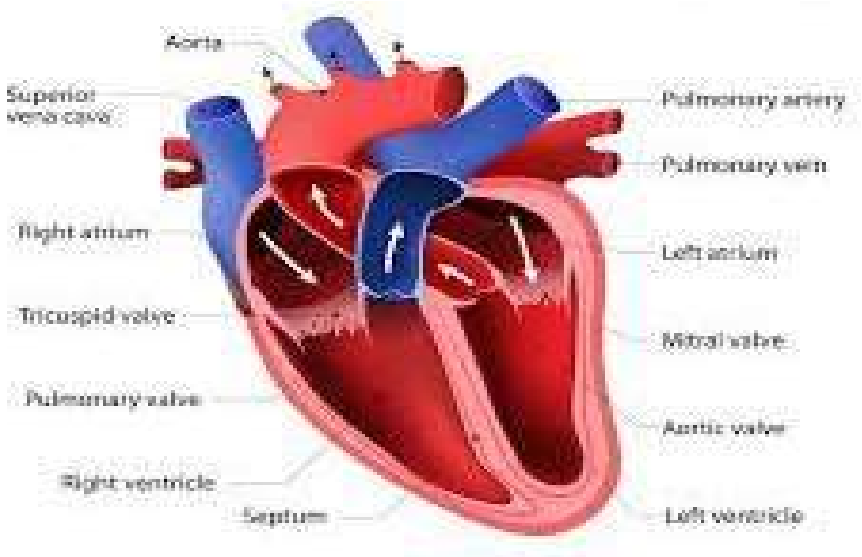
Department of Veterinary Physiology

MJF College of Veterinary & Animal Sciences,
Jaipur, Rajasthan- 303702

B.V.Sc. & A.H.

1st Year (2023-24)

Cardiovascular Physiology



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Lecture Outline

- **Cardiovascular System Function**
- Functional Anatomy of the Heart
- Myocardial Physiology
- 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
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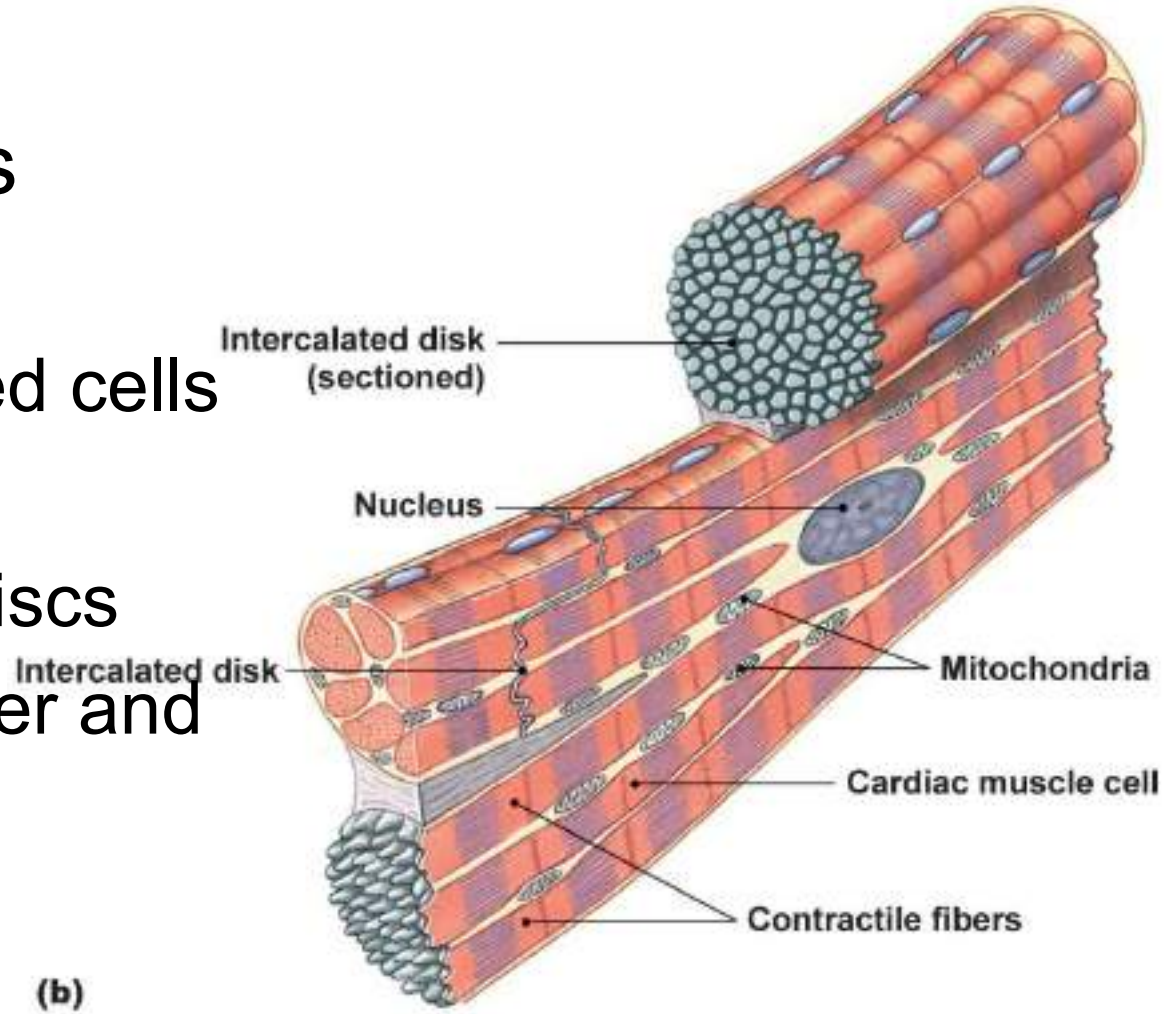
Functional Anatomy of the Heart

Cardiac Muscle

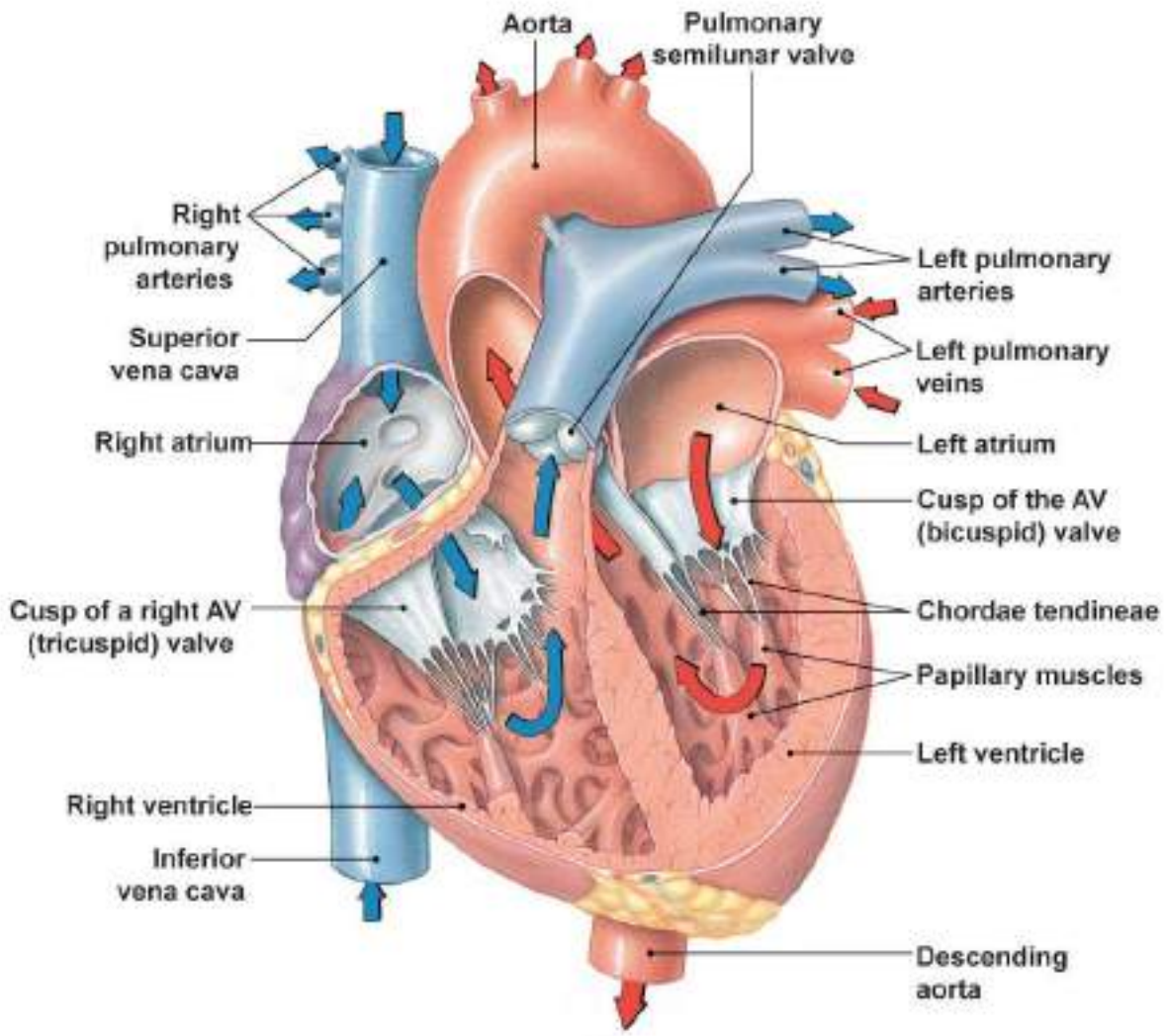
- Characteristics
  - Striated
  - Short branched cells
  - Uninucleate
  - Intercalated discs
  - T-tubules larger and over z-discs



Functional Anatomy of the Heart

Chambers

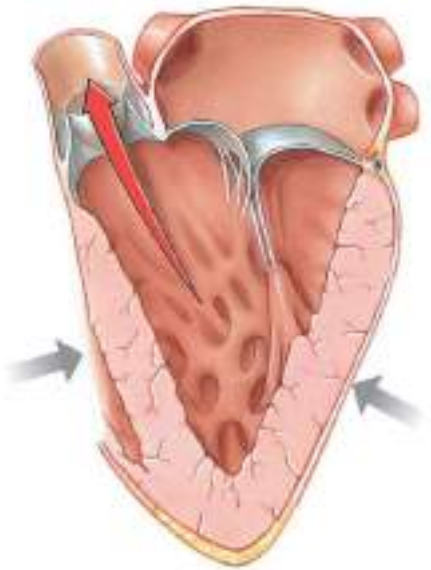
- 4 chambers
  - 2 Atria
  - 2 Ventricles
- 2 systems
  - Pulmonary
  - Systemic

