CARDIOVASCULAR SYSTEM:

Properties of cardiac muscle

- DR. SHAISTA SAIYAD

(MD, Ph.D., ACME, FAIMER)

PROPERTIES OF CARDIAC MUSCLE:

* CONDUCTIVITY (DROMOTROPIC PROPERTY)
* EXCITABILITY (BATHMOTROPIC PROPERTY)
* AUTORHYTHMICITY (CHRONOTROPIC PROPERTY)
* CONTRACTILITY (IONOTROPIC PROPERTY)
* LONG REFRACTORY PERIOD(NO TETANUS/FATIGUE)
* FUNCTIONAL SYNCYTIUM
* DISTENSIBILITY
* EXTRASYSTOLE AND COMPENSATORY PAUSE
* ALL OR NONE LAW
* STAIRCASE EFFECT (TREPPE)
* SUMMATION
* EFFECT OF PRELOAD (FRANK STARLING LAW)
* EFFECT OF AFTERLOAD

- AUTORHYTHMICITY (CHRONOTROPIC PROPERTY)

- SLOW RESPONSE TYPE: SAN, AVN, PURKINJEE FIBERS

ACTION POTENTIAL IN HEART

- FAST RESPONSE TYPE: ATRIAL AND VENTRICULAR MUSCLE
- SLOW RESPONSE TYPE: SAN, AVN, PURKINJEE FIBERS

SLOW TYPE RESPONSE : SAN

- PHASE 4: (SLOW DIASTOLIC DEPOLARISATION, PREPOTENTIAL, PACEMAKER POTENTIAL): CLOSURE OF K+ CHANNELS,

  LEAKY Na+ CHANNELS

  OPENING OF TRANSIENT Ca++ CHANNELS.
- PHASE 0: (DEPOLARISATION): OPENING OF 'LONG ACTING L-TYPE Ca++ CHANNELS'
- PHASE 3: (REPOLARISATION) :CLOSURE OF Ca++ AND OPENING OF K+ CHANNELS

* RECHARGING: Ca++ Na+ EXCHANGER, Na K+ ATPase PUMP.

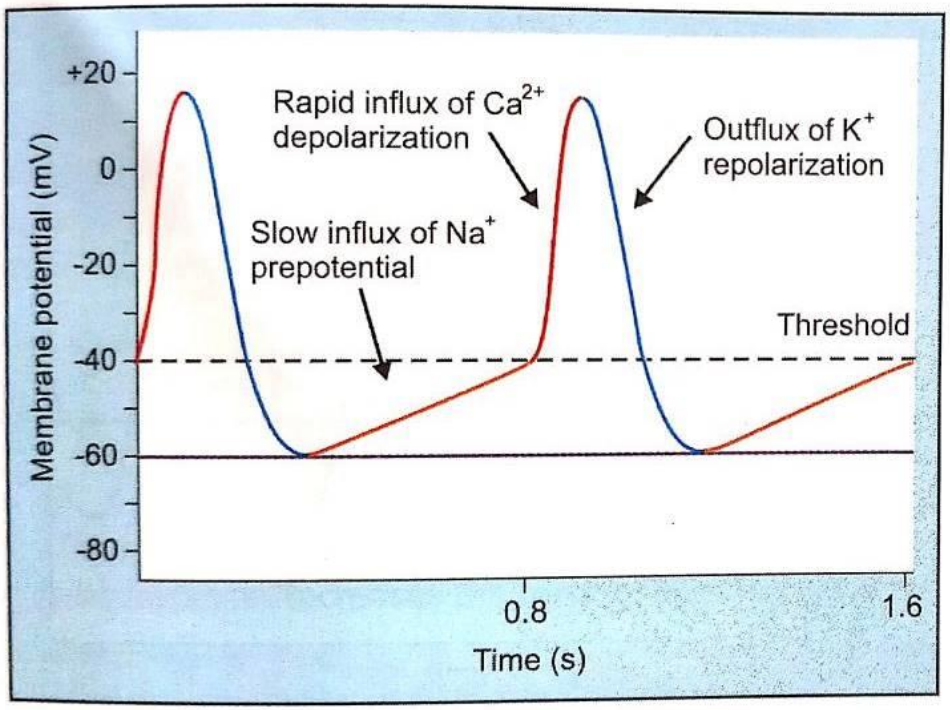

Fig. 87.3: Slow response action potentials in cardiac tissues (from SA node and AV node).

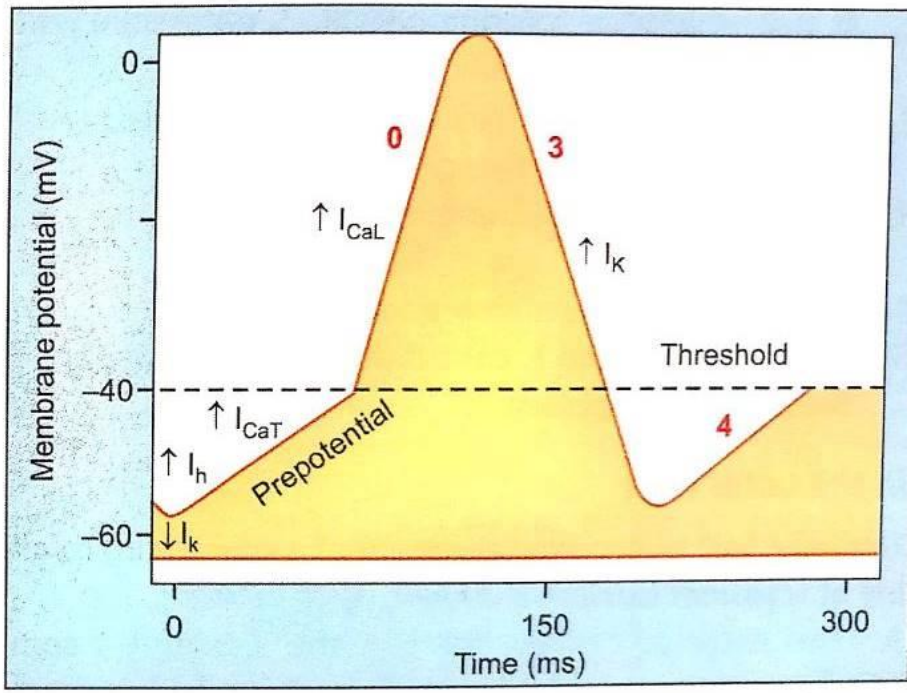

Fig. 87.4: Slow response action potential recorded from SA node. Phase 0: Phase of depolarization; Phase 3: Phase of repolarization; and Phase 4: Phase of slow depolarization to threshold.

