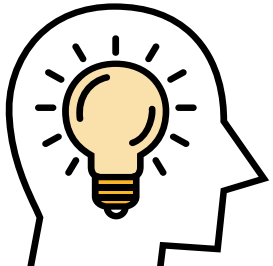
Why is the plateau phase is critical to cardiac muscle function?

-It causes ventricular contraction to last as much as 15 times as long in cardiac muscle as in skeletal muscle.
-It prevents additional impulses from spreading through the heart prematurely, thereby allowing the muscle sufficient time to contract and pump blood effectively.

02

What causes the plateau?

▪ Prolonged opening of the slow calcium-channels (L-Type) allows calcium to enter, cause plateau
. ▪Voltage-gated potassium channels are slower to open. This delays there return of the membrane to resting potential



REFRACTORY (RESISTANT) PERIOD OF CARDIAC MUSCLE

Video

Absolute Refractory period (ARP) of ventricle	Relative refractory period (RRP) of ventricle
signal cannot re excite an already excited area of cardiac muscle a protective mechanism in the heart	muscle difficult to excite but can be excited by a strong signal "premature" contraction
0.25-0.3 sec Phase 0,1,2	0.05 sec Phase 3

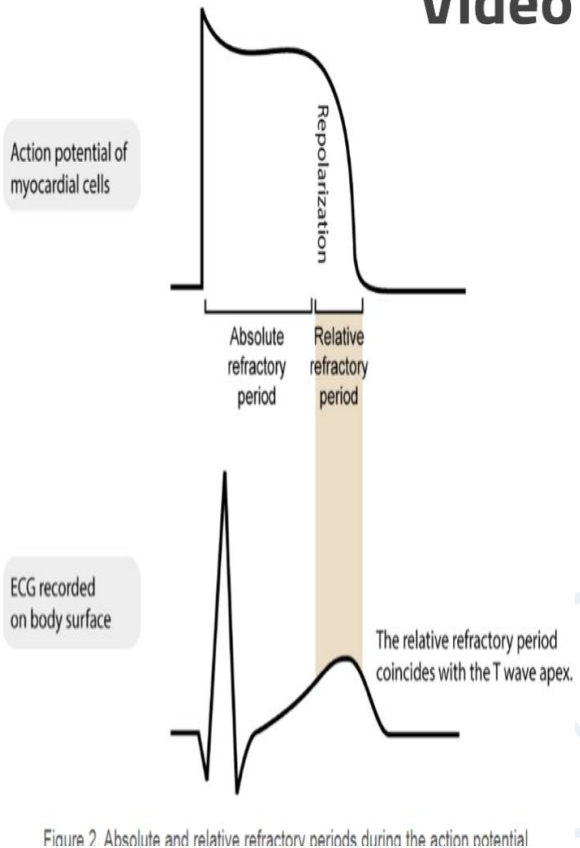


Figure 2. Absolute and relative refractory periods during the action potential

DURATION OF CONTRACTION

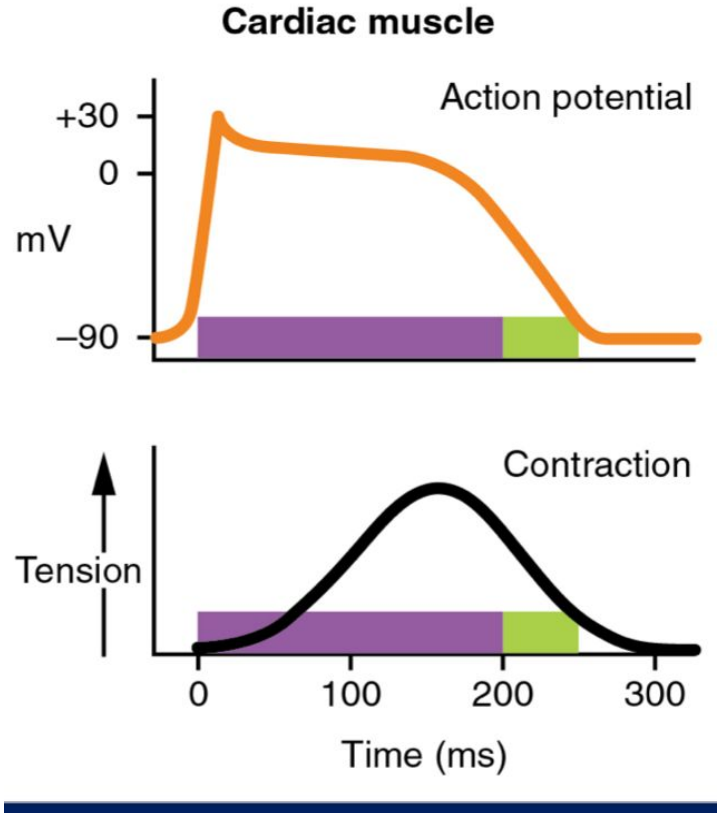
-Cardiac muscle begins to contract a few millisec after AP begins and continues to contract until a few millisec after AP ends.

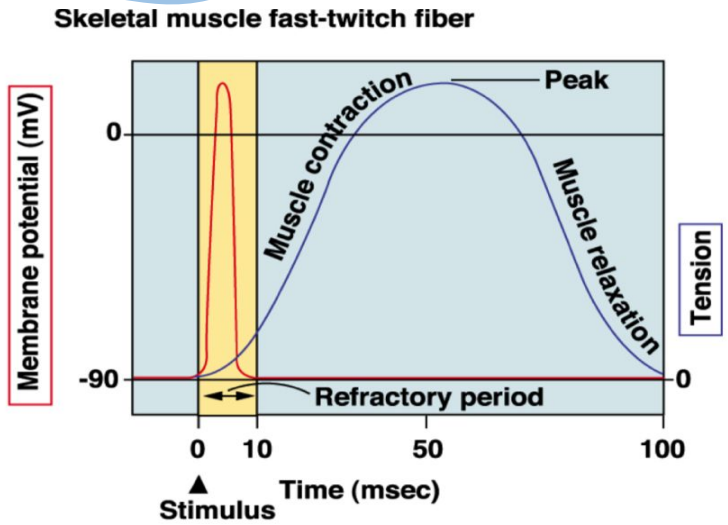
-The duration of contraction of cardiac muscle is mainly a function of the duration of AP

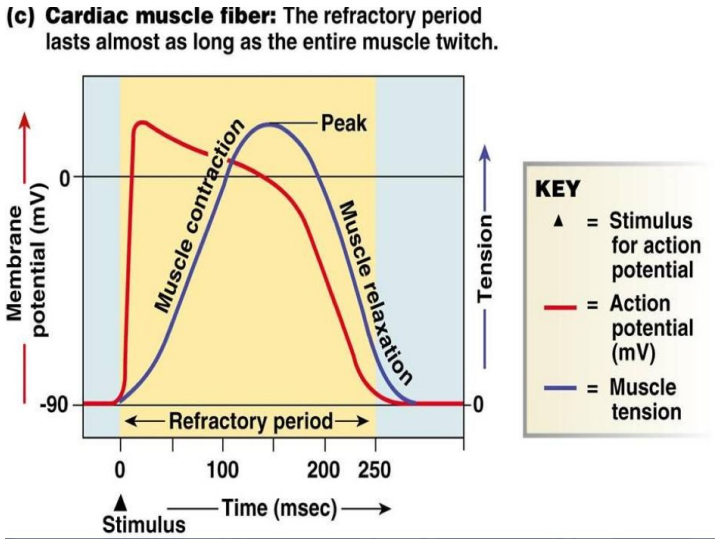
in ventricular: 0.3 sec

In atria: 0.2 sec

(Female Dr said these numbers are IMPORTANT)







- In skeletal muscle, duration of AP is shorter than its mechanical response.