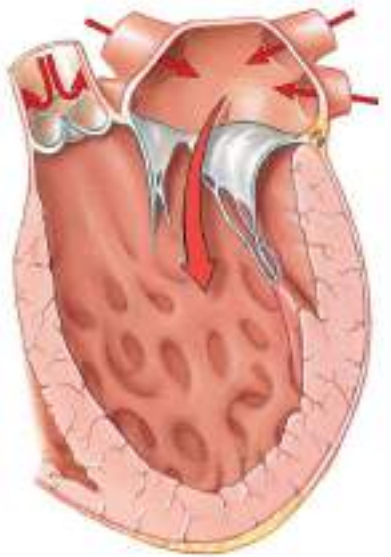


Functional Anatomy of the Heart

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

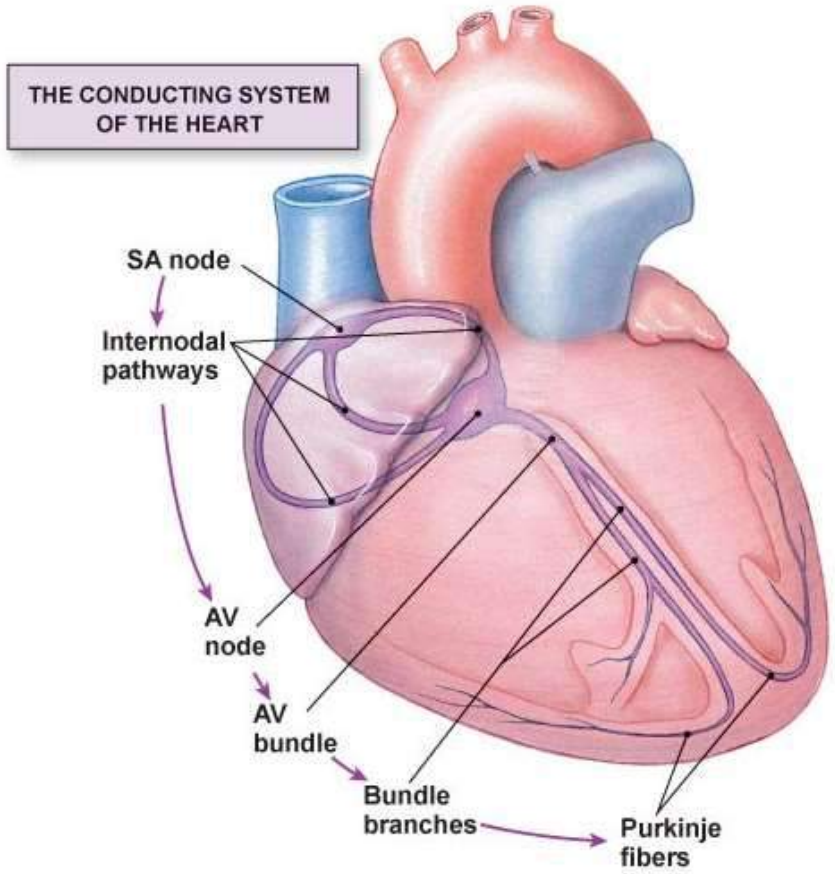




Functional Anatomy of the Heart

Intrinsic Conduction System

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



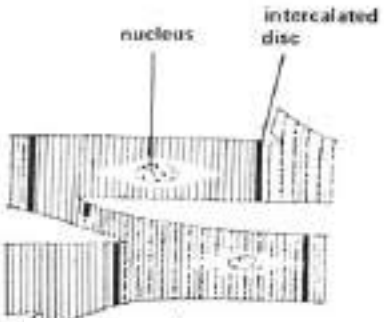
Lecture Outline

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

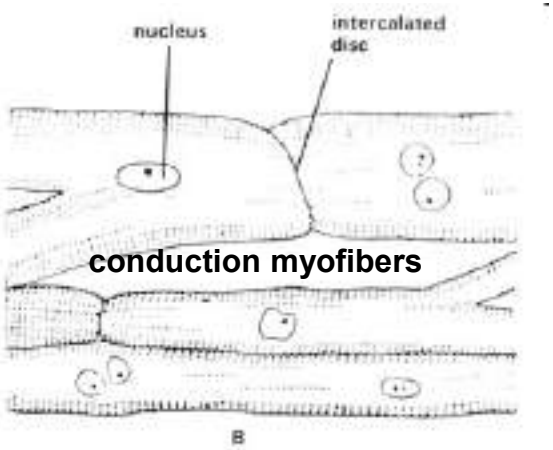
Myocardial Physiology

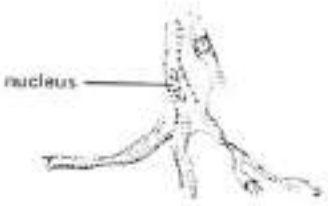
Autorhythmic Cells (Pacemaker Cells)

- 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

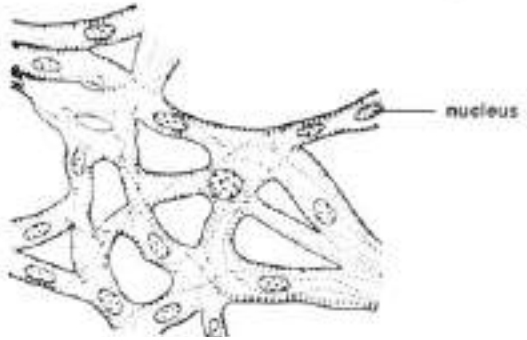


normal contractile myocardial cell





SA node cell



AV node cells

Myocardial Physiology

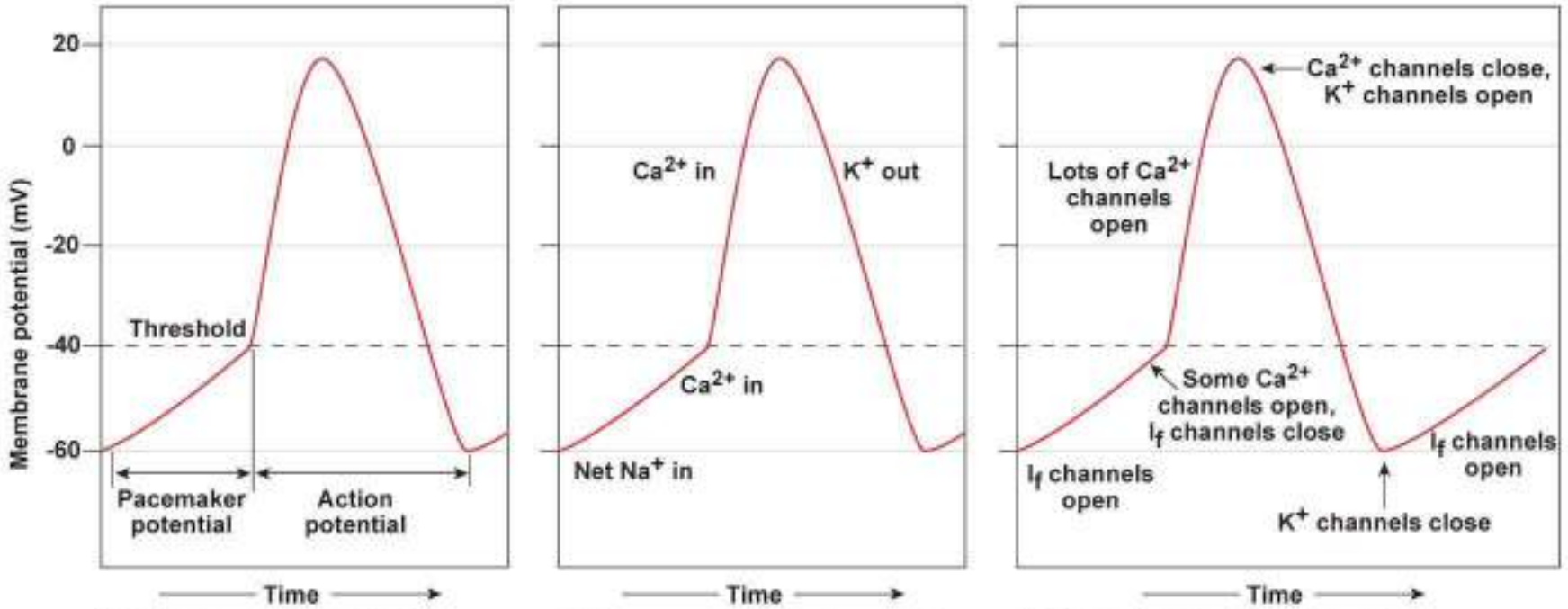
Autorhythmic Cells (Pacemaker Cells)

- 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



Myocardial Physiology

Autorhythmic Cells (Pacemaker Cells)

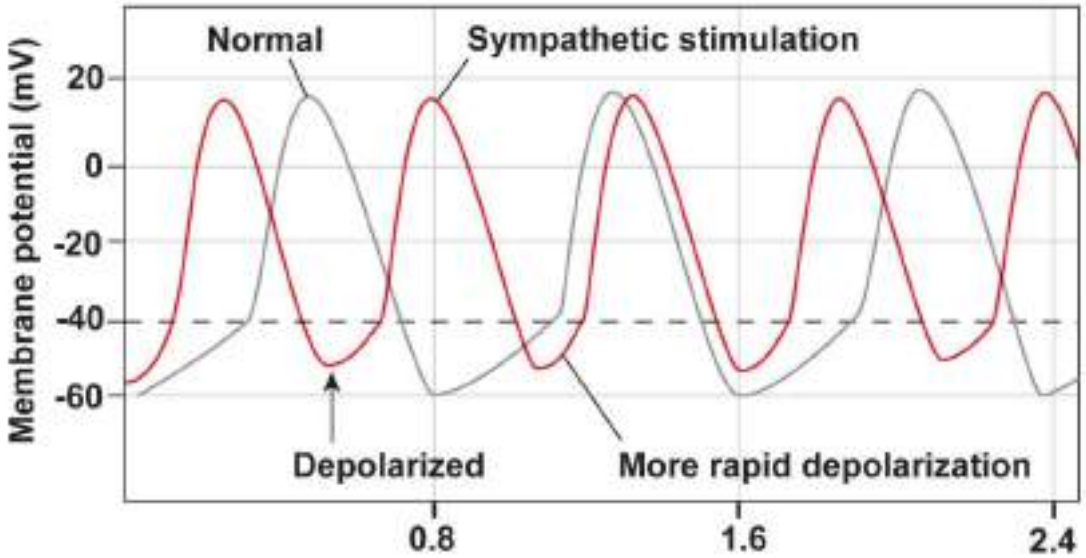
- Altering Activity of Pacemaker Cells
  - Sympathetic activity
    - NE and E increase I_f channel activity
      - Binds to β_1 adrenergic receptors which activate cAMP and increase I_f channel open time
      - Causes more rapid pacemaker potential and faster rate of action potentials

<u>Sympathetic Activity Summary:</u>

increased chronotropic effects
↑heart rate

increased dromotropic effects
↑conduction of APs

increased inotropic effects
↑contractility



Myocardial Physiology

Autorhythmic Cells (Pacemaker Cells)

