Cardio vascular system lecture 1

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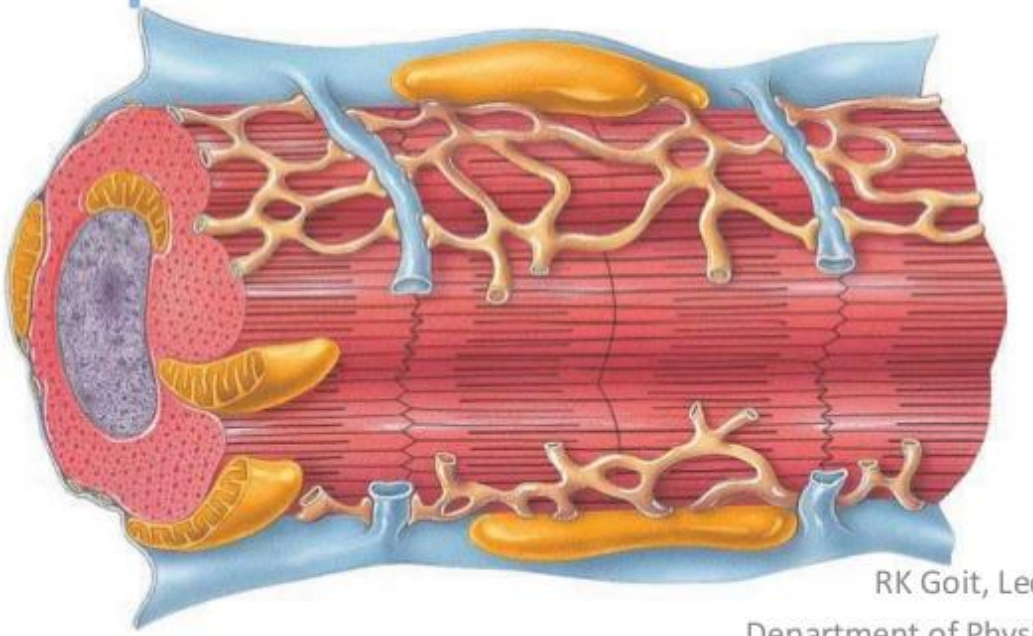
Learning objectives

- Define the terms; Rhythmicity, Excitability, Conductivity and Contractility.
- Describe cardiac syncytium.
- Outline the normal pathway of the cardiac impulse.
- Describe the excitation-contraction coupling in cardiac muscles and compare it to excitation-contraction coupling in skeletal muscles.
- Compare and contrast action potential in sino-atrial node and ventricular muscle.
- Explain the significance of the plateau and refractory period in ventricular muscle action potential.

Structure of Cardiac Muscle
Excitation-Contraction Coupling
Properties of Cardiac Muscle



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The Heart

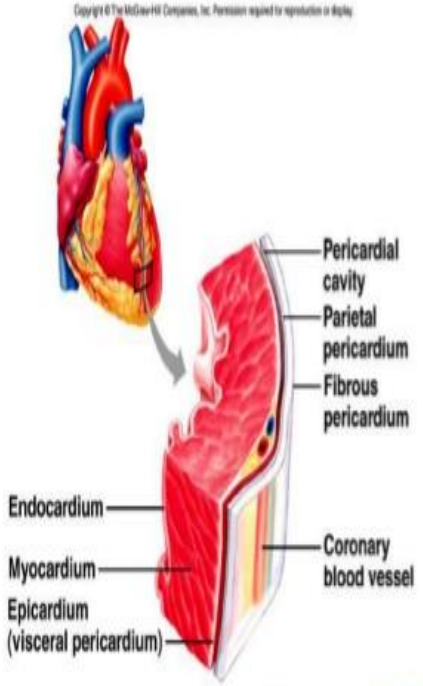
- Heart is a muscular organ that pumps blood throughout the circulatory system
- It is situated in between two lungs in the mediastinum
- It is made up of four chambers, two atria and two ventricles
- The musculature of ventricles is thicker than that of atria. Force of contraction of heart depends upon the muscles

The Heart: Coverings

- Pericardium – a double serous membrane
  - Visceral pericardium
    - Next to heart
  - Parietal pericardium
    - Outside layer
- Serous fluid fills the space between the layers of pericardium

The Heart: Heart Wall

- Three layers
  - Epicardium
    - Outside layer
    - This layer is the parietal pericardium
    - Connective tissue layer
  - **Myocardium**
    - **Middle layer**
    - **Mostly cardiac muscle**
  - Endocardium
    - Inner layer
    - Endothelium



The Heart: Chambers

- Right and left side act as separate pumps
- Four chambers
  - Atria
    - Receiving chambers
      - Right atrium
      - Left atrium
  - Ventricles
    - Discharging chambers
      - Right ventricle
      - Left ventricle

The Heart: Valves

- Allow blood to flow in only one direction
- Four valves
  - Atrioventricular valves – between atria and ventricles
    - Bicuspid valve (left)
    - Tricuspid valve (right)
  - Semilunar valves between ventricle and artery
    - Pulmonary semilunar valve
    - Aortic semilunar valve

THE CARDIAC MUSCLE

- Myocardium has three types of muscle fibers:

- i. Muscle fibers which form contractile unit of heart (99%)
- ii. Muscle fibers which form pacemaker
- iii. Muscle fibers which form conductive system

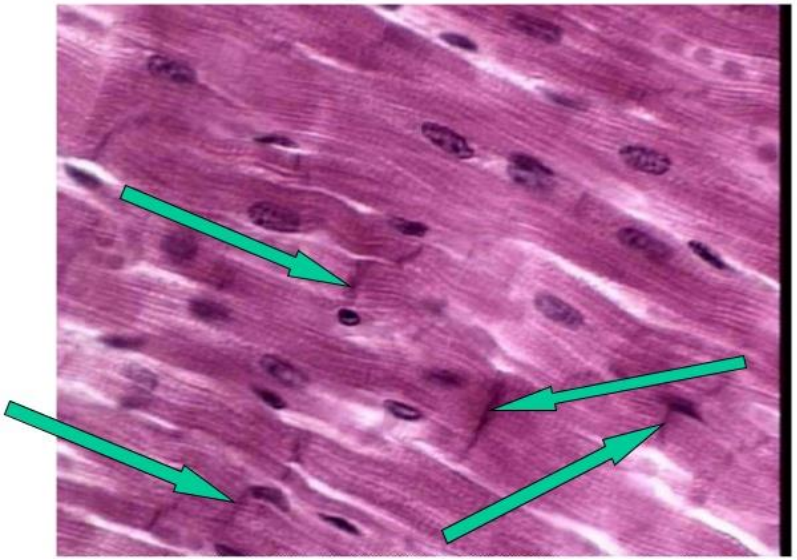
Muscle Fibres which Form the Contractile unit

- Striated and resemble the skeletal muscle fibre
- Cardiac muscle fibre is bound by **sarcolemma.** It has a centrally placed nucleus. **Myofibrils** are embedded in the sarcoplasm.
- **Sarcomere** of the cardiac muscle has all the contractile proteins, namely actin, myosin, troponin and tropomyosin.
- **Sarcotubular system** in cardiac muscle is slightly different to that of skeletal muscle.

