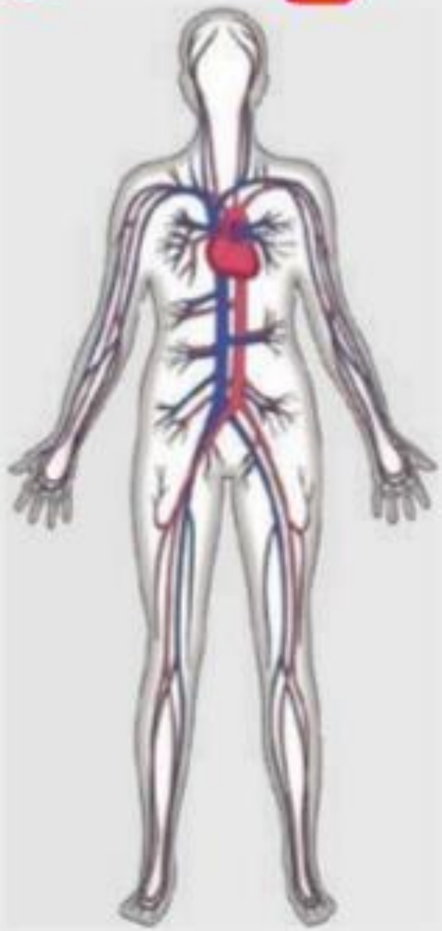
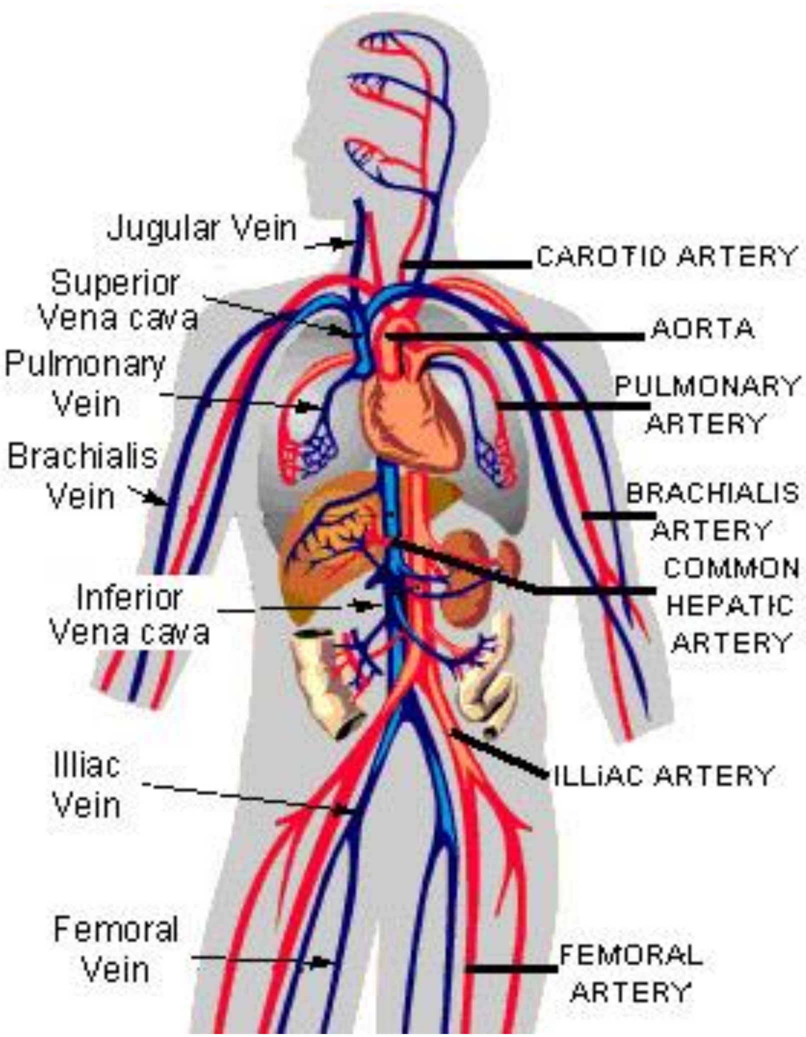