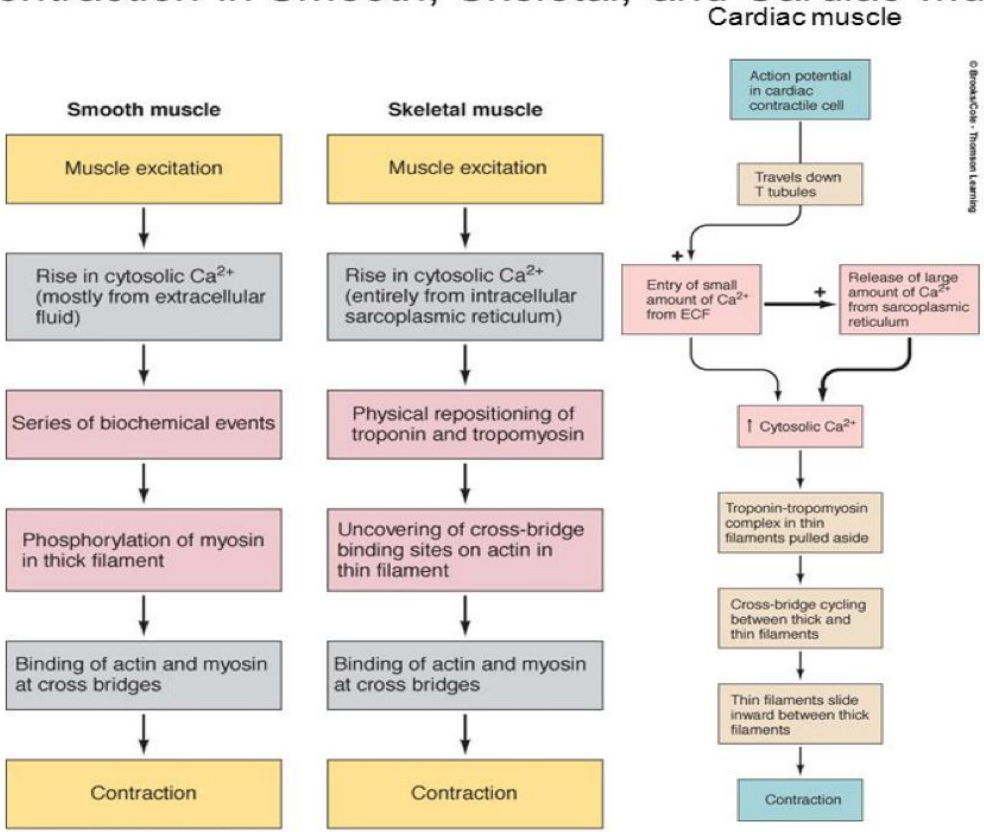
- This means that skeletal muscle can undergo tetanus via repeated stimulation

- In cardiac muscle, duration of AP is same as duration of its mechanical response.

-This means that cardiac muscle cannot undergo tetanus via repeated stimulation

★ What's the difference between cardiac and skeletal muscle contraction?
- Atrial and ventricular muscle contract in the same way as skeletal muscle, except that **duration of contraction is much longer in cardiac muscle**.

Comparison of Role of Calcium In Bringing About Contraction in Smooth, Skeletal, and Cardiac Muscle



FACTORS REGULATING CONTRACTILITY (INOTROPY)

Female slides only

What changes the contractility of muscles?

- Contractility correlates directly with the intracellular Ca2+ concentration
- Therefore, the larger the inward Ca2+ current and the larger the intracellular stores, the greater the increase in intracellular Ca2+ concentration and the greater the contractility.