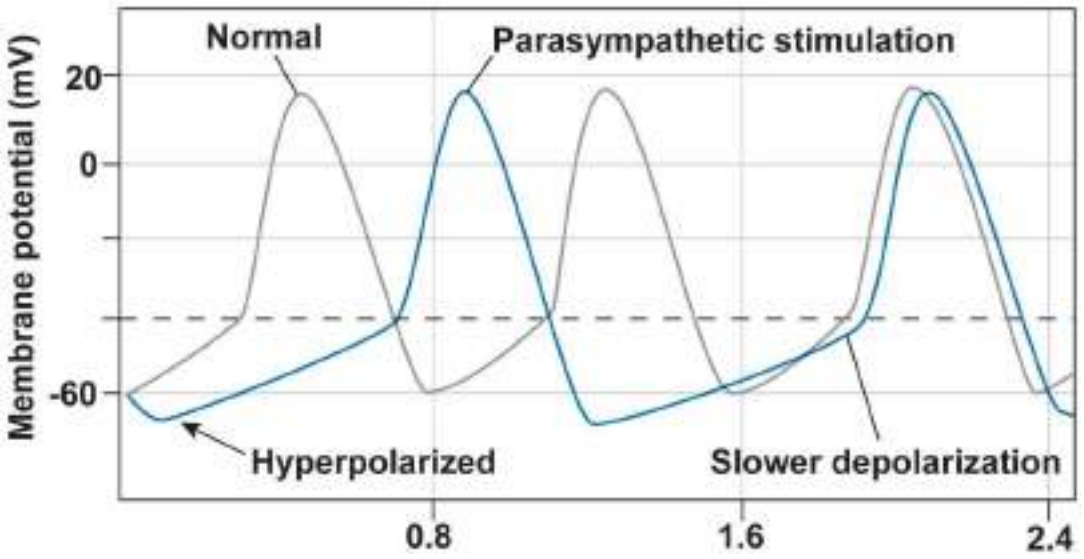
- Altering Activity of Pacemaker Cells
  - Parasympathetic activity
    - ACh binds to muscarinic receptors
      - Increases K^+ permeability and decreases Ca^{2+} permeability = hyperpolarizing the membrane
        - » Longer time to threshold = slower rate of action potentials

Parasympathetic Activity Summary:

decreased chronotropic effects
↓heart rate

decreased dromotropic effects
↓ conduction of APs

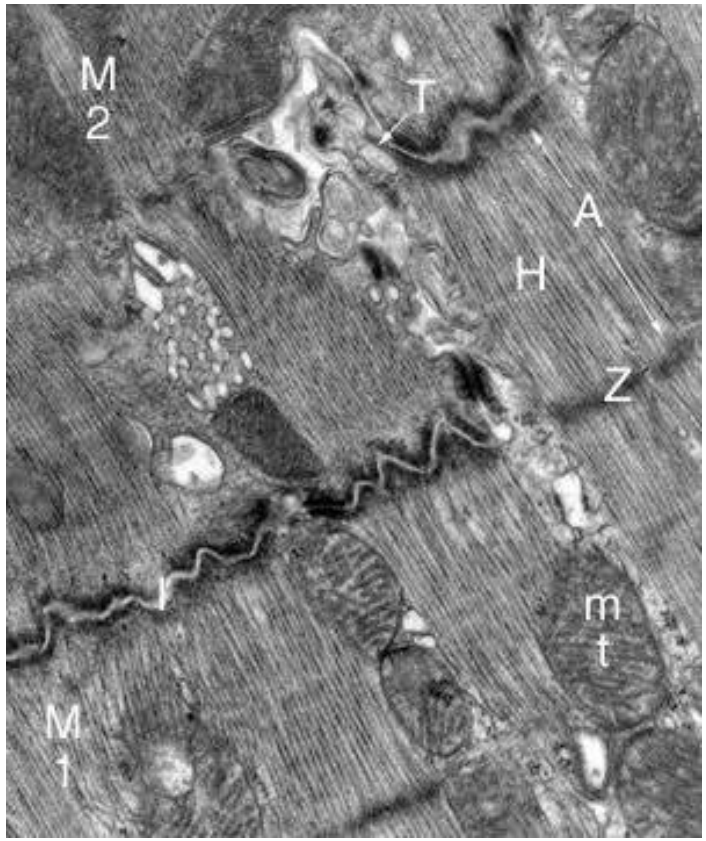
decreased inotropic effects
↓ contractility



Myocardial Physiology

Contractile Cells

- Special aspects
  - Intercalated discs
    - Highly convoluted and interdigitated junctions
      - Joint adjacent cells with
        - » Desmosomes & fascia adherens
      - Allow for synticial 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

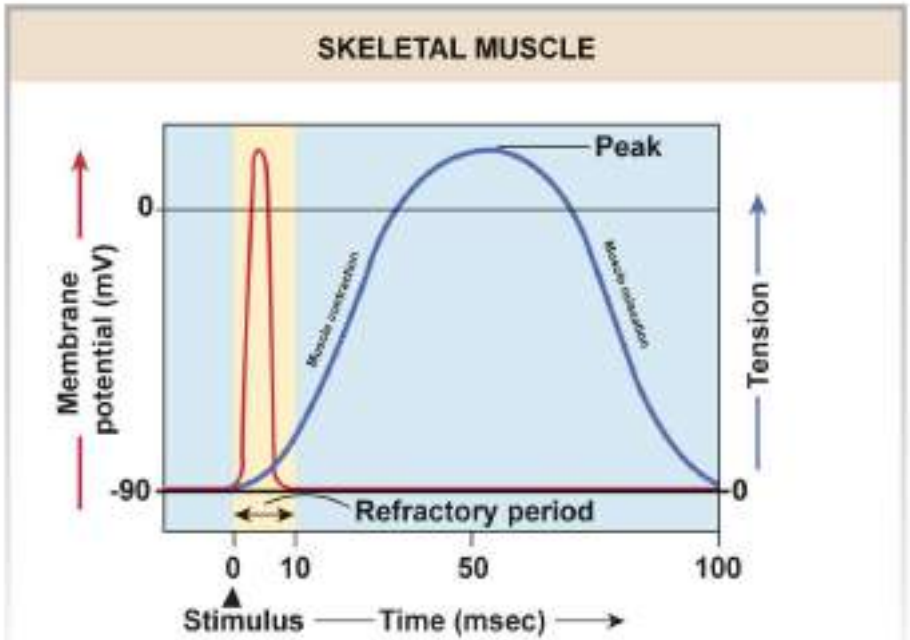
Contractile Cells

- 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?

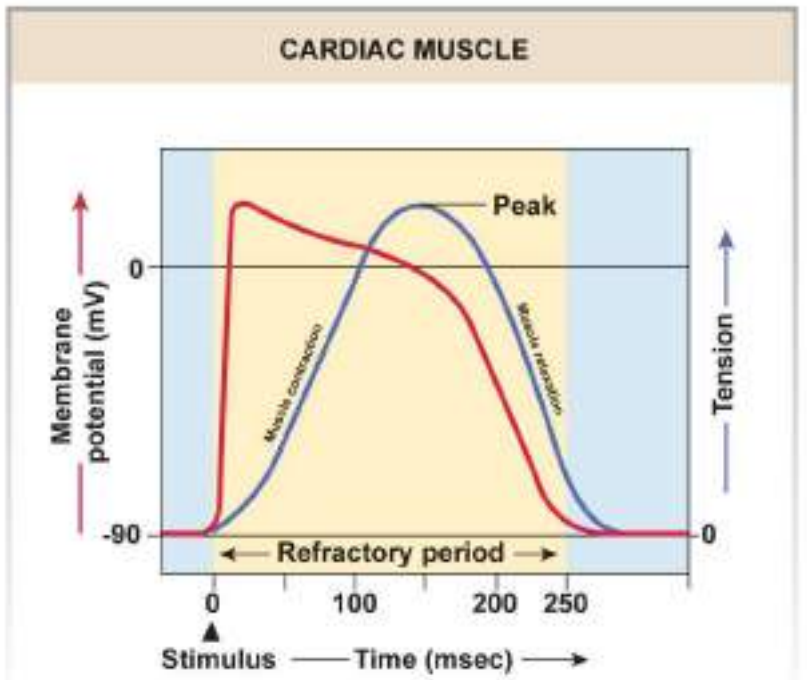
Myocardial Physiology

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.

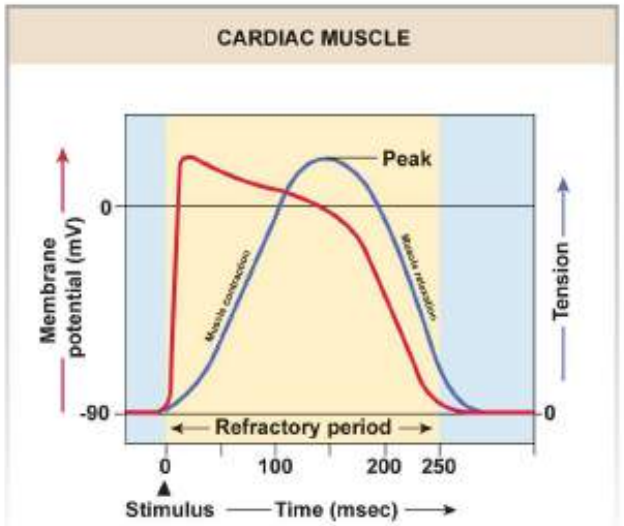


(c) **Cardiac muscle fiber:** The refractory period lasts almost as long as the entire muscle twitch.

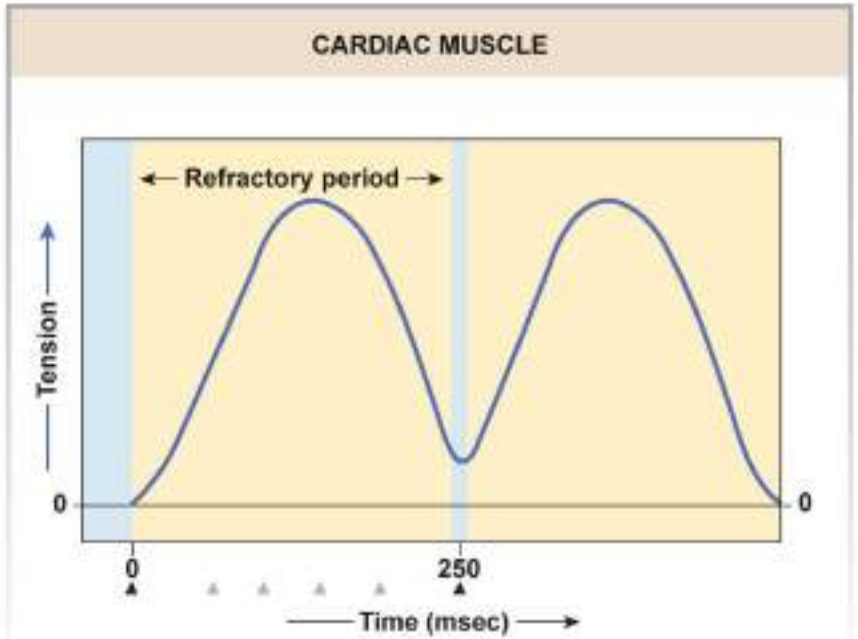
Myocardial Physiology

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

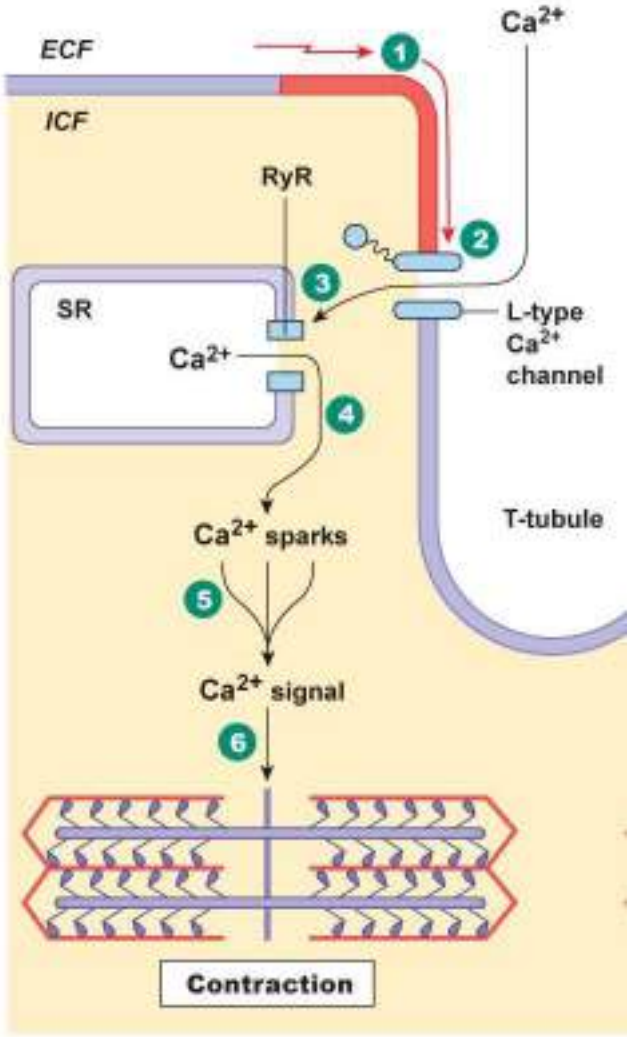
TABLE 14-3 Comparison of Action Potentials in Cardiac and Skeletal Muscle