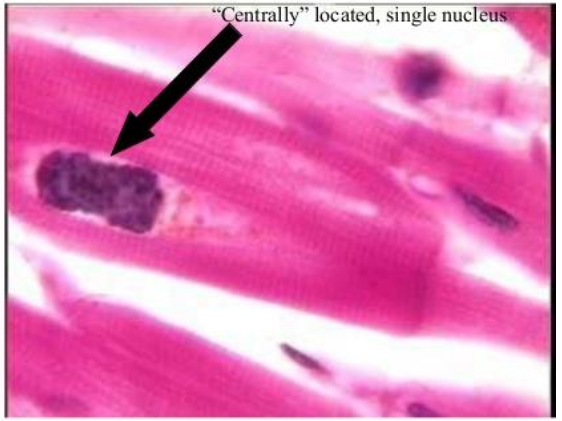
- Exhibit branching
- Adjacent cardiac cells are joined end to end by specialized structures known as intercalated discs
- Within intercalated discs there are two types of junctions
  - Desmosomes
  - Gap junctions that allow action potential to spread from one cell to adjacent cells
- Heart function as syncytium
  when one cardiac cell undergoes an action potential, the electrical impulse spreads to all other cells that are joined by gap junctions so they become excited and contract as a single functional syncytium

Atrial syncytium and ventricular syncytium

Another example of intercalated discs.



- With respect to another key identifying factor, each cardiac muscle fiber has one nucleus located deep within the cell.



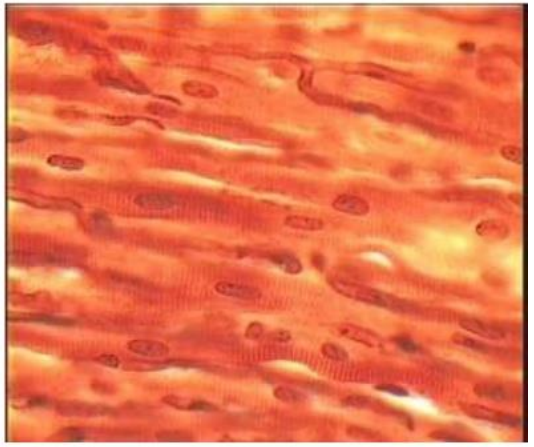
**(Note the faint striations and the intercalated disc)

3. Myofibrils -

- *Fill cell from end to end but less dense than skeletal*
- *Orderly; with light striations visible*

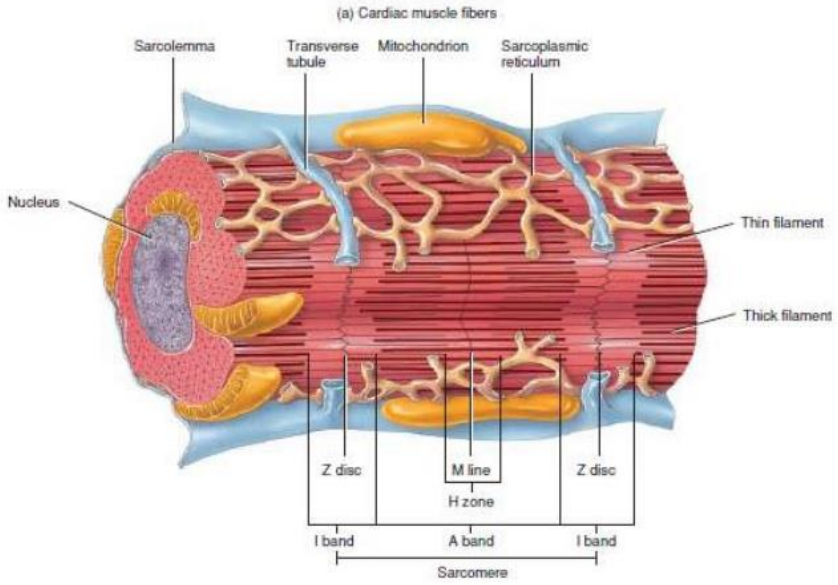
5. Vascular Supply and relative rank -

- *Dense blood capillary network with continuous supply*
- *Ranks 1st among muscle tissues*



Sarcotubular system in cardiac & skeletal muscle

	Cardiac muscle	Skeletal muscle
Location of T tubules	At Z line	At A-I junction
Diameter of T tubules	More (5times)	Less
L tubules	Narrow tubular cistern	Large dilated cistern
Association of T tubule (Tubule & cistern)	Diad (1 Tubule & 1cistern)	Triad (1 Tubule & 2cistern)
Sarcomeric organisation	Less regular	More regular



- In contrast to skeletal **muscle**, **cardiac muscle** fibers are short, fat, branched and interconnected.
- **Cardiac muscle** fibers also have only one or two nuclei,
- contain more mitochondria,
- have fewer T-tubules, and
- much less sarcoplasmic reticulum

Cardiac Muscle

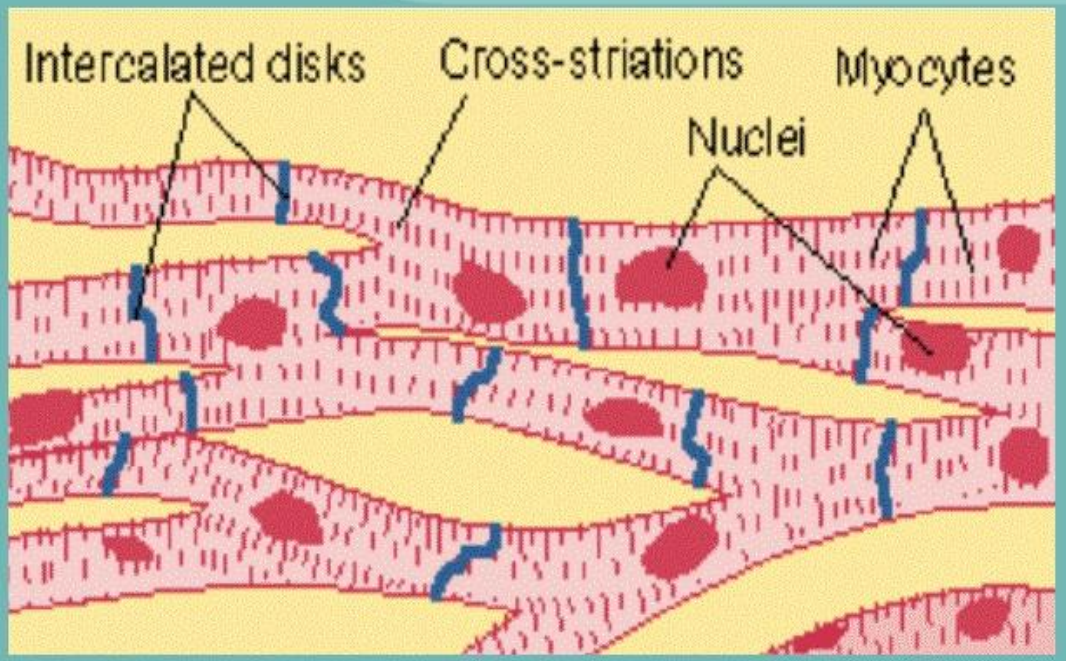
- SR is less abundant than in skeletal muscle.
- Sarcolemma has specialized ion channels that skeletal muscle does not → **voltage-gated Ca^{2+} channels.**