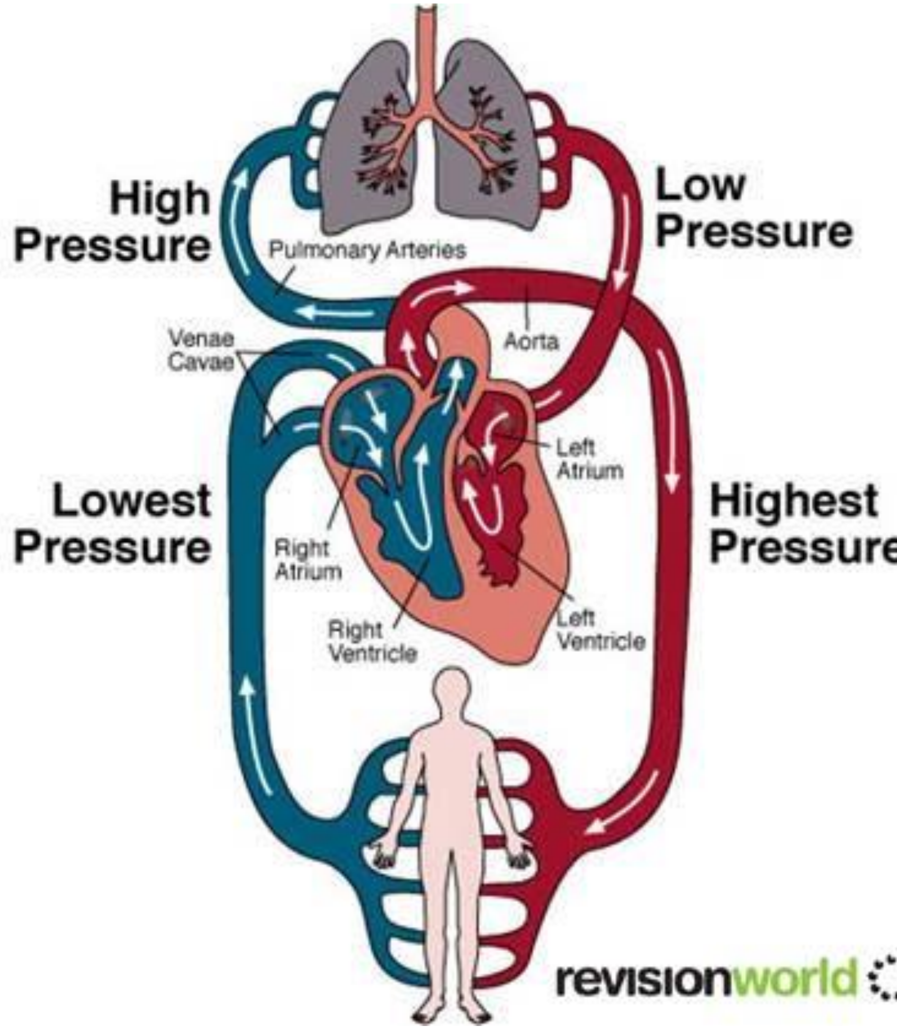
Circulatory System