	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

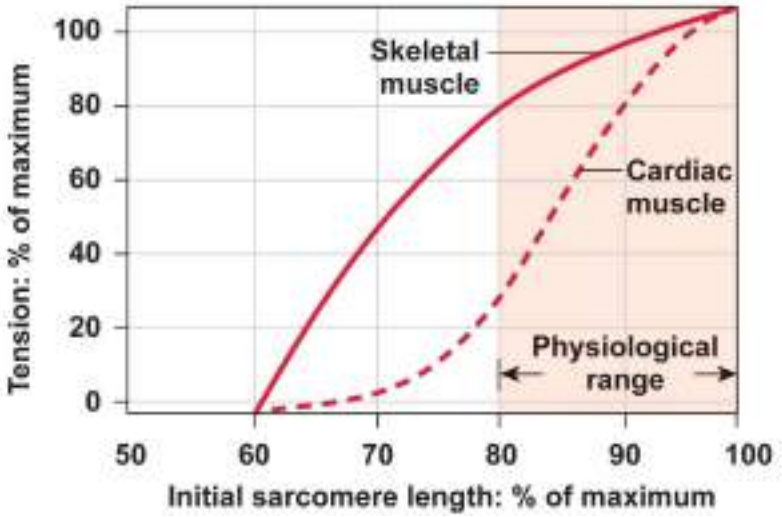


Spark Gif

Myocardial Physiology

Contractile Cells

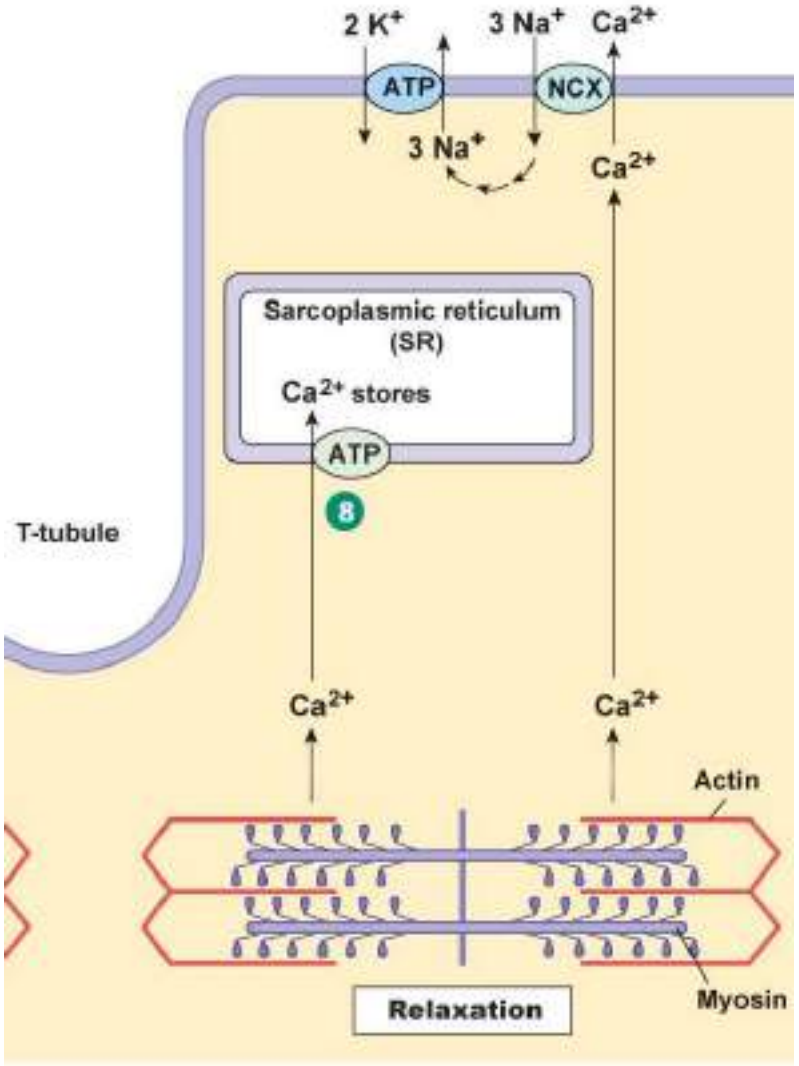
- Excitation-Contraction Coupling cont…
  2. Ca^{2+} signal (Ca^{2+} from SR and ECF) binds to troponin to initiate myosin head attachment to actin
- Contraction
  - Same as skeletal muscle, but…
  - Strength of contraction varies
    - Sarcomeres are not “all or none” as it is in skeletal muscle
      - 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



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

Cardiac Cycle

Coordinating the activity

- Cardiac cycle is the sequence of events as blood enters the atria, leaves the ventricles and then starts over
- Synchronizing this is the Intrinsic Electrical Conduction System
- Influencing the rate (chronotropy & dromotropy) is done by the sympathetic and parasympathetic divisions of the ANS

Cardiac Cycle

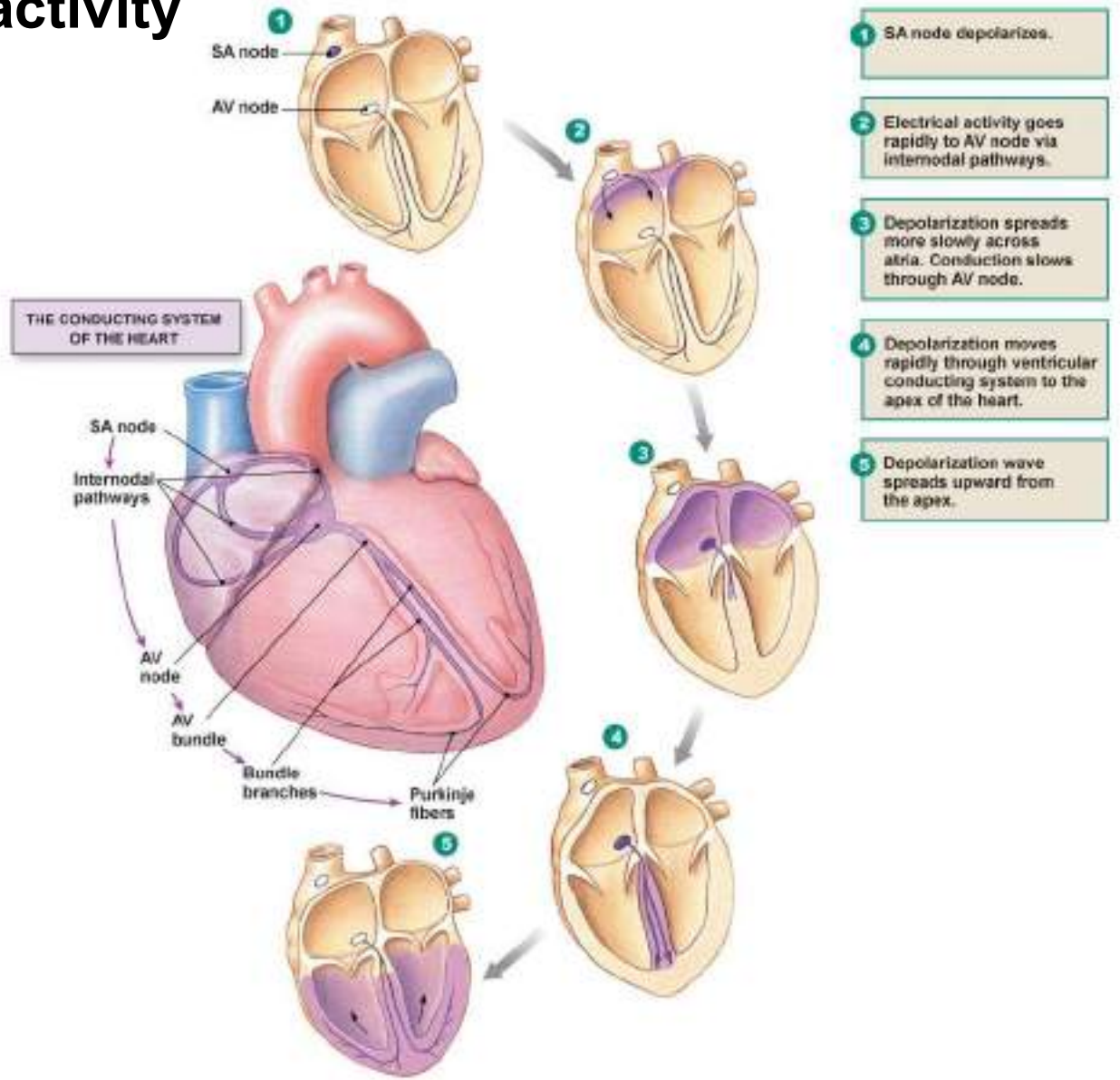
Coordinating the activity

- Electrical Conduction Pathway
  - Initiated by the Sino-Atrial node (SA node) which is myogenic at 70-80 action potentials/minute
  - Depolarization is spread through the atria via gap junctions and internodal pathways to the Atrio-Ventricular node (AV node)
    - The fibrous connective tissue matrix of the heart prevents further spread of APs to the ventricles
    - A slight delay at the AV node occurs
      - Due to slower formation of action potentials
      - Allows further emptying of the atria
  - Action potentials travel down the Atrioventricular bundle (Bundle of His) which splits into left and right atrioventricular bundles (bundle branches) and then into the conduction myofibers (Purkinje cells)
    - Purkinje cells are larger in diameter & conduct impulse very rapidly
      - Causes the cells at the apex to contract nearly simultaneously
        - » Good for ventricular ejection