Functional Syncitium

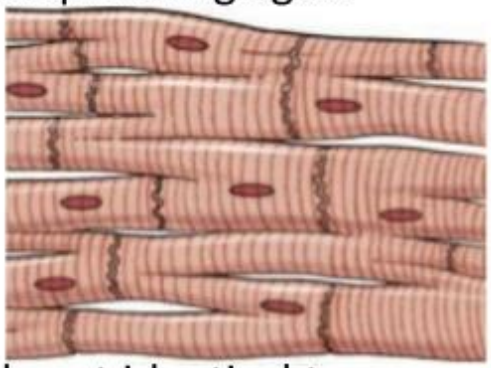
- Fibers are branched; connect to one another at *intercalated discs*.
- The discs contain several gap junctions providing cytoplasmic continuity.
- Rapid transmission of impulse.
- 2 syncitia
  - Atrial syncitium
  - Ventricular syncitium

    *Separated by fibrous ring

Cardiac Muscle



- cardiac muscle fibers arranged in a latticework, with the fibers dividing, recombining, & then spreading again

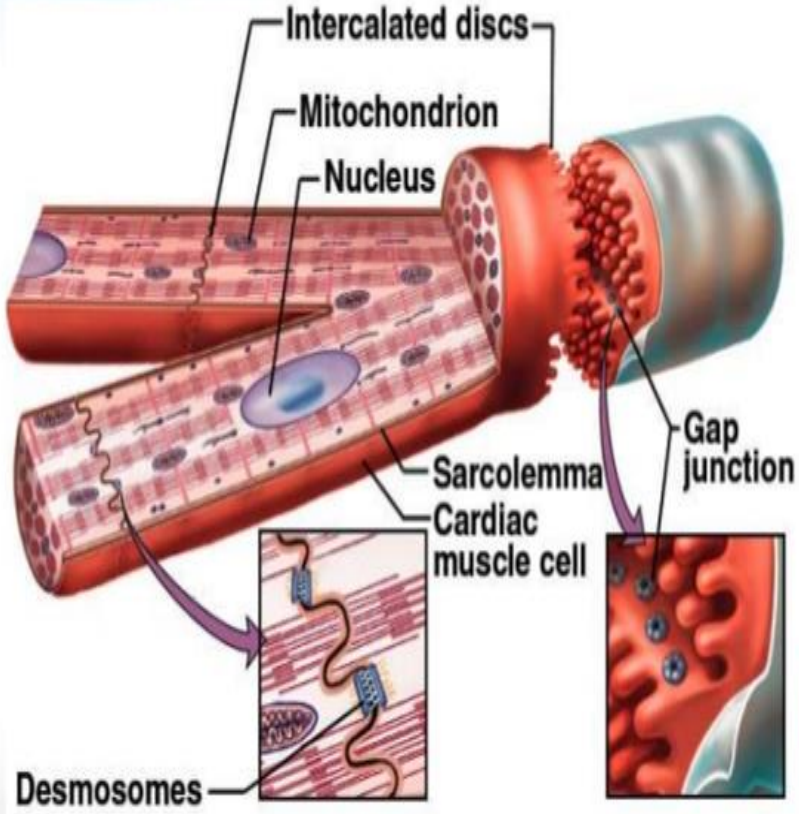


- cardiac muscle is *striated* in same manner as in skeletal muscle
- cardiac muscle has myofibrils that contain *actin* & *myosin filaments* almost identical to those found in skeletal muscle
  - these filaments lie side by side & slide along one another during contraction in the same manner as occurs in skeletal muscle

Muscle Fibres which Form the Pacemaker

- Some of the muscle fibres of heart are modified into a specialized structure known as pacemaker.
- These muscle fibres forming the pacemaker have less striation.
- They are named **pacemaker cells** or **P cells.**
- Sino-atrial (SA) node forms the pacemaker in human heart.

Structure of Cardiac Muscle Cell



Properties of cardiac muscle

- Electrical
  - Excitability (Bathmotropic action)
  - Auto rhythmicity
  - Conductivity (Dromotropic action)

- Mechanical
  - Contractility (Inotropic action)
  - Refractory period
  - Staircase / treppe effect

properties of heart can be divided into 2 groups:

Beating heart	Quiescent heart
• Automaticity • Rhythmicity • Contractibility • Excitability • Conductivity • Distensibility • Functional syncitium • Long refractory period • Extrasystole & compensatory pause	• All or none law • The staircase phenomenon • Length-tension relationship • Summation of subminimal stimuli

Properties of cardiac muscle

- Automaticity
  - capability of contract even in the absence of neural control
- Rhythmicity
  - heart beats are extremely regular
- Contractibility
  - cardiac muscle contracts in response to a stimulus
- Excitability
  - ability of the cardiac muscle to respond to different stimuli
- Conductivity
  - impulses produced in the SA node is conducted by the specialized conducting pathway
- Distensibility
  - occurs due to compliance of the cardiac muscle
- Functional syncytium
  - due to the presence of numerous gap junctions

Resting Membrane Potential

- **Definition**: it is the potential difference across cell membrane at rest:
- it is negative inside with respect to outside.