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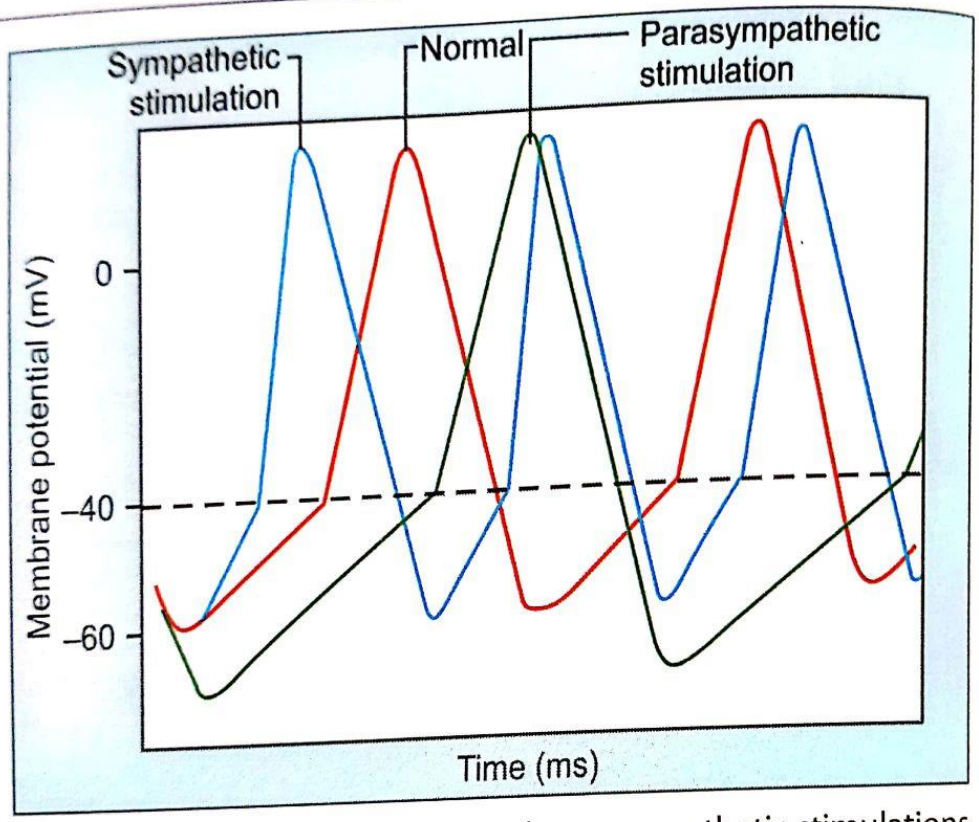

Fig. 87.5: Effects of sympathetic and parasympathetic stimulations on pacemaker potential. These effects on heart rate are mainly due to their influence on the slope of pacemaker potential. Note that sympathetic stimulation increases heart rate by rapidly raising the pacemaker potential so that the slope of prepotential reaches threshold earlier. Parasympathetic stimulation decreases heart rate by slowly raising the pacemaker potential so that slope of prepotential reaches threshold later. Also, parasympathetic stimulation causes hyperpolarization (makes the membrane potential more negative) so that prepotential takes more time to reach threshold from a more negative value. Also note, in the same time scale, the normal discharge pattern of SA node had produced two action potentials, whereas sympathetic stimulation resulted in three and parasympathetic stimulation produced only one action potential.

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- EXCITABILITY

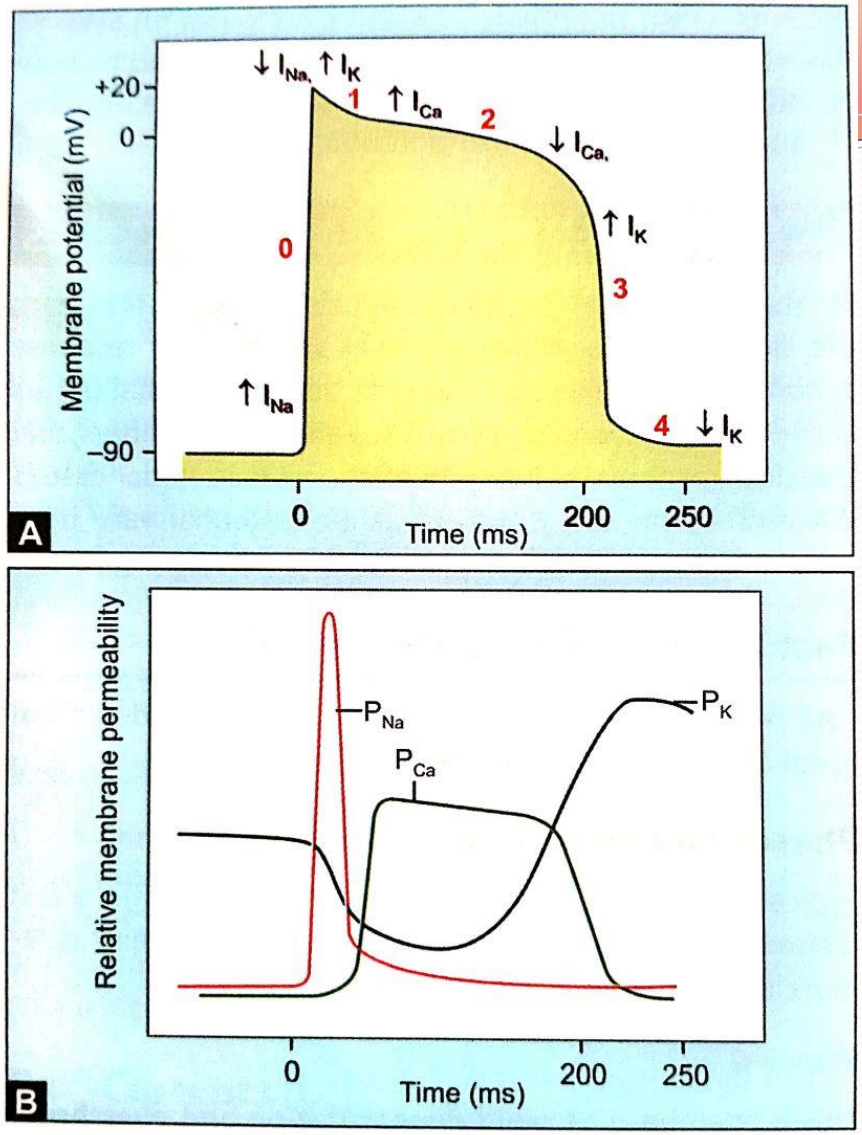
(BATHMOTROPIC PROPERTY)

FAST RESPONSE TYPE: ATRIAL AND VENTRICULAR MUSCLE

FAST RESPONSE TYPE

- PHASE 0: OPENING OF VOLTAGE GATED Na+ AND Ca++ CHANNELS, AUTOACTIVATION
- PHASE 1: CLOSURE OF Ca++, Na+ CHANNELS,

  OPENING OF 'OUTWARD TRANSIENT RECTIFYING K+ CHANNELS'
- PHASE 2 (PLATEAU): OPENING OF VOLTAGE GATED Ca++ CHANNELS, EFFLUX OF K+
- PHASE 3: CLOSURE OF Ca++ CHANNELS, OPENING OF 'OUTWARD DELAYED RECTIFYING K+ CHANNELS'
- PHASE 4 : OPENING OF INWARD RECTIFYING K+ CHANNELS, Na-K+ PUMP



Figs. 87.2A and B: Fast response action potential recorded from ventricular muscle fiber (A), and membrane permeability to different ions during various phases of the action potential (B). Phase 0: Phase of rapid depolarization and overshoot; Phase 1: Phase of initial rapid repolarization; Phase 2: Plateau phase; Phase 3: Phase of final repolarization; Phase 4: Phase of restoration of membrane potential; PNa: permeability to sodium; PCa: permeability to calcium; and PK: permeability to potassium.

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IONIC CURRENTS IN CARDIAC TISSUES

DUE TO PRESENCE OF VARIOUS ION CHANNELS.