Circulatory system

- The **circulatory system** is an organ system that passes nutrients (such as amino acids, electrolytes and lymph), gases, hormones, blood cells, etc. to and from cells in the body to help fight diseases, stabilize body temperature and pH, and to maintain homeostasis.
- This system may be seen strictly as a blood distribution network, but some consider the circulatory system as composed of the **cardiovascular system**, which distributes blood, and the **lymphatic system**, which distributes lymph.
- While humans, as well as other vertebrates, have a closed cardiovascular system (meaning that the blood never leaves the network of arteries, veins and capillaries), some invertebrate groups have an open cardiovascular system.

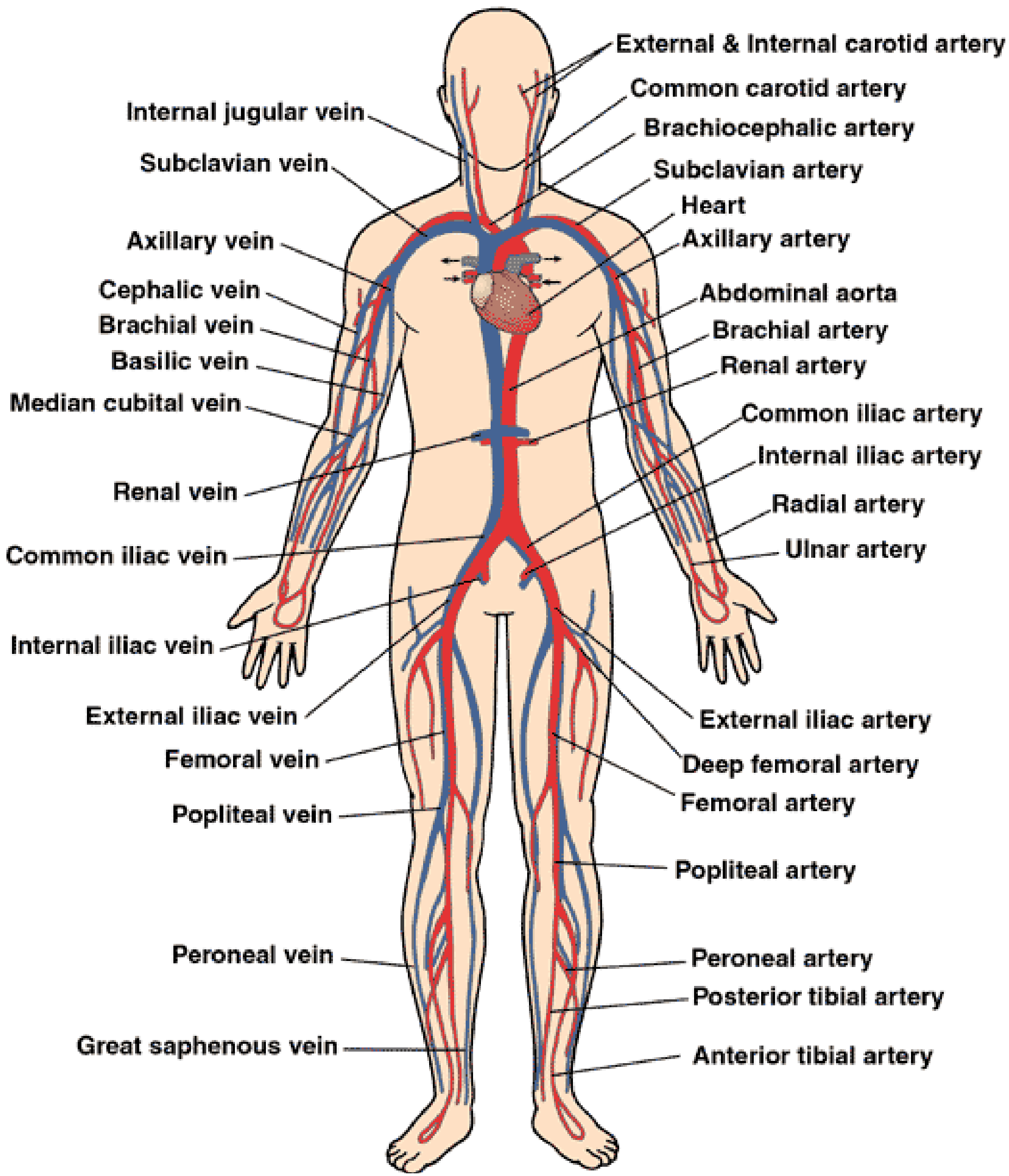

Jugular Vein
CAROTID ARTERY
Superior Vena cava
AORTA
Pulmonary Vein
PULMONARY ARTERY
Brachialis Vein
BRACHIALIS ARTERY
COMMON HEPATIC ARTERY
Inferior Vena cava
Illiac Vein
ILLiAC ARTERY
Femoral Vein
FEMORAL ARTERY