Cardiac Cycle

Coordinating the activity

- Electrical Conduction Pathway

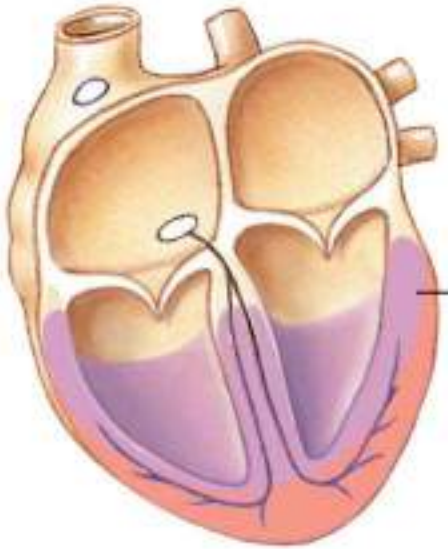


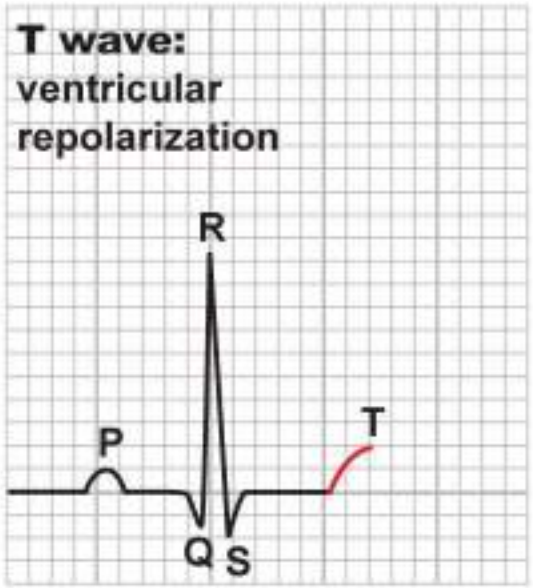
Cardiac Cycle

Coordinating the activity

- The electrical system gives rise to electrical changes (depolarization/repolarization) that is transmitted through isotonic body fluids and is recordable
  - The ECG!
    - A recording of electrical activity
    - Can be mapped to the cardiac cycle

ELECTRICAL EVENTS OF THE CARDIAC CYCLE





Cardiac Cycle

Phases

- Systole = period of contraction
- Diastole = period of relaxation
- Cardiac Cycle is alternating periods of systole and diastole
- Phases of the cardiac cycle
  1. Rest
     - Both atria and ventricles in diastole
     - Blood is filling both atria and ventricles due to low pressure conditions
  2. Atrial Systole
     - Completes ventricular filling
  3. Isovolumetric Ventricular Contraction
     - Increased pressure in the ventricles causes the AV valves to close… why?
       - Creates the first heart sound (lub)
     - Atria go back to diastole
     - No blood flow as semilunar valves are closed as well

Cardiac Cycle

Phases

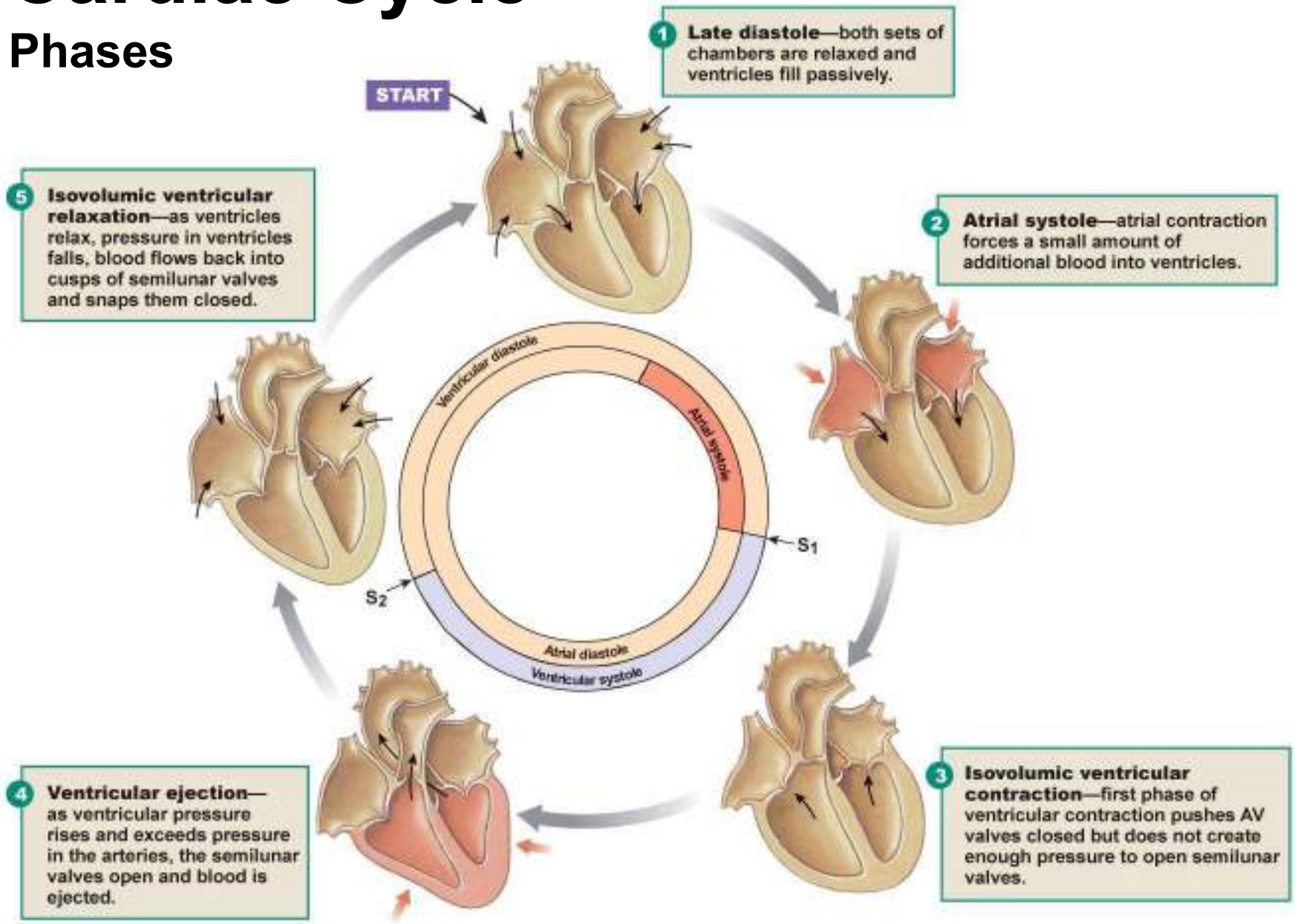
- Phases of the cardiac cycle

4. Ventricular Ejection
    - Intraventricular pressure overcomes aortic pressure
        - Semilunar valves open
        - Blood is ejected
5. Isovolumetric Ventricular Relaxation
    - Intraventricular pressure drops below aortic pressure
        - Semilunar valves close = second heart sound (dup)
    - Pressure still hasn't dropped enough to open AV valves so volume remains same (isovolumetric)