1) Na+ CURRENT:

+nt IN CARDIAC MUSCLE, PURKINJEE FIBERS

-nt IN SANode AND AVNode

VOLTAGE GATED FAST Na+ CHANNELS: DEPOLARISATION

OUTER GATE: ACTIVATION GATE

INNER GATE: INACTIVATION GATE

2) Ca++ CURRENT

- 2 TYPES OF Ca++ CHANNELS:

1. L-TYPE (LONG LASTING) VOLTAGE GATED Ca++ CHANNELS

IN PACEMAKER TISSUES: UPSTROKE OR DEPOLARISATION OF AP

IN CARDIAC MUSCLE: SUSTAINED DEPOLARISATION-PLATEAU PHASE

Ca++ CHANNEL BLOCKERS (VERAPAMIL, NIFEDIPINE) : BLOCK L-TYPE Ca++ CHANNELS

2. T-TYPE (TRANSIENT) VOLTAGE GATED Ca++ CHANNELS

+nt ONLY IN SANode AND AVNode

RESPONSIBLE FOR LATER PART OF PREPOTENTIAL

3) K+ CURRENT

- 2 TYPES:
- VOLTAGE GATED

1. INWARD RECTIFYING K+ CHANNELS
2. OUTWARD TRANSIENT RECTIFYING K+ CHANNELS
3. OUTWARD DELAYED RECTIFYING K+ CHANNELS

- LIGAND GATED:

1. G- PROTEIN ACTIVATED
2. Ca++ ACTIVATED
3. Na+ ACTIVATED
4. ARACHIDONIC ACID ACTIVATED
5. ATP SENSITIVE

K+ CHANNELS

1. INWARD RECTIFYING K+ CHANNELS

MAINTAIN RMP IN PHASE 4.

2. OUTWARD TRANSIENT RECTIFYING K+ CHANNELS

+ nt IN ATRIAL AND VENTRICULAR MUSCLE CELLS

* PHASE 1 OF REPOLARISATION

3. OUTWARD DELAYED RECTIFYING K+ CHANNELS

+ nt IN ATRIAL AND VENTRICULAR MUSCLE CELLS

* PHASE 3 OF REPOLARISATION

- CONTRIBUTES TO PACEMAKER POTENTIAL BY CLOSING EARLY IN PHASE 4

4. G- PROTEIN ACTIVATED K+ CHANNELS

- ACTIVATED BY ACETYLCHOLINE
- HYPERPOLAISES THE SANode AND AVNode DURING PHASE 4

Pacemaker cells(or P cells)

- small, round cells, with few organelles, abundant cytoplasm rich in glycogen & mitochondria.
- highly vascular

- embryonal cardiac muscle cells

- Concerned with initiation & propagation of impulse
- At SA node, AV node, AV bundle, Purkinje fibers
- More embryonal in character ,less striations so feebly contract.
- Rate of rhythmical discharge of SA node is faster compared to other parts so acts as pace maker of normal heart.
- Show rhythmicity & varying rates of conduction

4) PACEMAKER CURRENT

- FOUND IN SANode AND AVNode
- NON SPECIFIC CATION CHANNEL CALLED:

  HCN CHANNELS: HYPERPOLARIZATION ACTIVATED CYCLIC NUCLEOTIDE GATED CHANNELS

  CONDUCT BOTH K+ AND Na+.

PRODUCE INWARD DEPOLARISING CURRENT: SLOWLY ACTIVATED AT END OF PHASE 3

CONTRIBUTES (VERY LESS) TO PACEMAKER POTENTIAL

Table 87.1: Major membrane currents in cardiac tissues.

Current	Type of channels involved	Functions
I_{Na}	Voltage-gated Na^+ channel	Produces Phase 0 of fast response action potential (FRAP)
I_{CaL}	L-type Ca^{2+} channel Produces	Phase 2 of FRAP
		Produces Phase 0 of slow response action potential (SRAP)
I_{CaT}	T-type Ca^{2+} channel	Contributes to later part of pacemaker potential
I_{Kr}	Inward rectifying K^+ channels	Maintains RMP (phase 4) of cardiac muscle cells
I_{TO}	Outward transient rectifying K^+ channels	Contributes partially to phase 1 of FRAP
I_{Ks}	Outward delayed rectifying K^+ channels	Produces Phase 3 of FRAP Produces Phase 3 of SRAP
		Contributes to early part of prepotential by its closure
I_{KG}	G protein activated K^+ channels	Hyperpolarization of membrane in phase 4 of FRAP and SRAP
I_{KATP}	ATP sensitive K^+ channels	Play role in electrically regulated contracting behaviur
I_f	Mixed cation channel for both Na^+ and K^+	Contributes to pacemaker potential

Note: FRAP occurs in atrial and ventricular muscles and Purkinje fibers, and SRAP occurs in SA and AV nodes.

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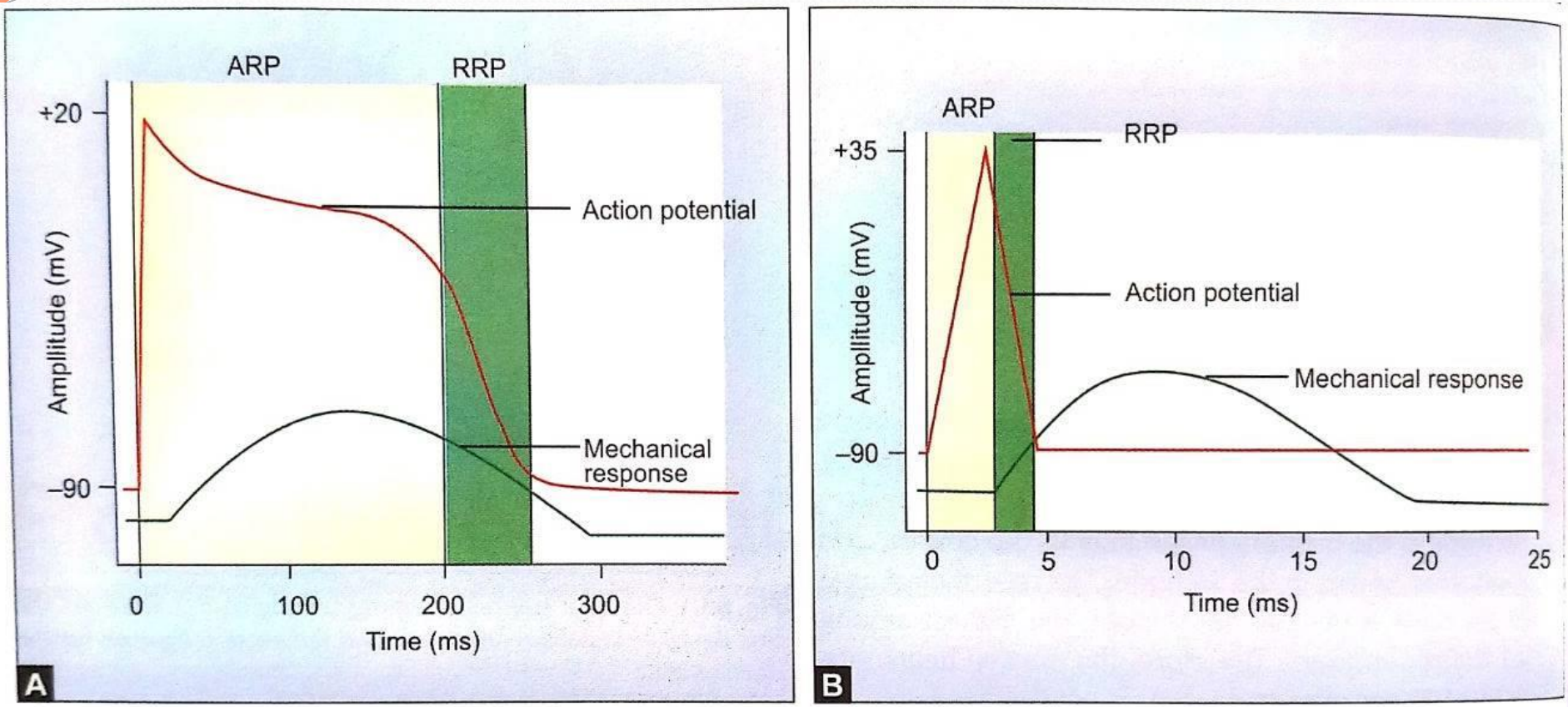

Figs. 86.2A and B: Relationship between electrical and mechanical responses in cardiac (A) and skeletal (B) muscles. Note, in cardiac muscle, due to long refractory period, a greater part of the mechanical response falls in the absolute refractory period (ARP) of the action potential, whereas in skeletal muscle, the mechanical response starts almost after the ARP. Therefore, skeletal muscle can be tetanized but not the cardiac muscle. (RRP: Relative refractory period).