Potential

- values of RMP vary in various excitable tissues:
- In nerve fiber: -90 mV
- In skeletal muscle: -90 mV
- In cardiac muscle: -85 mV
- SA node: -55 mV
- In nerve cell body: -70 mV
- In smooth muscle: -55 mV to -60 mV

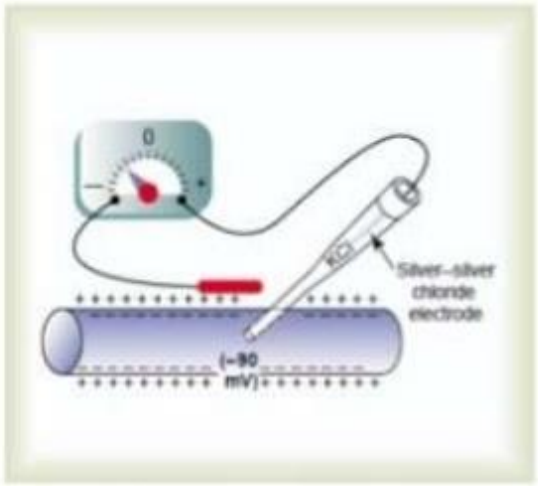
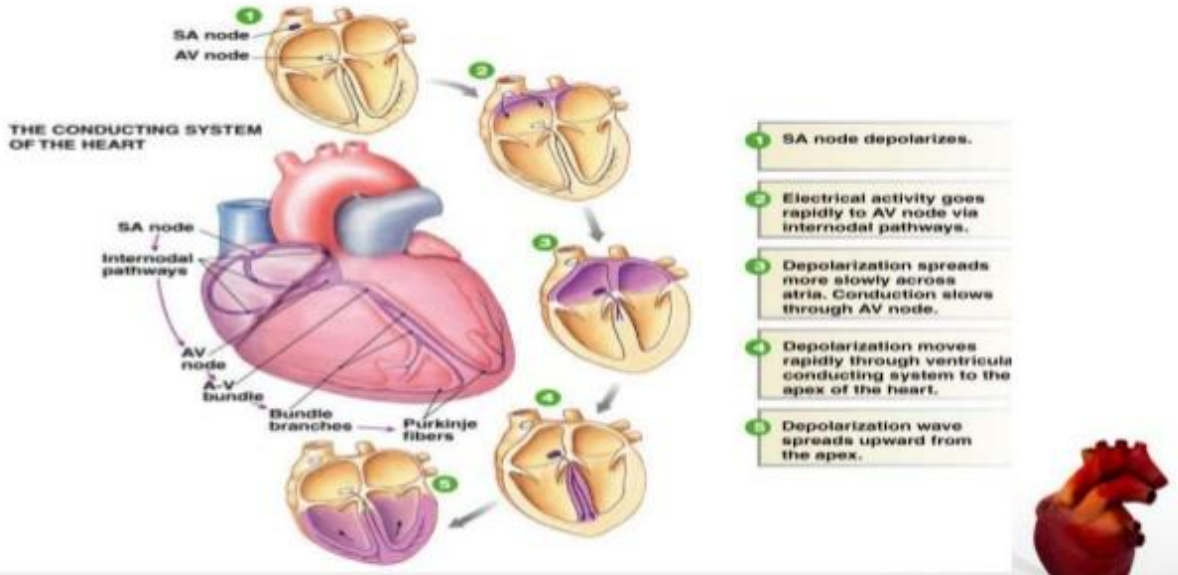


Figure 5-2

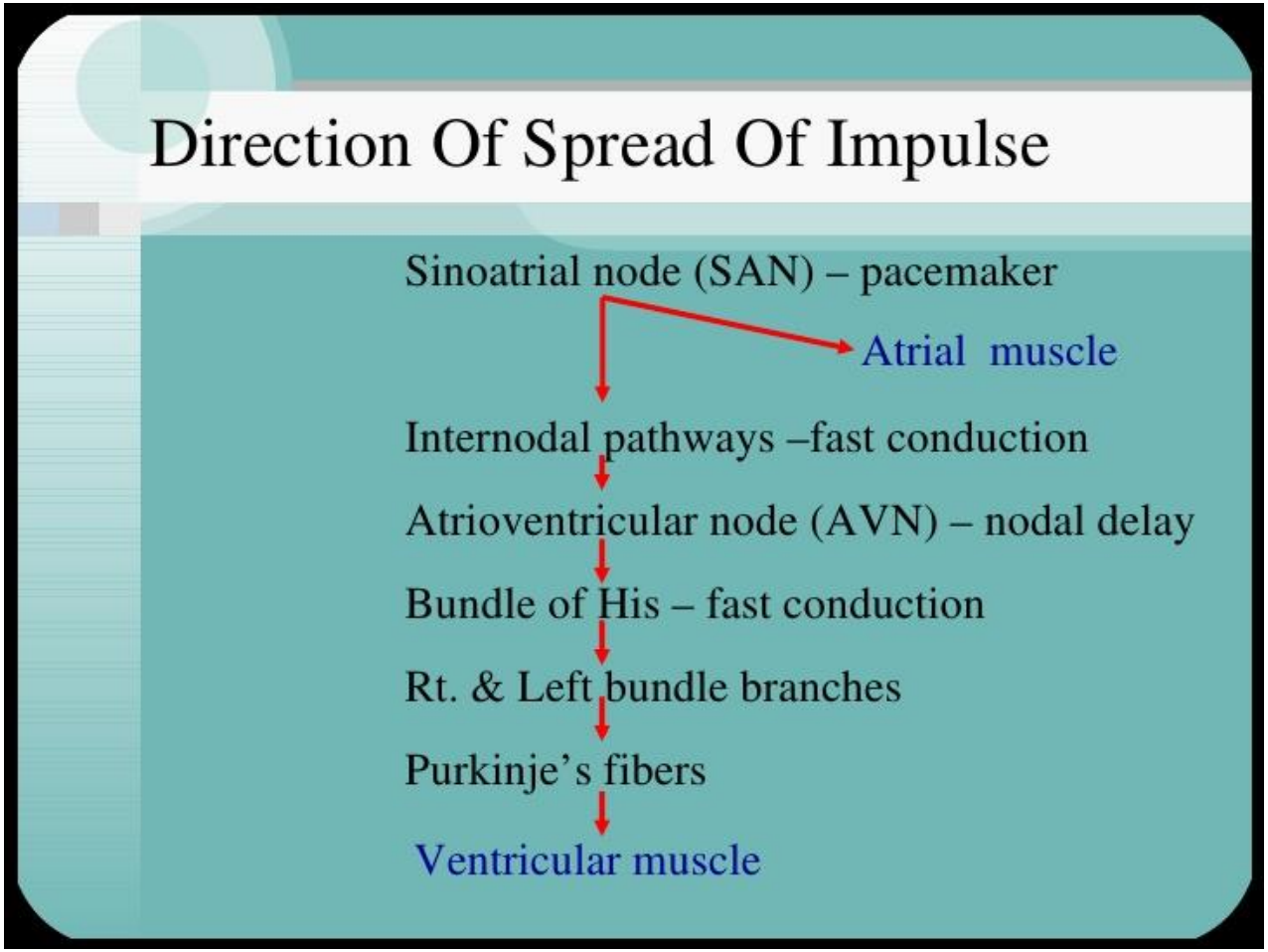
Measurement of the membrane potential of the nerve fiber using a microelectrode.