High Pressure
Low Pressure
Pulmonary Arteries
Aorta
Venae Cavae
Left Atrium
Lowest Pressure
Highest Pressure
Right Atrium
Right Ventricle
Left Ventricle
revisionworld

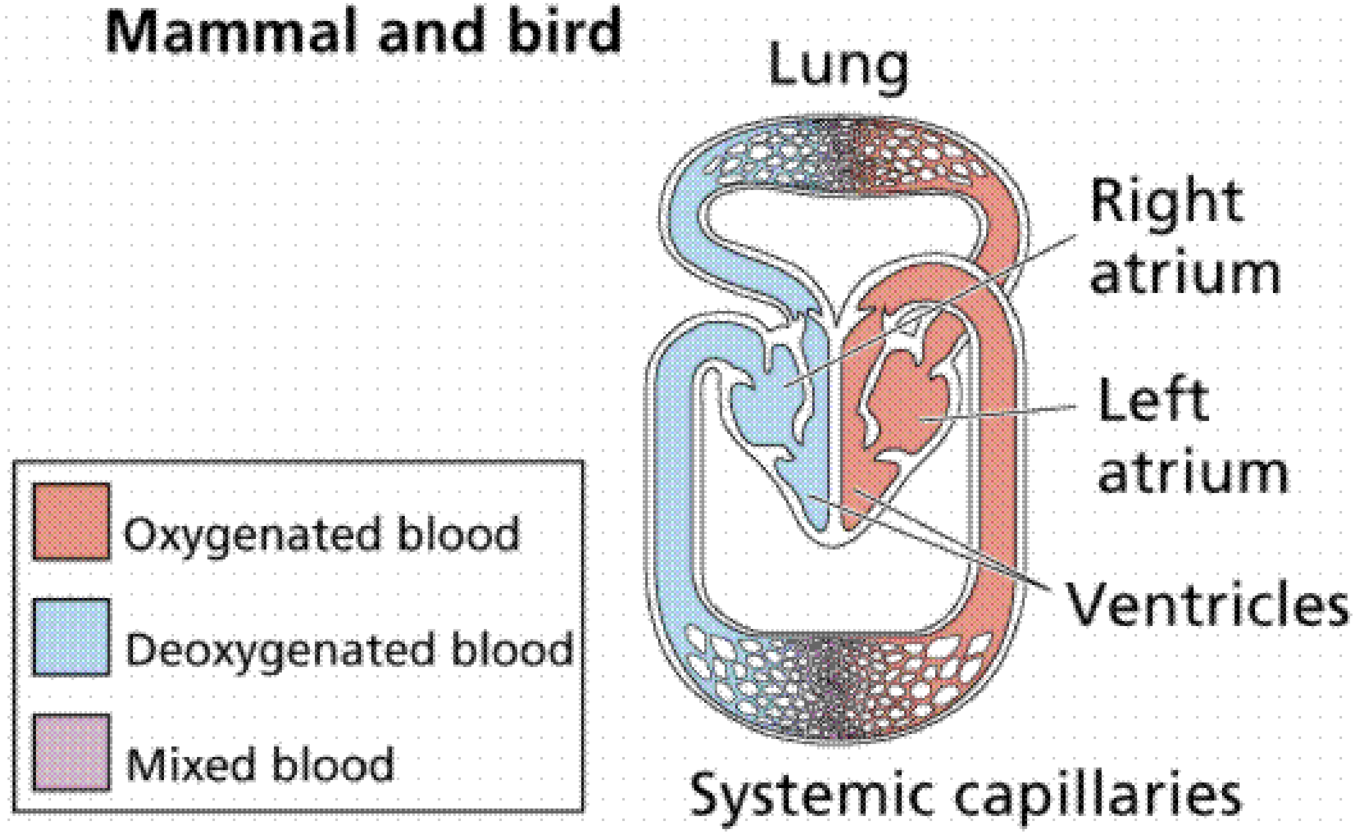
순환계

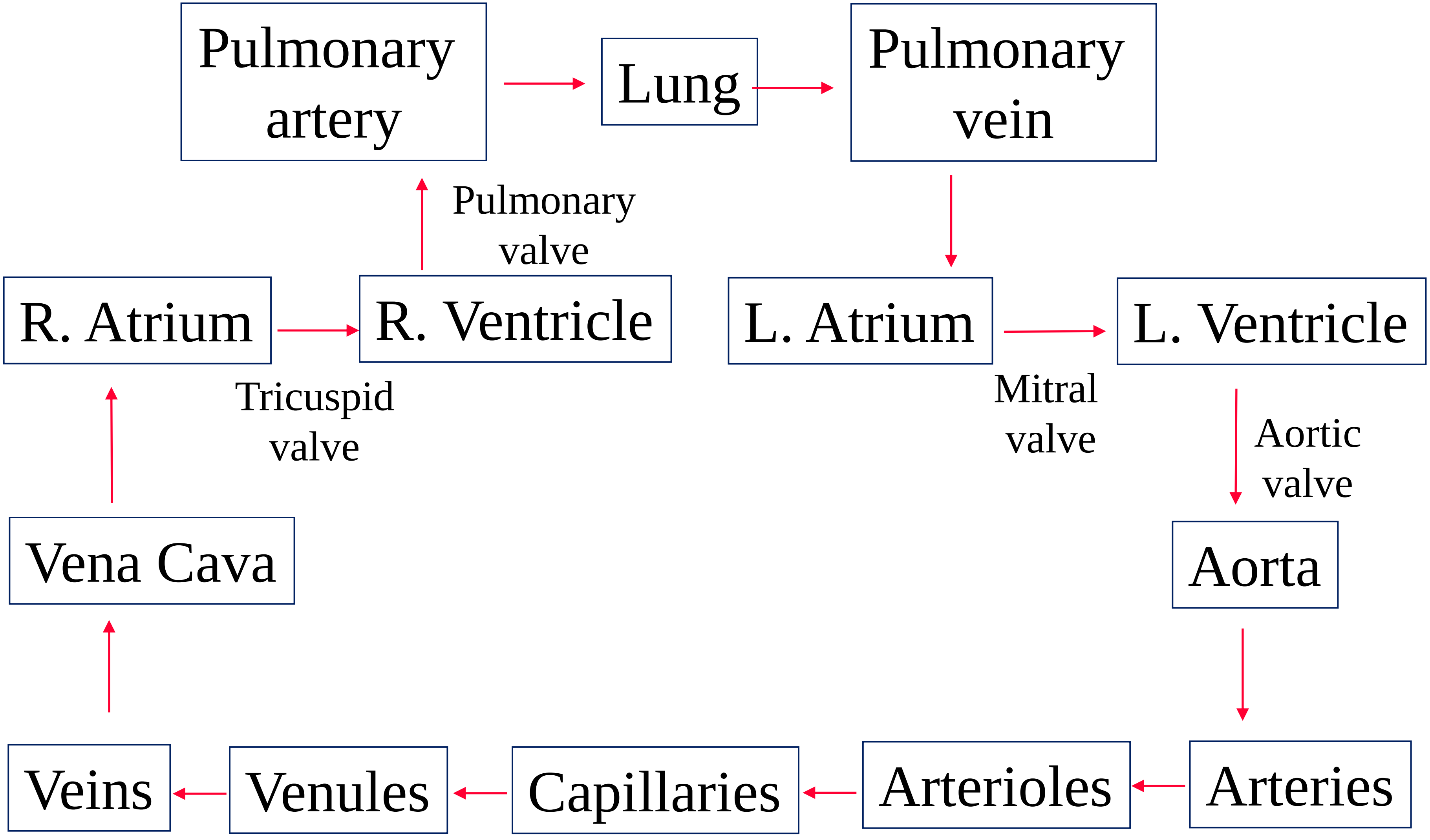
- 기능; 물질 전달
- 구성;
    - 혈관; 정맥, 동맥
    - 심장
- 폐; 가스 교환
- 위장간; 영양분
- 신장; 노폐물 제거
- 골수 (혈액); 산소, 면역 및 방어 체계