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MYOCARDIUM

1) CARDIAC MUSCLE
2) PACEMAKER:
   SINO-ATRIAL NODE
3) CONDUCTING SYSTEM

* ATRIO-VENTRICULAR NODE

- AV BUNDLE(BUNDLE OF HIS)
- RIGHT & LEFT BUNDLE BRANCH
- PURKINJE FIBERS

ORIGIN AND SPREAD OF CARDIAC IMPULSE

CONDUCTING SYSTEM OF HEART

- CONDUCTIVITY (DROMOROPIC PROPERTY)

SPECIALISED EXCITATORY & CONDUCTING TISSUE

- SINO-ATRIAL NODE
- INTER-NODAL ATRIAL PATHWAYS:-

ANTERIOR INTERNODAL TRACT OF BACHMANN,
MIDDLE INTERNODAL TRACT OF WANCKEBACH,
POSTERIOR INTERNODAL TRACT OF THOREL

*** ANTERIOR ALSO CONNECTS SAN TO LEFT ATRIA**

- ATRIO-VENTRICULAR NODE
- AV BUNDLE(BUNDLE OF HIS)
- RIGHT & LEFT BUNDLE BRANCH
- PURKINJE FIBERS

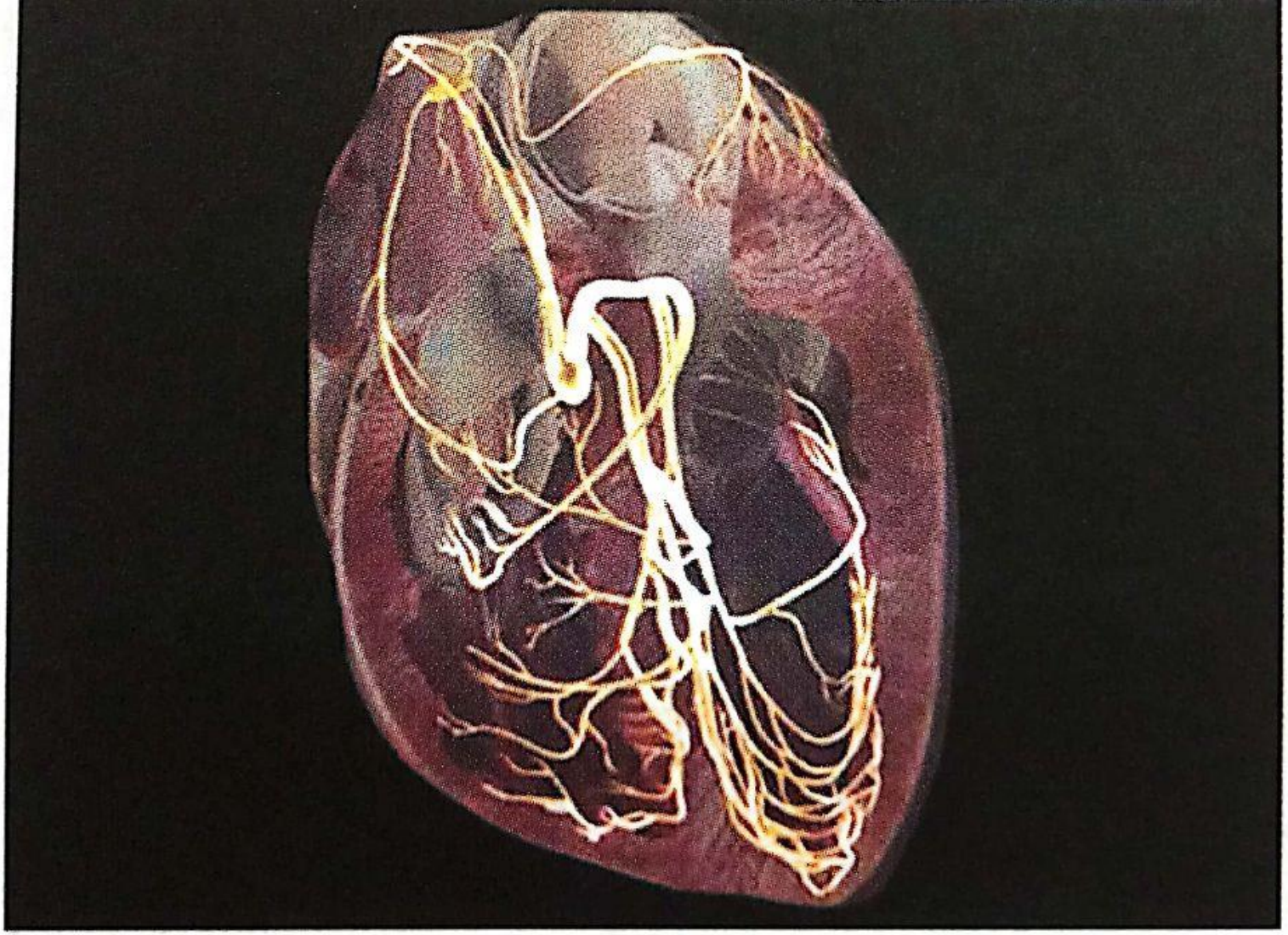

Fig. 85.10: Conducting system of the heart, as actually positioned in a human heart.

Courtesy: Figure 27.1, page 503, Color Atlas of Cardiovascular Disease, by Glenn N Levine, 1st edition, 2015; Jaypee Brothers Medical Publishers (P) Ltd.

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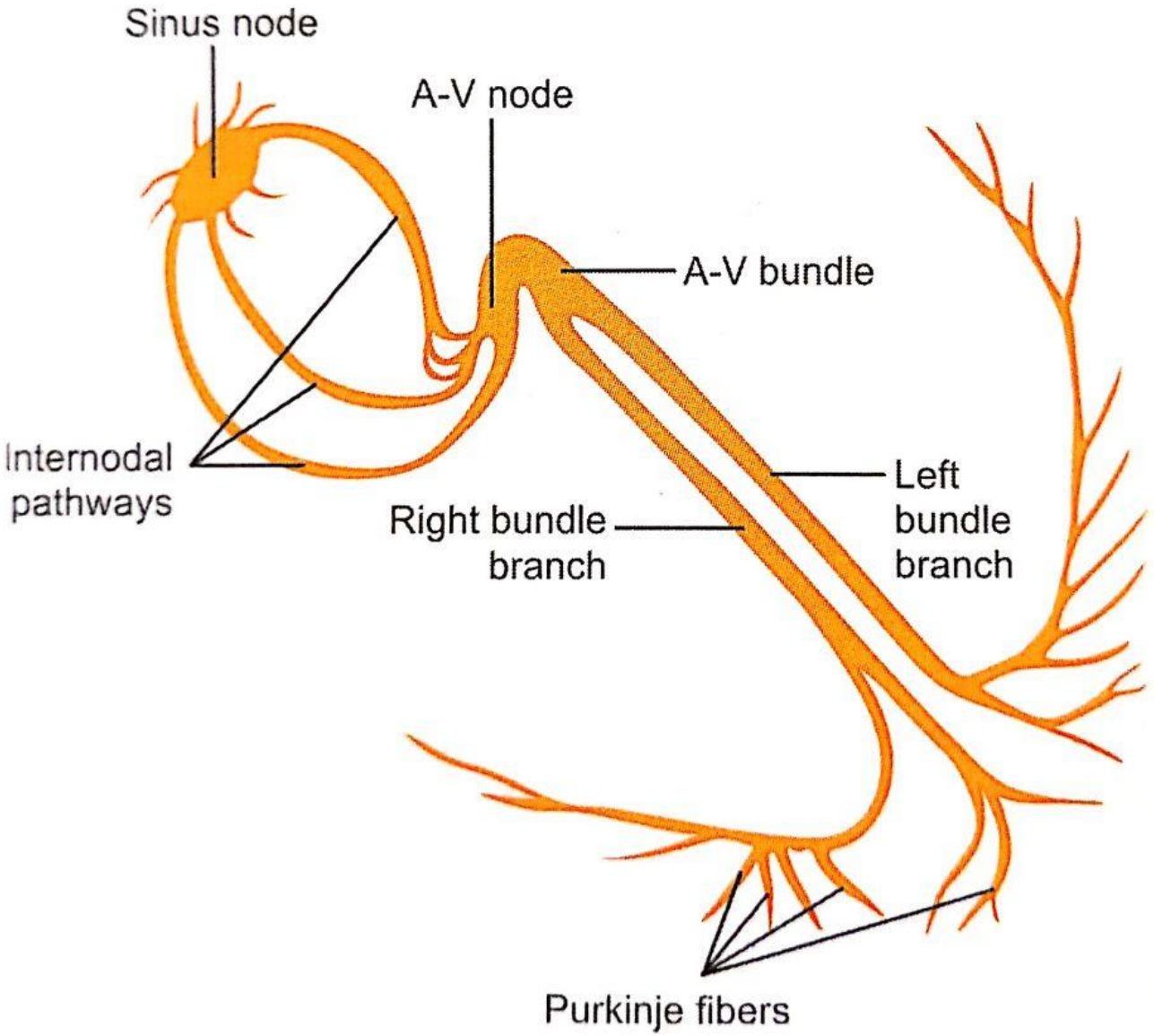