4. Conductivity

Definition: property by which excitation is conducted through the cardiac tissue



Direction Of Spread Of Impulse



1. Autorhythmicity

Definition: the ability of the heart to initiate its beat continuously and regularly without external stimulation

- **myogenic** (independent of nerve supply)

- due to the **specialized excitatory & conductive system** of the heart

↓

intrinsic ability of self-excitation
(waves of depolarization)

↓

cardiac impulses

Autorythmic fibers

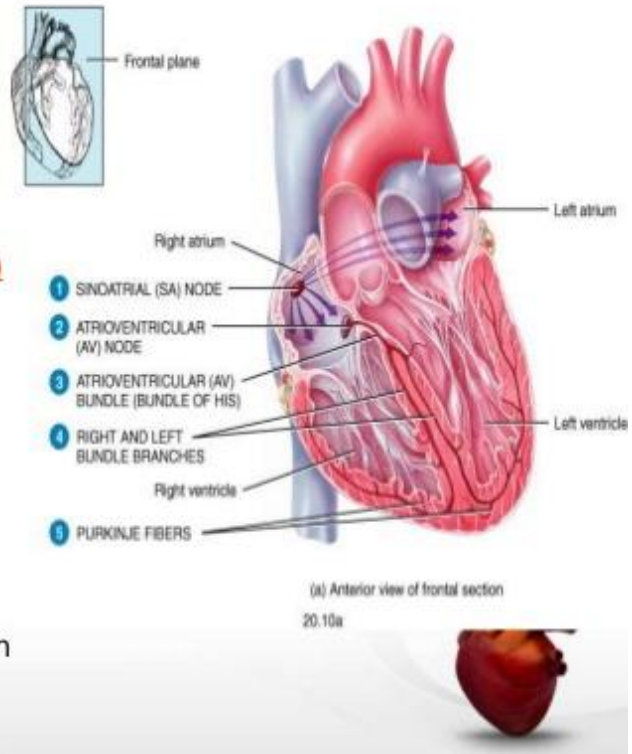
Forms 1% of the cardiac muscle fibers

Have two important functions

1. Act as a pacemaker (set the rhythm of electrical excitation)
2. Form the conductive system (network of specialized cardiac muscle fibers that provide a path for each cycle of cardiac excitation to progress through the heart)

Locations of autorhythmic cells

- Sinoatrial node (SA node)
  Specialized region in right atrial wall near opening of superior vena cava.
- Atrioventricular node (AV node)
  Small bundle of specialized cardiac cells located at base of right atrium near septum
- Bundle of His (atrioventricular bundle)
  Cells originate at AV node and enters interventricular septum
  Divides to form right and left bundle branches which travel down septum, curve around tip of ventricular chambers, travel back toward atria along outer walls
- Purkinje fibers
  Small, terminal fibers that extend from bundle of His and spread throughout ventricular myocardium



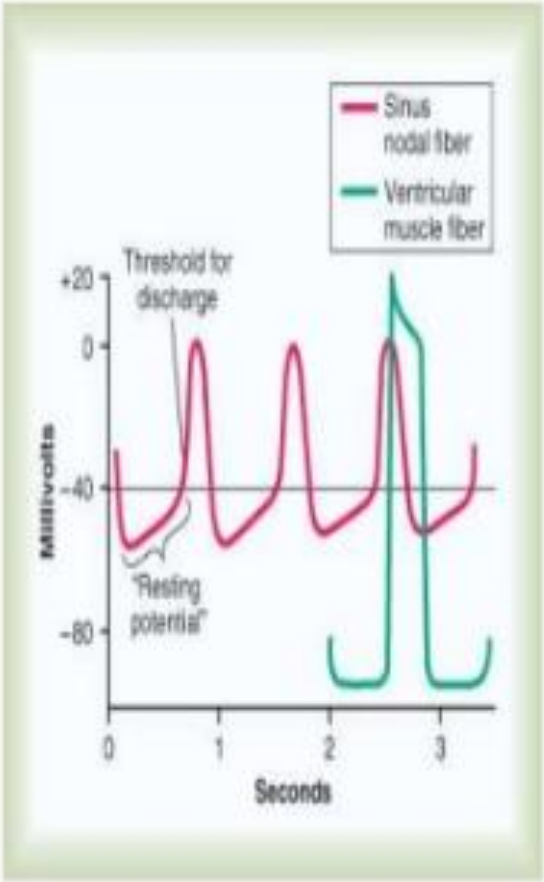
Rate of generation of AP at different sites of the heart

SITE	RATE (Times/min)
SA node	70 - 80
AV node	40 - 60
AV bundle, bundle branches,& Purkinje fibres	20 - 35

- SA node acts as heart pacemaker because it has the fastest rate of generating action potential
- Nerve impulses from autonomic nervous system and hormones **modify** the timing and strength of each heart beat but do not establish the fundamental rhythm.

Mechanism of Autorhythmicity

- Autorhythmic cells do not have stable resting membrane potential (RMP)
- Natural leakiness to Na & Ca→ spontaneous and gradual depolarization
- Unstable resting membrane potential (= pacemaker potential)
- Gradual depolarization reaches threshold (-40 mv) → spontaneous AP generation