Back to Atrial & Ventricular Diastole

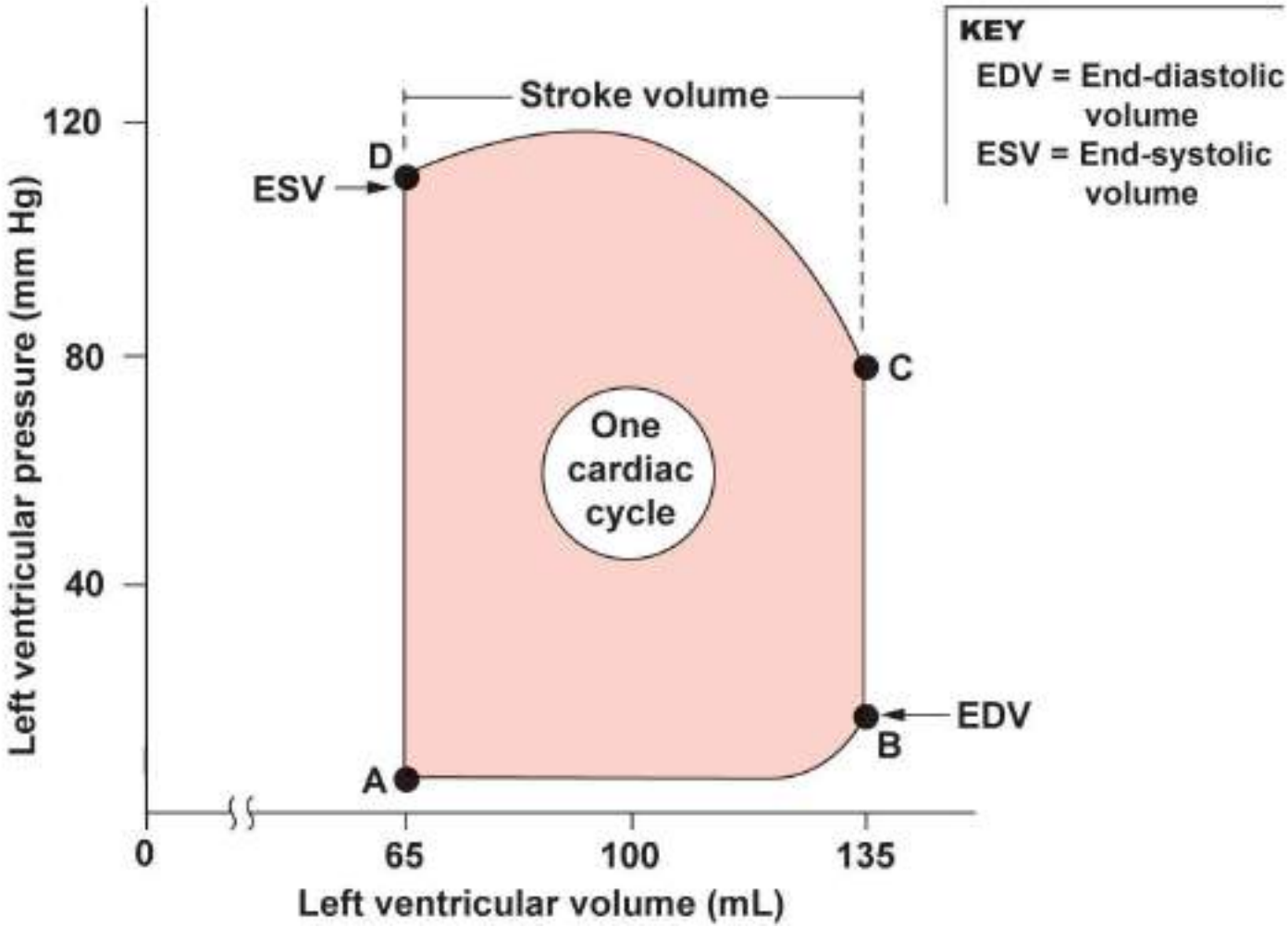
Cardiac Cycle

Phases



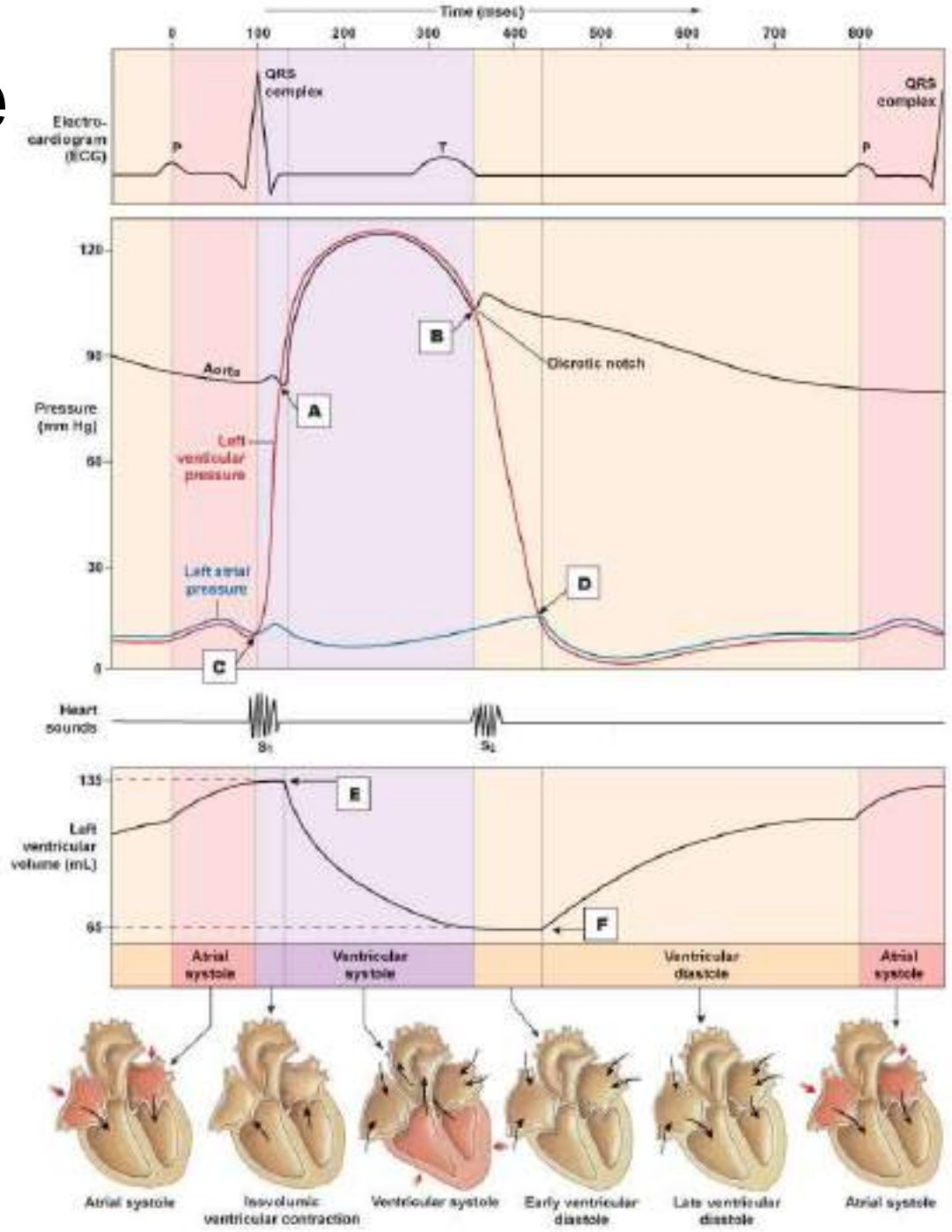
Cardiac Cycle

Blood Volumes & Pressure



Cardiac Cycle

Putting it all together!



Cardiovascular System

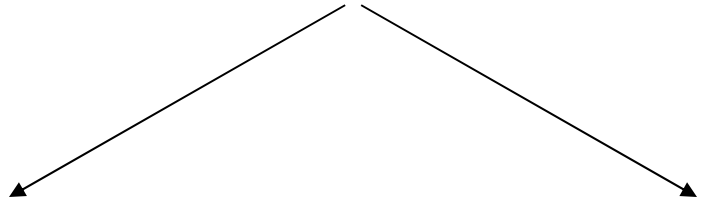
- **Blood**
- **Vascular System**
  - **Arteries**
  - **Veins**
  - **Capillaries**
- **Heart**

Blood

- Blood is red coloured semi liquid viscid fluid.

- Blood constitutes about 5 - 7% of total body weight or 2 - 3 litres/ Sq.metre of **body surface area** of the animal

Blood



Cellular

Non – Cellular

Erythrocytes
Leukocytes
Thrombocytes

Serum/
Plasma

Blood Composition

Water --- 91 to 92%

Solid matter ---8 to 9 %

Protein...7 %

Fats ,fatty acids,cholesterol & lecithin .

Inorganic salts (0.9%)Na, K, Cl, HCo3,Ca, Mg & Po4 and micro minerals, Enzymes and Hormones etc.

Plasma Vs Serum

Plasma

Prothrombin &

Fibrinogen present

Serum

Prothrombin &

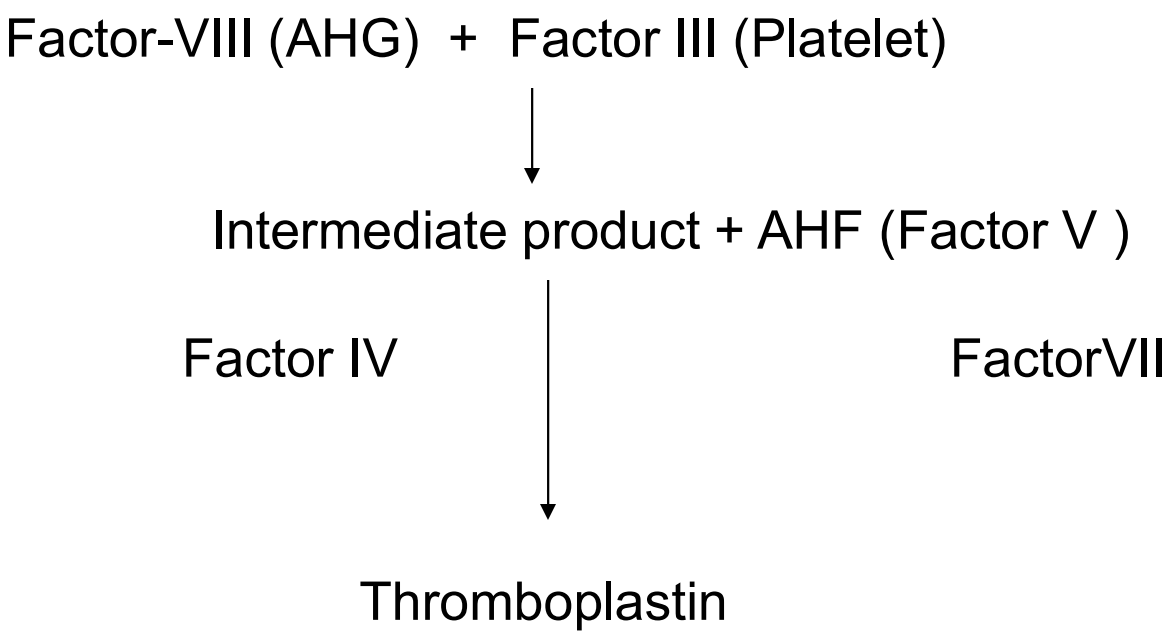
Fibrinogen absent

BLOOD COAGULATION

Blood is drawn , with out adding anticoagulants clotting factors are converted to active form to form a clot. Semi-liquid state of blood is converted to gel like mass, of clot.

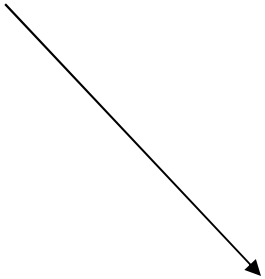
- Formation of thromboplastin
- Formation of thrombin
- Formation of fibrin

Formation of Thromboplastin



Formation of Thrombin

Prothrombin

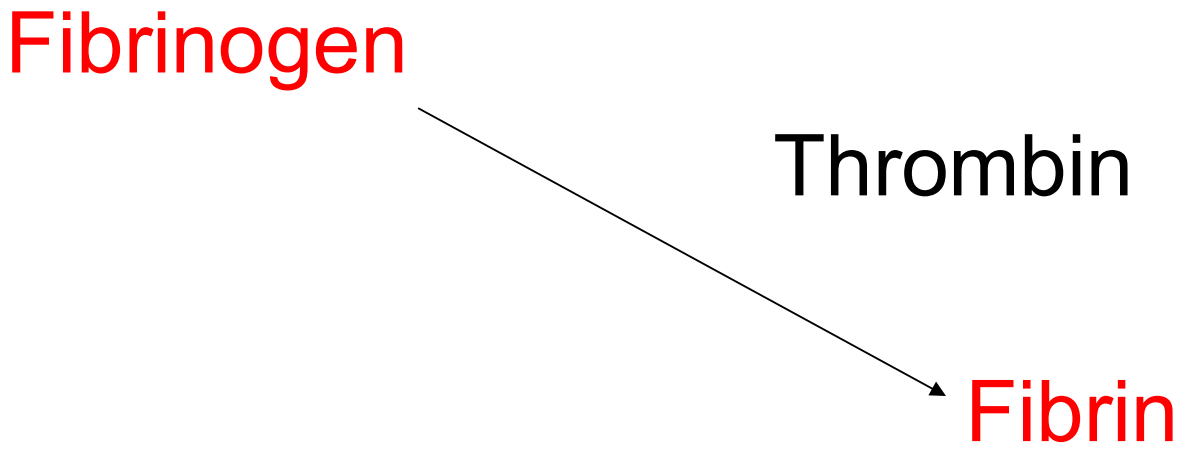


Thromboplastin

Thrombin

- Thromboplastin immediately acts on inactive prothrombin to convert it into thrombin

Formation of Fibrin



Polymerization of fibrin molecule to form a clot in network & formed elements gets entrapped.

Macfarline theory of blood coagulation

Intrinsic factors

Factor XII / Hageman factor---activated to--> Factor XIIa

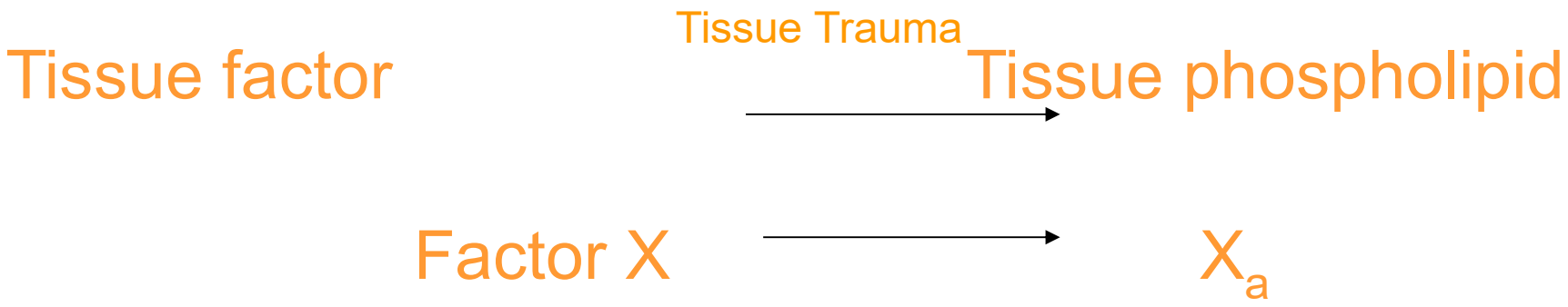
Factor XI----------XIIA acts---------->XIa

Factor IX----------XIa----------> IXa

Factor VIII----------IXa----------> VIII a

Factor X----------VIIIa ----------> Xa (Thromboplastin)

Extrinsic Factors



Erythrocytes

RBC's Non- nucleated, biconcave or circular disc shaped.