Fig. 85.11: Schematic mapping of conducting system of the heart. *Courtesy*: Figure 27.6A, page 506, Color Atlas of Cardiovascular Disease, by Glenn N Levine, 1st edition, 2015; Jaypee Brothers Medical Publishers (P) Ltd.

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CONDUCTION SPEED

- SA NODE:- .05m/SEC
- ATRIAL PATHWAYS :-1.0m/SECS
- AV NODE:-0.04 m/SEC
- BUNDLE OF HIS:-1m/SEC
- PURKINJEE SYSTEM:-4m/SEC
- VENTRICULAR MUSCLE:-1m/SEC
- ATRIAL MUSCLE:-1m/SEC

Table 85.2: Conduction velocity in cardiac tissues.

Tissue	Conduction velocity (m/s)
SA node	0.05
Internodal pathways	1
AV node	0.05
His bundle	1
Purkinje fibers	4
Ventricular muscle	1

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A V Nodal delay

- At AV node: delay of 0.09 second
- further delay in 'A V bundle': 0.04 second.
- Total delay is 0.13 second : A V Nodal delay.
- • Fibres connecting internodal tract and AV node: transitional fibres: very small fibres conducting the impulse at a very slow rate, i.e. 0.02 to 0.05 m/s.
- Velocity of impulse conduction in AV nodal fibres is also slow.
- AVNodal cells have a long refractory period.

- IMPORTANCE OF AV NODAL DELAY:
- Atria and ventricles are excited at different times and as a result, atria contract before ventricles.

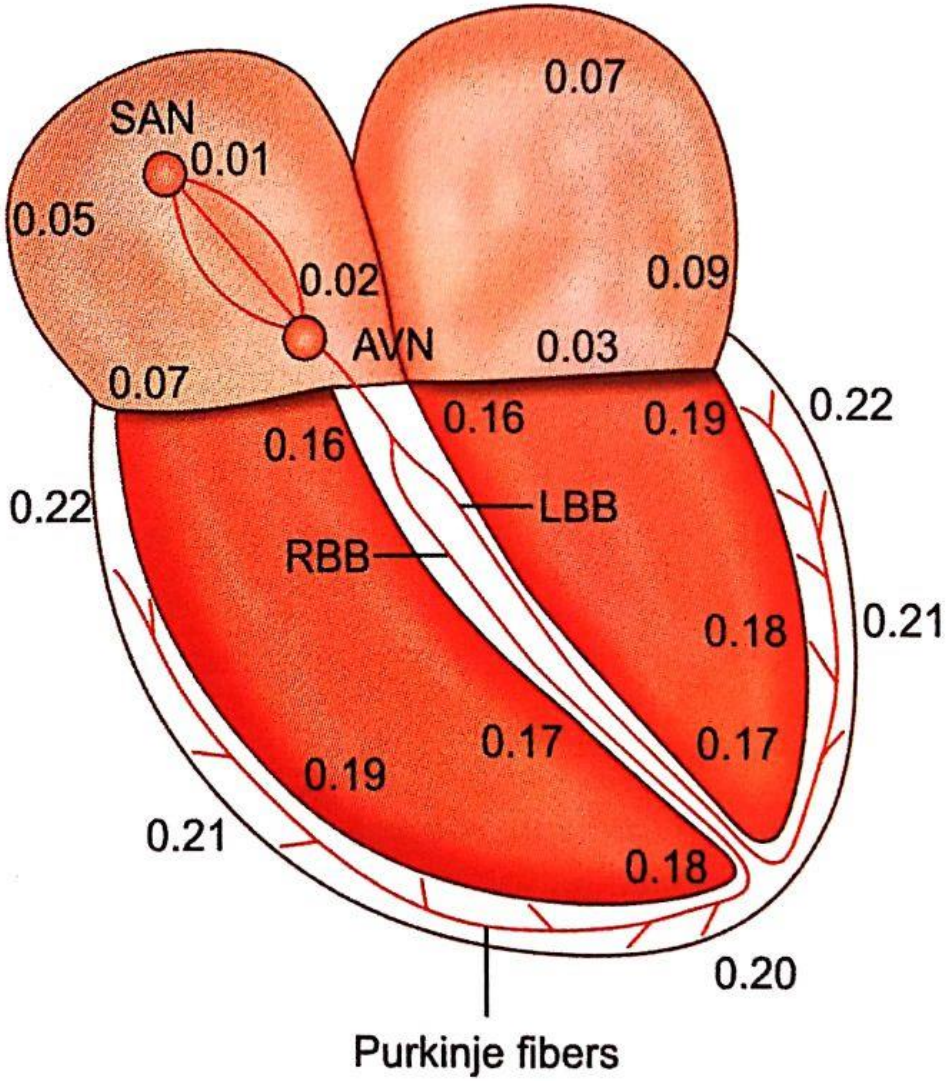

Fig. 87.7: Timing of excitation of different areas of heart by the impulse that originates from SA node (SAN), depicted in fraction of a second. (AVN: AV node; LBB: Left bundle branch; RBB: Right bundle branch). Note, last to be excited are posterobasal portion of left ventricle, pulmonary conus and uppermost portion of septum.