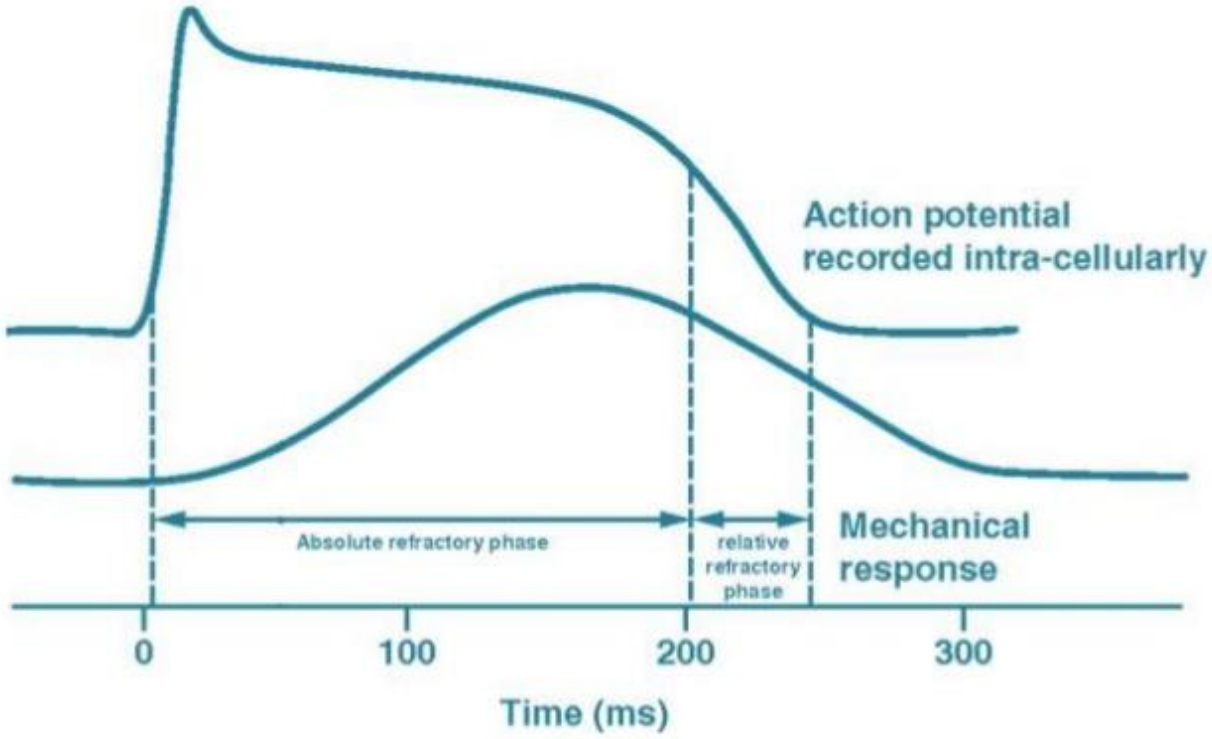


2. Excitability

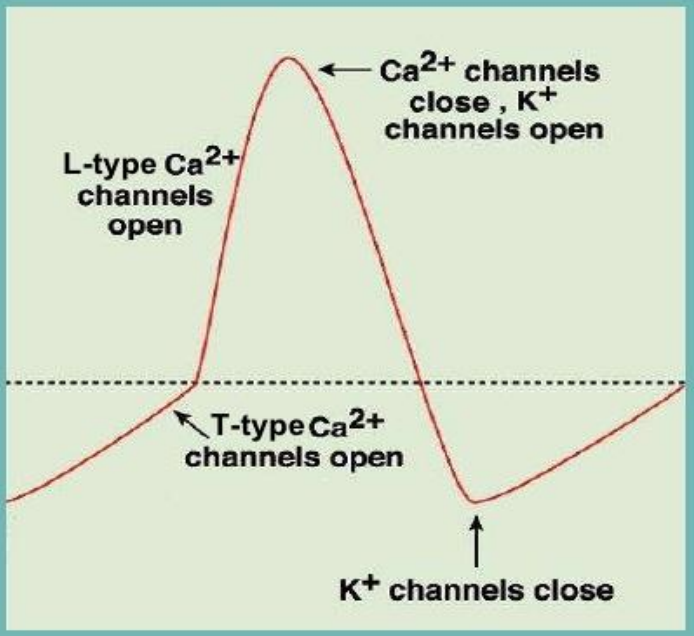
Definition: The ability of cardiac muscle to respond to a stimulus of adequate strength & duration by generating an AP

- AP initiated by SA node→ travels along conductive pathway→ excites atrial &ventricular muscle fibres

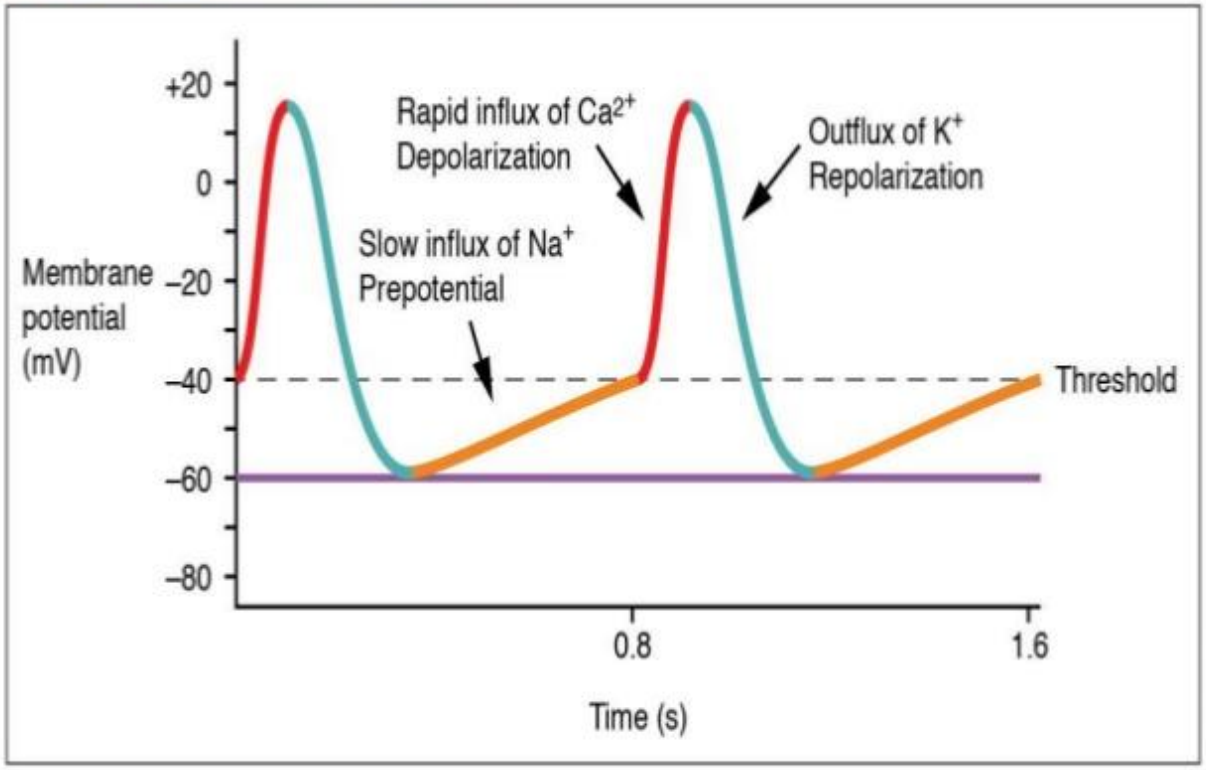
- Long refractory period



Membrane Potential Of SAN



Prepotential / pacemaker potential/ Diastolic potential



Cardiac Muscle as a Syncytium

- cardiac cells are so interconnected that when one of these cells becomes excited, the action potential spreads to all of them, from cell to cell throughout the latticework interconnections

- heart actually is composed of two syncytiums: the atrial syncytium, which constitutes the walls of the two atria, & the ventricular syncytium, which constitutes the walls of the two ventricles