Average Diameter 4-7 µ.

In hypotonic solution RBC's swells up and becomes ballon shaped and may even rupture leaving behind a mass of ipo_protein.

In hypertonic solution They shrink and appear crenated .

Theories about RBC Structure

- Mass of sponge like material , in the interstices of which , haemoglobin is fixed.

- RBC 'S are vesicles which enclose haemoglobin and other fluid material .

- RBC is a baloon like structure , outer of which is made up of lipo- protein, which encloses haemoglobin .

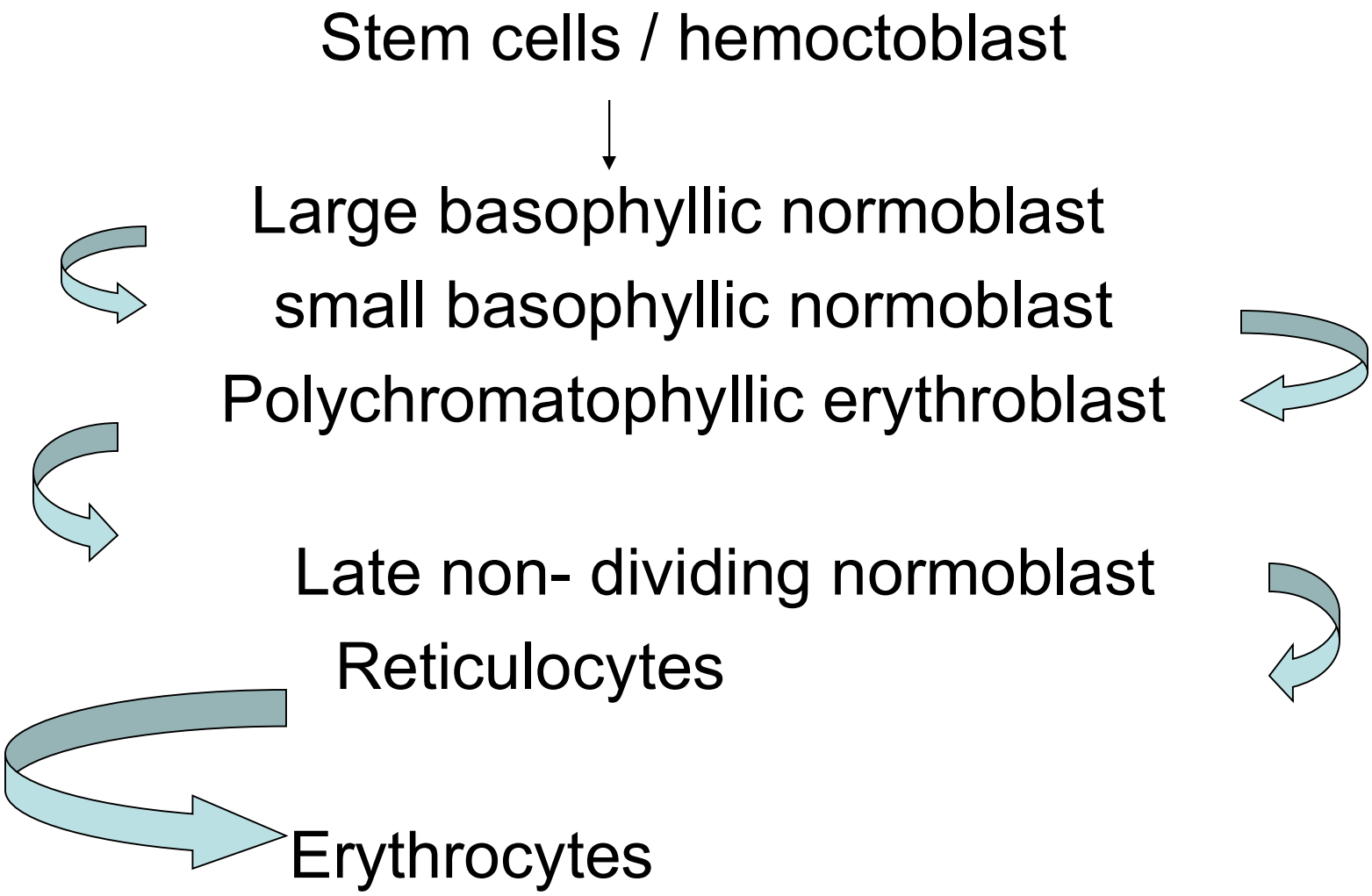
Erythrocytes are easily **compressible** **elastic** in nature and due to this character they can easily pass through capillaries which have diameter less than erythrocytes.

ERYTHROPOIESIS

Sites of erythropoiesis

- **Prenatal** :Stem cells/Haemocytoblast are present in bone marrow, yolk sac , spleen, thymus, lymph nodes & liver.
- **After birth** :Bone Marrow, but after 20 Years of age large bones, almost stops RBC production and is carried out by the ribs, Sternum.
- **In Pathological conditions** : liver and spleen and rarely lymph nodes.

ERYTHROPOIESIS



ERYTHROPOIESIS

- Total time required for maturation of erythrocytes is 120 hours.
- Remains in circulation for 120 days.
- Normally 60 late normoblast are produced per 1000 of proerythroblast but during anemia production is reduced to 5- 6 cells per 1000 proerythroblast.

Leukopoiesis

- Granulocytes

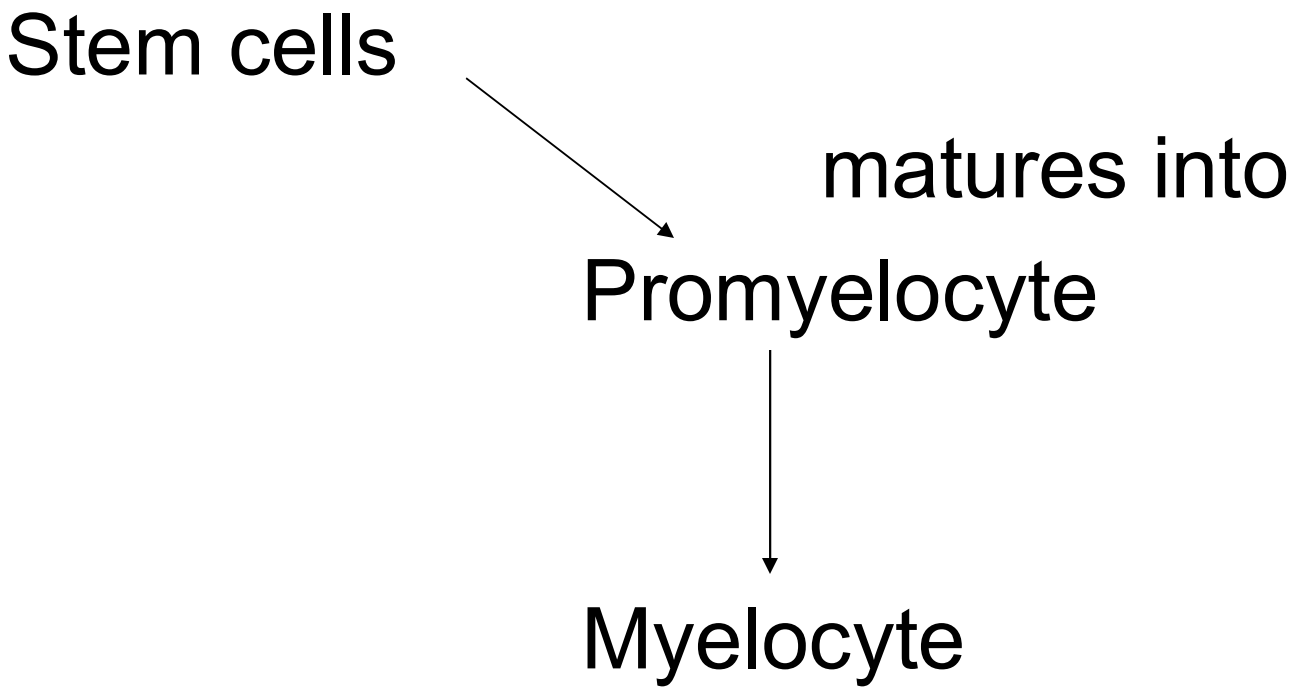
  Neutrophils, Eosinophils & Basophils
- Agranulocytes

  Lymphocytes and Monocytes

Granulocytes are produced from bone marrow so they are called as Myelocyte cells.

Lymphocytes formed by the bone-marrow, & lymph nodes, while monocytes origin is not certain but mostly formed by spleen or lymph nodes.

Leukocytic promoting factor


Stem cells
matures into
Promyelocyte
Myelocyte

TLC & DLC

- TLC (5-9 thousand/ul)
- cattle 5-12 thousand/cumm
- Bitch 9-15 thousand/cumm
- N 3-5 thousand/ul - 60-70%
- L 1500-2000 in no. - 20-30%
- E 100-400 in no. - 2-4%
- M 100-800 in no. - 2-8%
- B 25-100 in no. - 0.5-2%