Tissue	Rate of impulse /min
SA node	72 (highest: that's why is pacemaker)
AV node	40-60
Bundle of His	40
Purkinje system	24
Ventricular & Atrial muscle	Only when diseased or injured

SPREAD OF WAVE OF DEPOLARIZATION AND REPOLARIZATION

First part in heart to get depolarized	atria
First part in ventricle to get depolarized	Inter ventricular septum from left to right
Next part in ventricle to get depolarized	Apex or anteroseptal part of V. myocardium (endo to epi)
Last part in ventricle to get depolarized	base of lt V., pulmonary conus, top of interventricular septa
First part in ventricle to get repolarized	apical epicardial surface

STANNIUS LIGATURE

- EXPERIMENTAL PREPARATION TO STUDY PROPERTIES OF CARDIAC MUSCLE
- IN FROG'S HEART
- 1ST: BETWEEN SINUS VENOSUS AND ATRIA: QUIESENT PREPARATION
- 2ND: BETWEEN ATRIA AND VENTRICLES (CRESCENT)

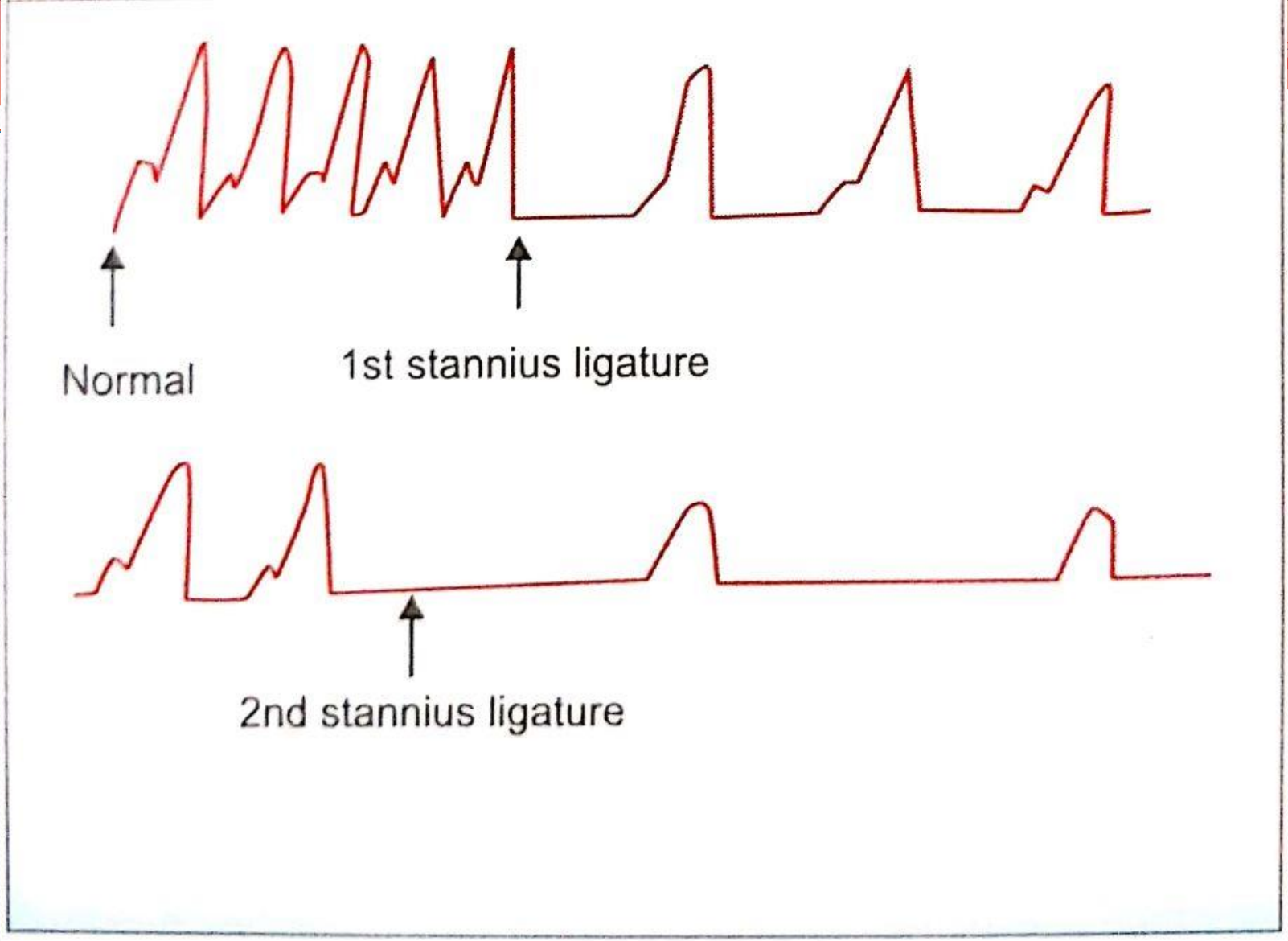

Fig. 86.1: Effects of Stannius ligatures on frog heart's activities. The first ligature decreases heart rate and the second ligature further decreases it.

CONTRACTILITY

- 'T' TUBULE AT 'Z' LINE. DIAD.
- Strength of cardiac muscle contraction depends to a great extent on calcium concentration in extracellular fluid.
- Calcium induced calcium release (CICR).
- Duration of contraction for atrial muscle is 0.1 second and for ventricular muscle is 0.3 second.

LONG REFRACTORY PERIOD

- **ABSOLUTELY REFRACTORY PERIOD**: DOES NOT SHOW ANY RESPONSE AT ALL.

  EXTENDS :PHASE 0 TO HALF OF PHASE 3 OF ACTION POTENTIAL. , 200ms.
- **RELATIVE REFRACTORY PERIOD**: SHOWS RESPONSE IF THE STRENGTH OF STIMULUS IS INCREASES TO MAXIMUM.

  EXTENDS : SECOND HALF OF PHASE 3 TO PHASE 4 OF ACTION POTENTIAL, 50ms.
- **CARDIAC MUSCLE CANNOT BE TETANIZED.**
- BY APPLYING 1ST STANNIUS LIGATURE

EXTRASYSTOLE AND COMPENSATORY PAUSE

- When a strong stimulus applied in relative refractory period (diastole) in an experimental recording of normal cardiogram, an extra contractile response occurs: extrasystole.

- The natural stimulus (from SAnode) falls in the refractory period of the extrasystole and does not evoke a response, therefore natural contraction is missed: long pause is seen following extrasystole. This pause is called as compensatory pause.

* Post extrasystolic potentiation (psp)