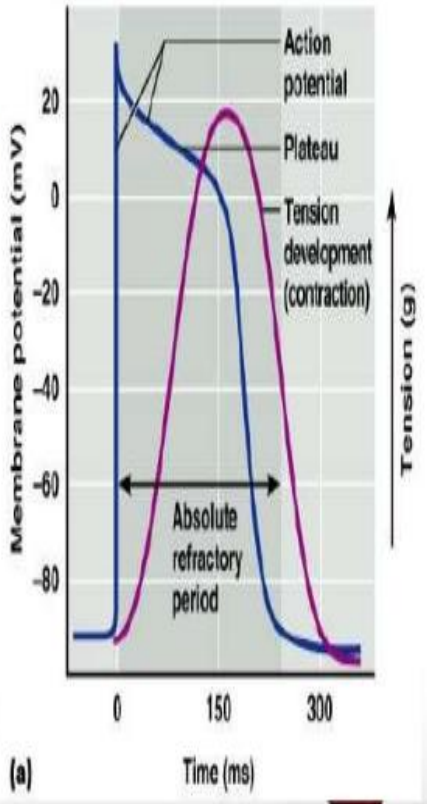
- division of the muscle of the heart into two functional syncytiums allows the atria to contract a short time ahead of ventricular contraction

Refractory Period

- It is that period during which a second stimulus fails to evoke a response.
- Absolute Refractory Period : It is that period during which a second stimulus however high it is fails to evoke a response.
- Relative Refractory Period : It is that period during which a second stimulus evokes a response if it is sufficiently high.

Refractory period

- Long refractory period (250 msec) compared to skeletal muscle (3msec)
- During this period membrane is refractory to f urther stimulation until contraction is over.
- It lasts longer than muscle contraction, prevents tetanus
- Gives time to heart to relax after each contract ion, prevent fatigue
- It allows time for the heart chambers to fill during diastole before next contraction



3. Contractility

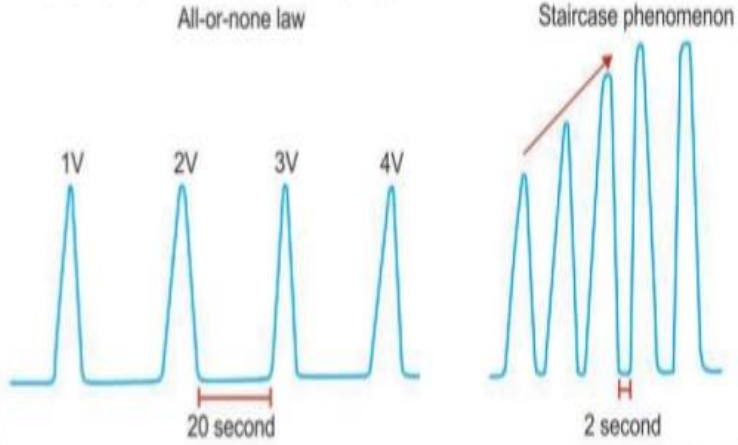
Definition: ability of cardiac muscle to contract in response to stimulation

All Or None Law

- The response to a threshold stimulus is maximal. If the stimulus is below threshold there is no response provided the physiological conditions remain constant
- The cardiac muscle follows the all or none law as a whole.
- In the case of skeletal muscle, all-or-none law is applicable only to a single muscle fiber.

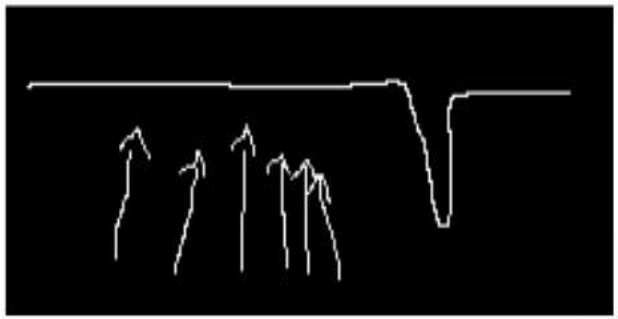
Treppe or Stair-case Phenomenon

- When stimuli of same strength are applied at short intervals, an increase in the height of contraction is observed.
- This is due to the **BENEFICIAL EFFECT** - decrease in viscosity, mild increase in temperature and increase in the level of calcium ions.



Summation of Sub-minimal Stimuli

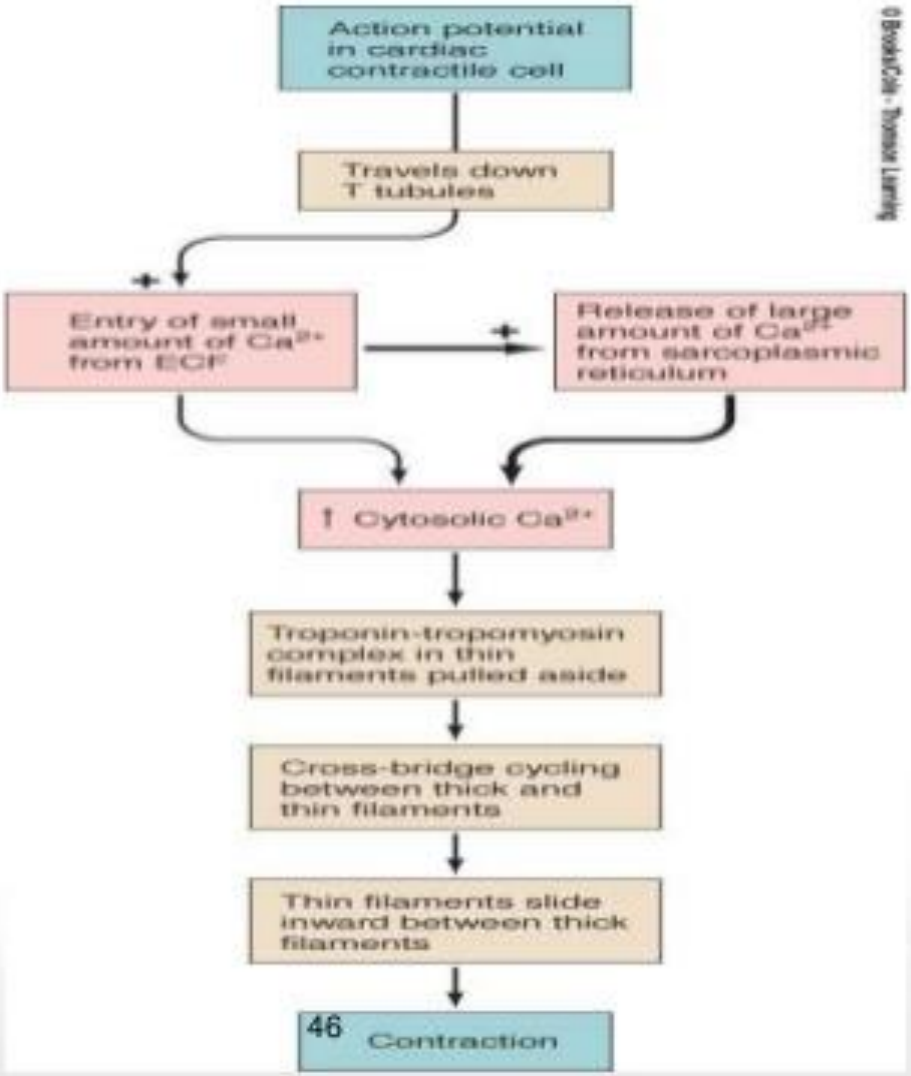
When a series of sub-minimal stimuli are applied to the cardiac muscle, it responds with a contraction once all the sub –minimal add up to produce a threshold stimulus.