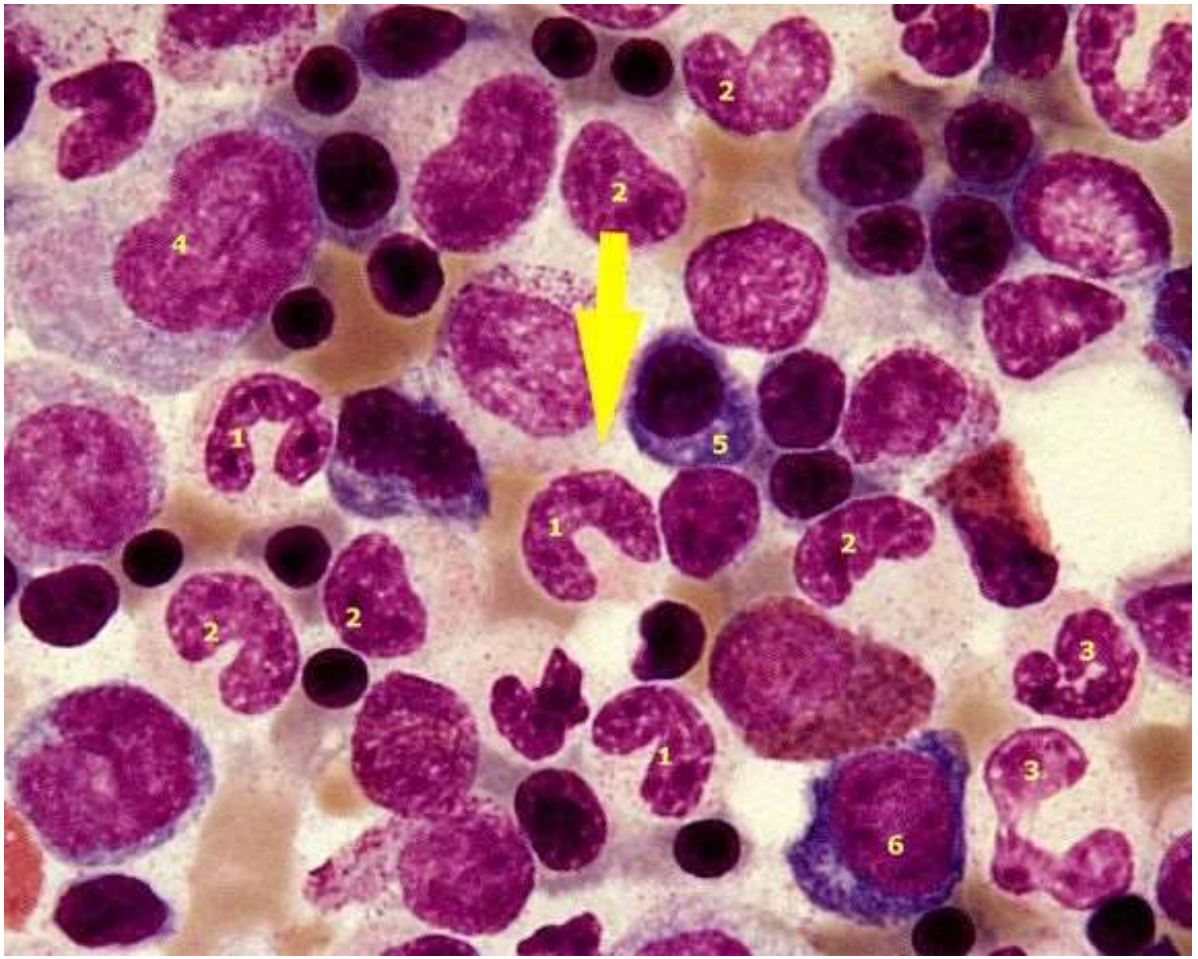
Sequestration

- Destruction of leukocytes by reticulo endothelial cells in lungs or lymph nodes.

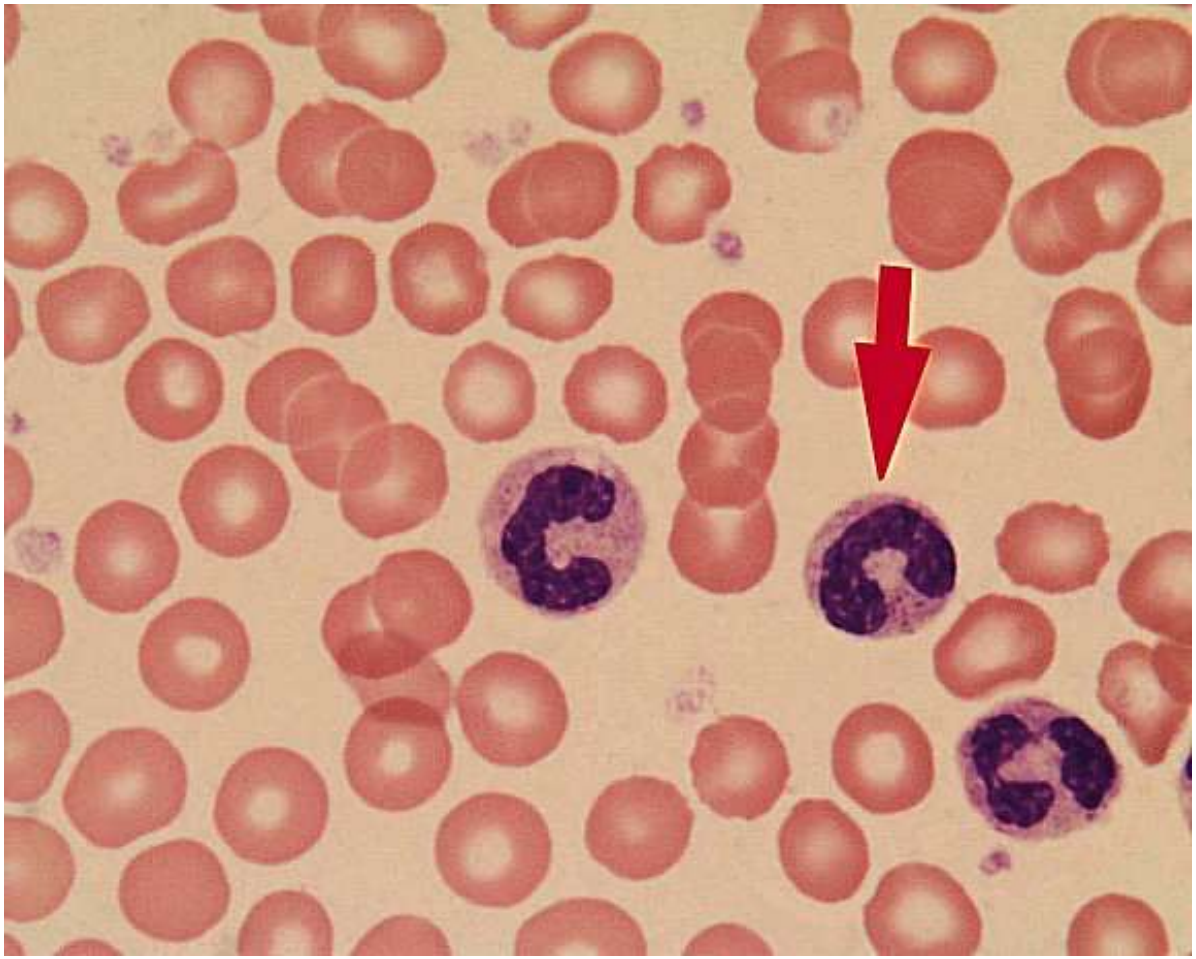
Neutrophils

- Neutrophils have bilobed, trilobed or tetralobed nuclei, so they are called as polymorphs. Cytoplasmic granules are very small in diameter, that is 0.02 to 0.5 μ. Diameter of neutrophils is 10-12 μ & they are amoeboid and phagocytic in character. Nucleus of each cell is divided into lobes or segments connected by filaments - called as segmented cells. Neutrophils have ascorbic acid, glutathione, Histamine and number of enzymes like lipase, Protease, catalase, phosphatase, Nucleotidase etc.
- In poultry Neutrophils are reffered as heterophils, its large fusiform bodies that takees eosin stain.

Band Neutrophils



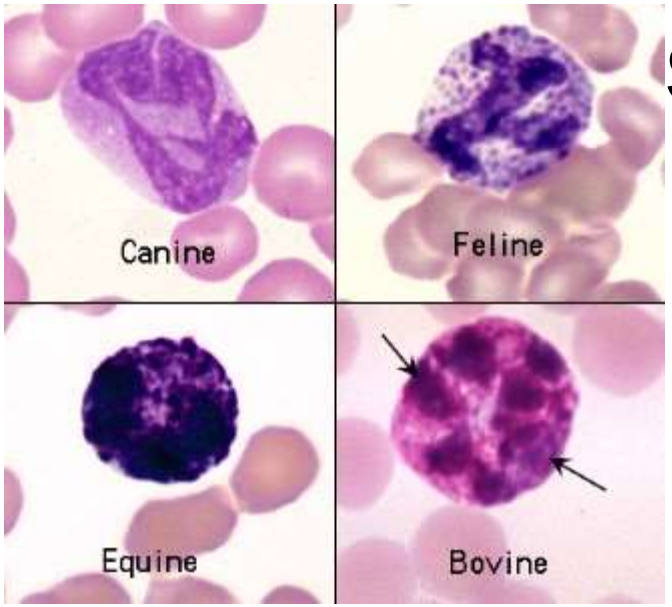
Band Neutrophils



Eosinophils

- Cells with diameter of 10-12 μ.
- Cytoplasmic granules with diameter of 0.7to1.2 μ.
- Nuclei is less lobulated than those of neutrophils. motile and slightly phagocytic in nature. Eosinophillia - allergy, anaphylactic shock and parasitic infestation conditions.
- Eosinopaenia- stress related conditions, and due to ACTH inj. Epinephrine also causes eosinopaenia through ACTH release.


White Blood Cells
Granulocytes
Agranulocytes
Lymphocytes
mainly found in lymph
B Cells
make antibodies
NK Cells
T Cells



sophils

Water soluble cytoplasmic granules, which stains with alkaline dyes. Nuclei is bilobed. Diameter of basophils is 8-10 μ and cytoplasmic granules measures 0.5 to 1 μ in diameter. Phagocytic power is either very low or absent. It originates from basophilic myelocytes of the bone marrow.

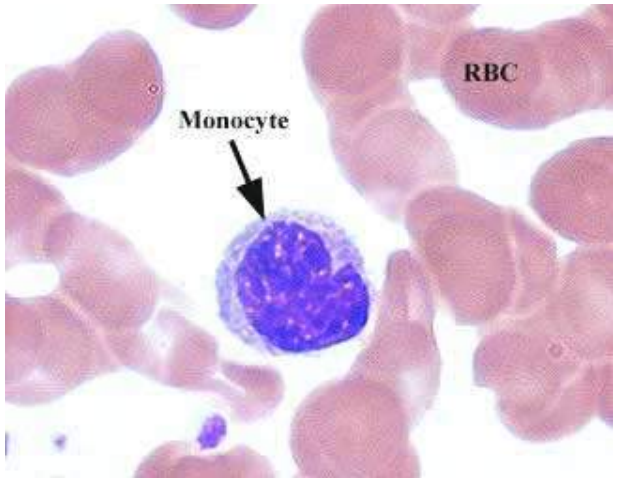
Lymphocytes

- **Small lymphocytes** are 7 μ in diameter and have rounded compact nucleus, with very little cytoplasm around it. Life span is 2-3 days & produced by lymph nodes.

- **Large lymphocytes** are 10-12 μ in diameter. Nuclear material is not as compact as in small lymphocytes. Its' life span is 100-200 days and produced by thymus mainly.

- Physiological function of lymphocytes is phagocytosis, they engulf bacteria and removes infection from body. They also forms immunoblast, which is responsible for acceptance/rejection of grafted tissue in the body. Long life span of lymphocytes plays a major role in its production of immunoblast. Lymphopenia is due to stress or exogenous ACTH.

MONOCYTES



- characterised by presence of kidney/Horse Shoe shaped nucleus, produced by spleen and undergoing mitotic divisions, they matures into monocytes. Largest cells present in circulation, with diameter of 16-22 μ.
- They may have slight pinkish cytoplasmic granules, also known as histiocytes. Physiological function is phoyocytosis, they engulf bacteria and removes infection, thus acts as scavangers to

THROMBOCYTES/PLATELETS

- Thrombocytes are smallest formed elements present in circulation. Formed from stem cells present in bone marrow and differentiates into megakaryoblast, measuring 20-40 μ. Before they emerges from sinosoids, they extend their Pseudopods, therefore pseudopods are nipped-off and released into circulation. These are small, colourless, round or rod shaped bodies circulating into blood. Average diameter is 3 μ. In chicken they are nucleated and size is relatively larger.
- Life span of platelets is 8-11 days in circulation. Average concentration of platelets is 2.5 to 5 lakhs/cubic mm. Their physiological function is that they helps in hemostasis by agglutination at injury site.

Thankyou for your patience