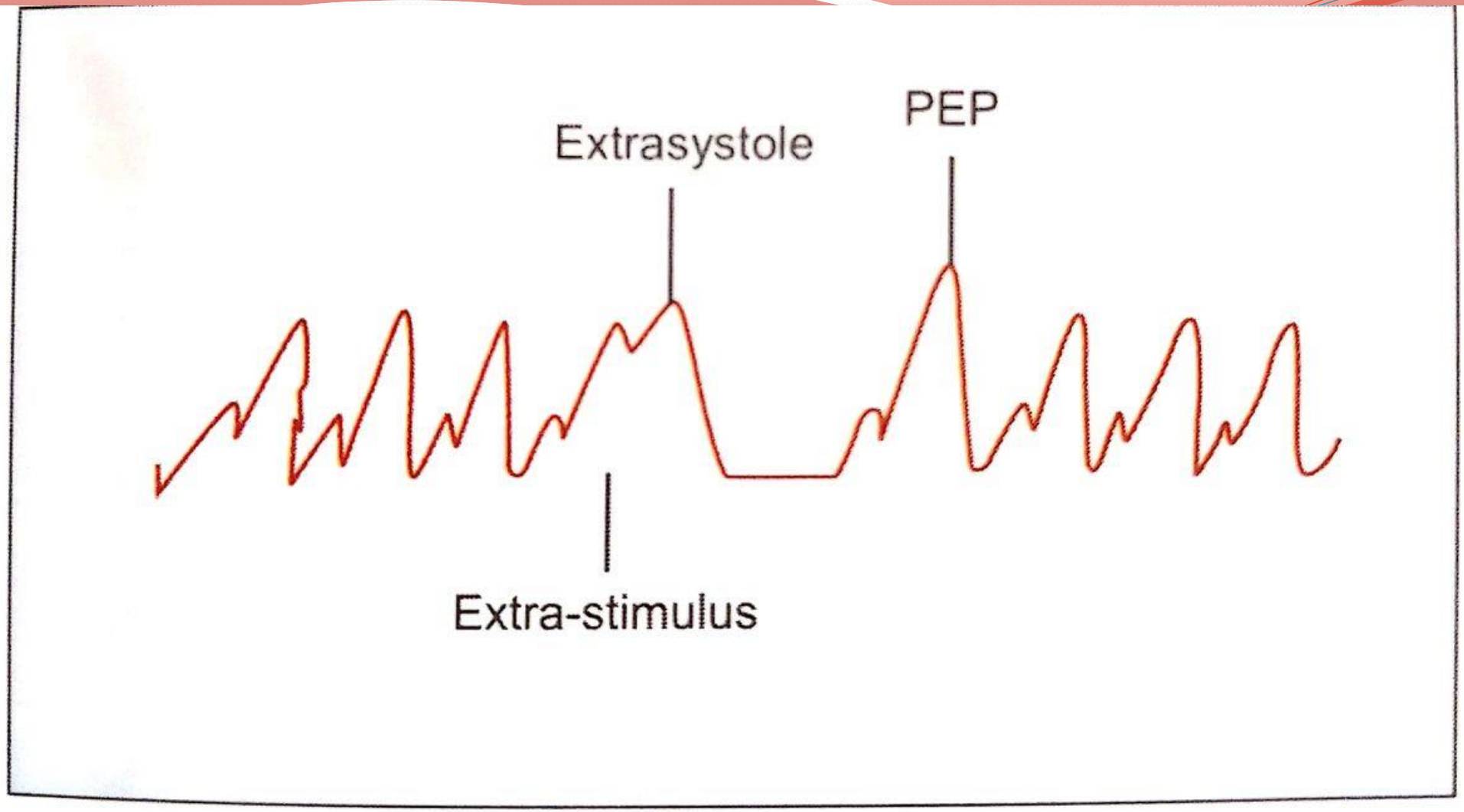

Fig. 86.3: Demonstration of extrasystole in a normal cardiogram of frog. (CP: Compensatory pause; PEP: Post-extrasystolic potentiation).

DISTENSIBILITY

Ability of cardiac muscle to stretch.

Due to compliance of the cardiac muscle.

Helps in filling of atrial and ventricular chambers.

Decreased ventricular distensibility decreases filling of ventricles.

FUNCTIONAL SYNCYTIUM

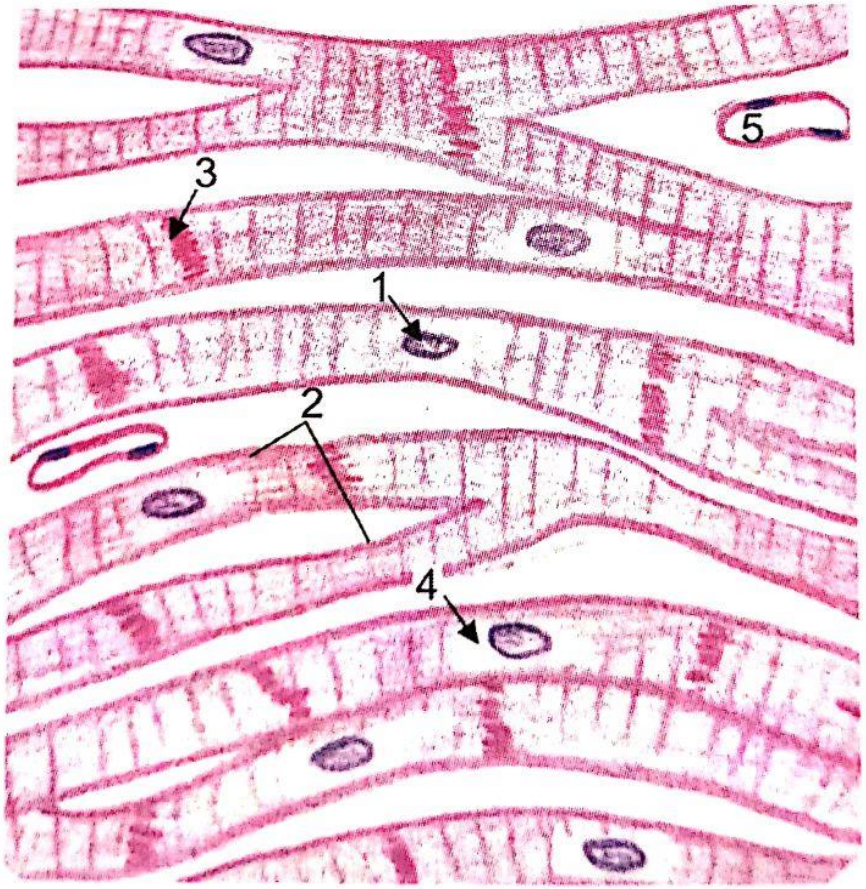

Fig. 85.7: Structure of cardiac muscle fiber. Note the branching pattern and the interacted discs. 1: Central nucleus; 2: Branching fibers; 3: Intercated discs; Perinuclear halo, 5: Capillary.

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ALL OR NONE LAW

- The magnitude of response of a tissue to stimuli remains same irrespective of strength of stimuli.

- If the tissue responds, it responds to its maximum or it does not respond at all.