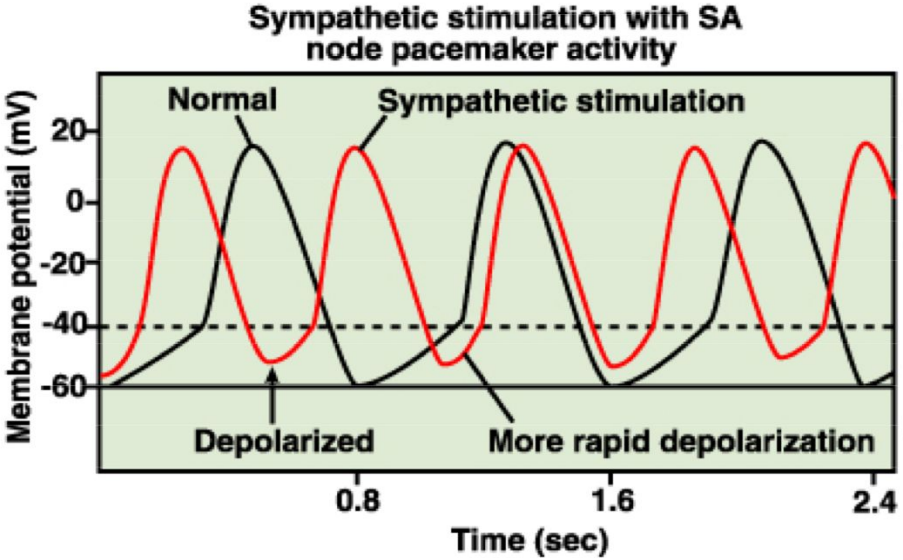
Factors regulating contractility

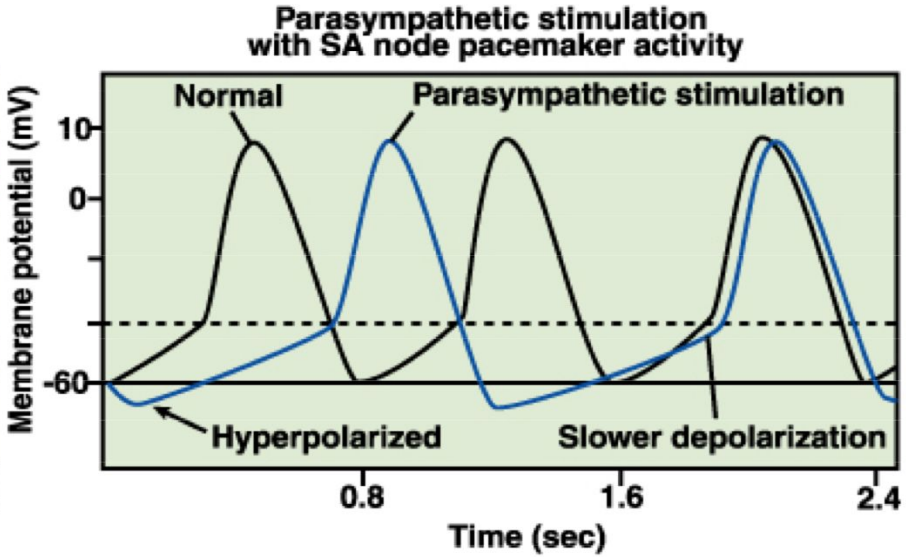
Region affected	Sympathetic Nerve effects	Parasympathetic Nerve Effects
Arterial muscle	Increase the strength of contraction (+ve inotropic effect)	Decrease the strength of contraction (-ve inotropic effects)
Ventricular muscle	Increased the strength of contraction (+ve inotropic effect)	No significant effect

Factors regulating contractility

Male slides only

- Autonomic nervous system modulates the frequency of depolarization of pacemaker
  - Sympathetic stimulation (neurotransmitter); binds to b1 receptors on the SA nodal membranes
  - Parasympathetic stimulation (neurotransmitter); binds to muscarinic receptors on nodal membranes increases conductivity of K+ and decreases conductivity of Ca2+





Team Leaders

QBank Team

Rand aldajani

Nawaf Alshehri

Sub Leader

Samiah AlQutub

Team Members

Norah Alawlah

Anas Alharbi

Special thanks to Arwa Almobeirek for designing the theme!

Click here for a summary done by the team