- All or none law
  - if the heart is stimulated with subthreshold stimuli no response is seen
  - a threshold stimulus is the weakest stimulus that evokes a response
  - amplitude of contraction in response to the suprathreshold stimuli remains the same as that with the threshold stimuli

Excitation-Contraction Coupling in Cardiac Contractile Cells

Similar to that in skeletal muscles

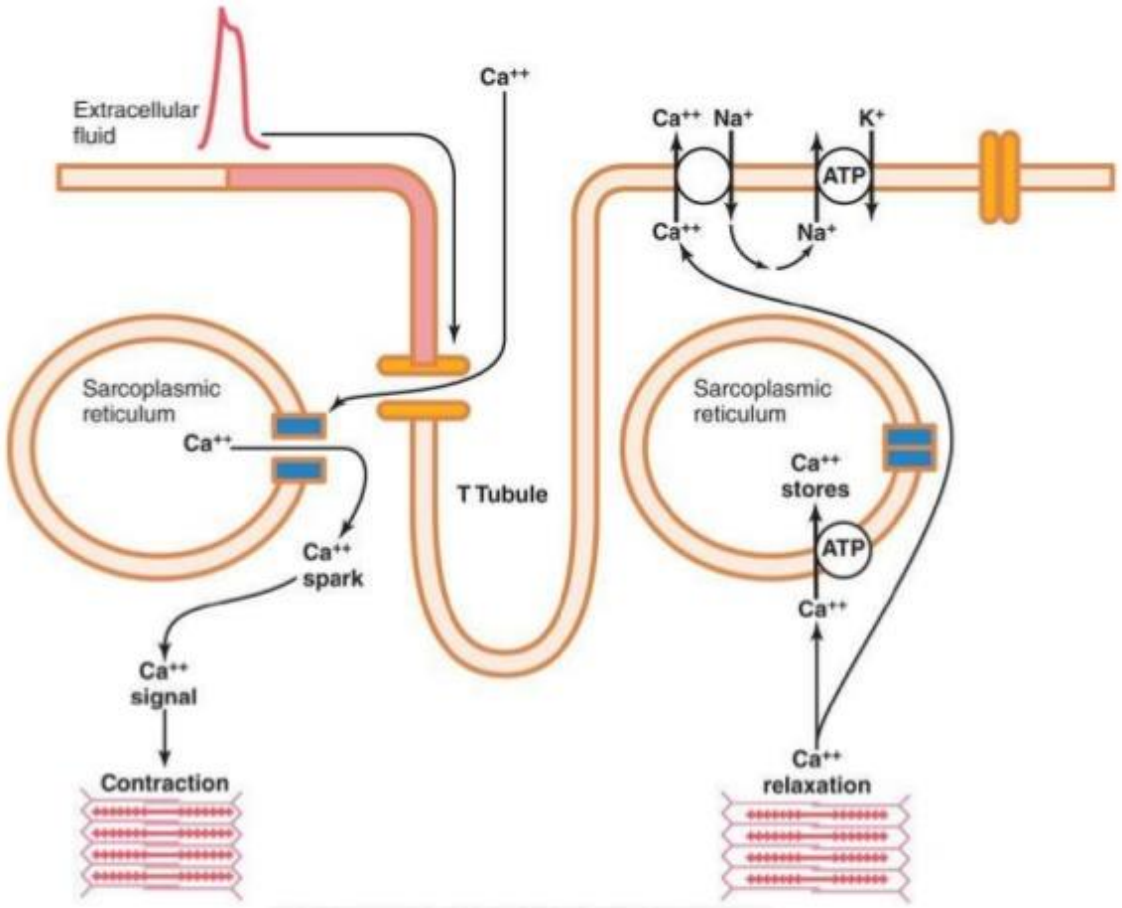


The cardiac muscle stores much more calcium in its tubular system than skeletal muscle and is much more dependent on extracellular calcium than the skeletal muscle.

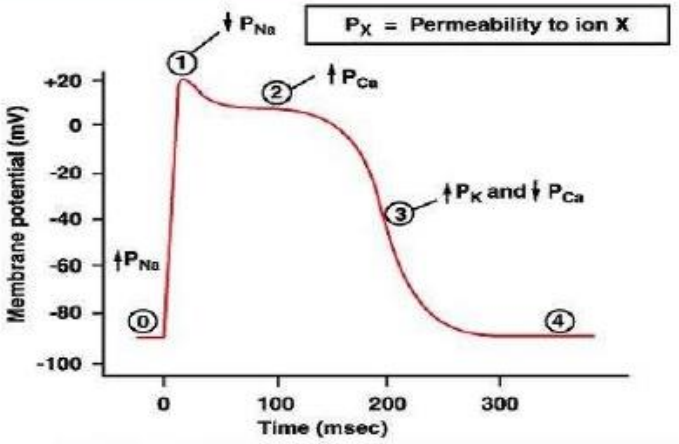
An abundance of calcium is bound by the mucopolysaccha -rides inside the T-tubule.

This calcium is necessary for contraction of cardiac muscle, and its strength of contraction depends on the calcium concentration surrounding the cardiac myocytes.

At the initiation of the action potential, the fast sodium channels open first, followed later by the opening of the slow calcium channels.


Extracellular fluid
Ca++
Ca++ Na+ K+
ATP
Ca++
Na+
Sarcoplasmic reticulum
Ca++
T Tubule
Ca++ spark
Ca++ signal
Contraction
Sarcoplasmic reticulum
Ca++ stores
ATP
Ca++
Ca++ relaxation

Ventricular Action Potential



Phase	Membrane channels
⓪	Na^+ channels open
①	Na^+ channels close
②	Ca^{2+} channels open
③	Ca^{2+} channels close; K^+ channels open
④	Resting potential