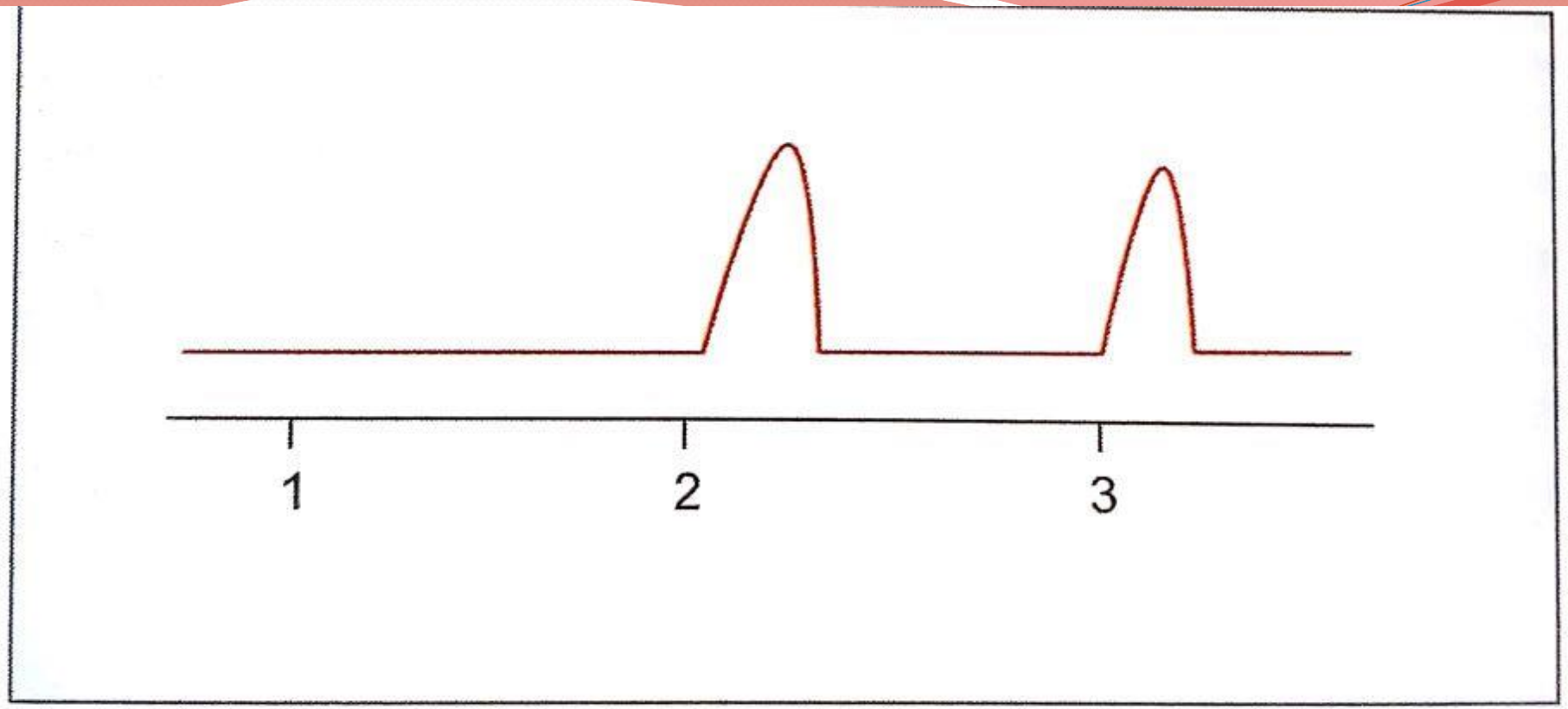

Fig. 86.4: Demonstration of all or none law in heart muscle of frog. (1) Subthreshold stimulus; (2) Threshold stimulus; (3) Suprathreshold stimulus. Note, subthreshold stimulus does not evoke a response and suprathreshold stimulus does not change the height of contraction.

STAIRCASE EFFECT (TREPPE)

- If the heart is stimulated repeatedly, keeping the interval between the stimuli less than 10 sec, the magnitude of first 3-4 contractions progressively increases.

- DUE TO BENEFICIAL EFFECT

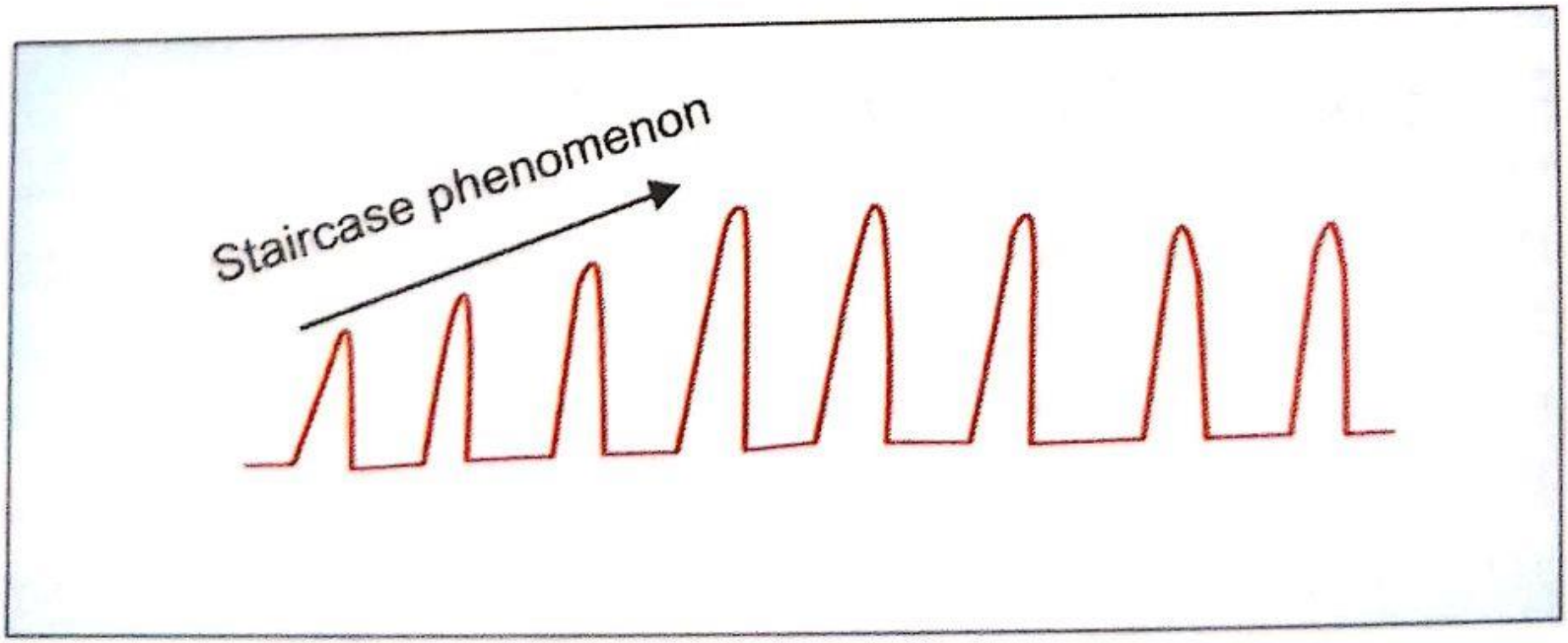

Fig. 86.5: Demonstration of staircase phenomenon in heart muscle of frog. Note, the gradual increase in the height of tracings for first four contractions, which then remains same for subsequent contractions.

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SUMMATION OF 2 SUBMINIMAL STIMULUS

- WHEN A SUBTHRESHOLD STIMULUS IS APPLIED TO A QUIESCENT HEART, THERE IS NO RESPONSE.
- BUT IF THE SUBTHRESHOLD STIMULI ARE APPLIED REPEATEDLY AT AN INTERVAL OF HALF SECOND :CONTRACTION OF HEART AFTER 10-12 STIMULI.
- THIS IS CALLED AS TEMPORAL SUMMATION OF SUBMINIMAL STIMULI.

PRELOAD: FRANK STARLING LAW

- "WITHIN PHYSIOLOGICAL LIMITS, THE FORCE OF CONTRACTION OF HEART (VENTRICLE) IS PROPORTIONAL TO ITS END DIASTOLIC VOLUME".
- GREATER THE END DIASTOLIC VOLUME, GREATER IS THE FORCE OF CONTRACTION OF VENTRICLES.
- CLINICAL APPLICATION OF THIS LAW IS IN CONTROL OF CARDIAC OUTPUT.

Scientist contributed

EH Starling
(1866–1927)

Ernest Henry Starling (1866–1927), was a great teacher and researcher in physiology, whose long career was marked by many contributions to the development in physiology. He studied the mechanism of lymph formation and described the mechanical factors for lymph production. He studied the osmotic effects of serum proteins on fluid movements along the capillaries, for which the mechanism of capillary filtration is popularly known as Starling hypothesis, and the factors are called ***Starling forces***. He studied the chemical regulation of pancreatic secretion. He described the principles of cardiac functions, especially the ***length–tension relationship of cardiac muscle***, which is popularly known as **Starling's law** or **Frank-Starling law of the heart**. He had also studied the factors determining the growth of mammary gland.

EFFECT OF AFTERLOAD

- AFTERLOAD :RESISTANCE OFFERED BY ARTERIES (BP) DURING EJECTION PHASE OF VENTRICLES.

  THE RESISTANCE OFFERED BY ARTERIOLES IN SYSTEMIC CIRCULATION IS CALLED AS PERIPHERAL RESISTANCE. ITS RELEVANCE IS MORE IN REGULATION OF CARDIAC OUTPUT AND BLOOD PRESSURE.

- CARDIAC MUSCLE CONTRACTION WITH AFTERLOAD ALSO OCCURS DURING ISOMETRIC CONTRACTION PHASE OF VENTRICULAR SYSTOLE.

- Vagal(parasympathetic) stimulation – flattens slope of prepotential – decrease the heart rate

- Sympathetic stimulation – makes the slope steep – increase the heart rate

THANK YOU