Circulatory System



순환 체계


Mammal and bird
Lung
Right
atrium
Left
atrium
Ventricles
Systemic capillaries
Oxygenated blood
Deoxygenated blood
Mixed blood


Pulmonary artery
Lung
Pulmonary vein
Pulmonary valve
R. Atrium
R. Ventricle
L. Atrium
L. Ventricle
Tricuspid valve
Mitral valve
Aortic valve
Vena Cava
Aorta
Veins
Venules
Capillaries
Arterioles
Arteries

Heart 심장

- 기능; pump
- 구성;
  - 심실 (ventricle); 우, 좌
  - 판막 (valve);
    - 삼천판 (tricuspid)
    - 폐반월판 (pulmonary)
    - 승모판 (mitral)
    - 대동맥판 (aortic)
  - 심방 (atrium); 우, 좌

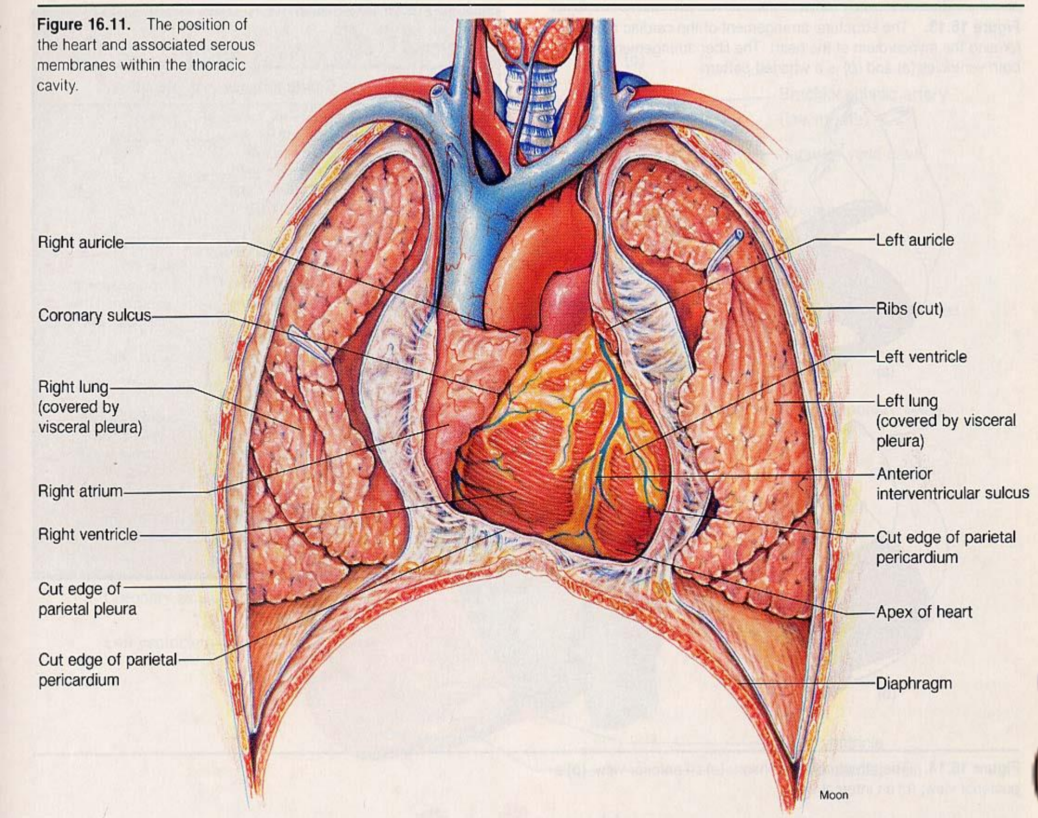
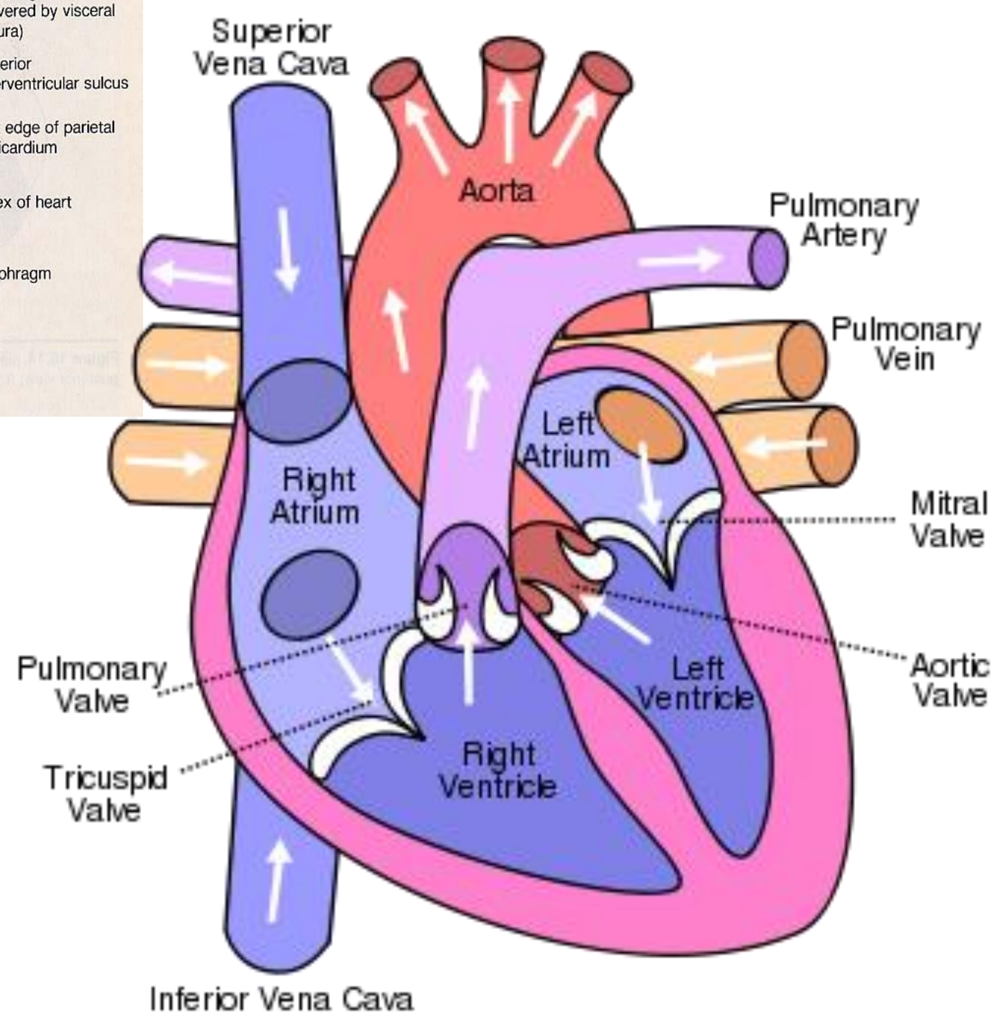


Figure 16.11. The position of the heart and associated serous membranes within the thoracic cavity.



The Heart as a Pump

I. Structure and Contraction of Heart Muscle

A. composed of individual cell packed tightly connected by intercalated discs.

B. During excitation (an action potential),

- Ca^{++} channels in the membrane: open
- Ca^{++} ions interact with the contractile proteins
  → cause the cell to contract.

C. Cell arranged parallel to each other on layers

→ simultaneous contraction of cells

→ decrease its chamber size

→ volume ejection.

D. All cardiac cells contract with every beat: gradation in force of contraction come from changing the force of contraction of each cell, not by recruitment of more cells as in skeletal muscle.

II. Anatomy of the Heart

A. Four chambers.

1. Right atrium (RA) and left atrium (LA)
   a. thin walls(produces low pressures).
   b. fills ventricle

2. Right ventricle (RV)
   a. Thinner than left ventricle (low pressure pump; 22/8 mmHg)
   b. Pumps blood to lungs (pulmonary circulation)

3. Left ventricle(LV)
   a. Thick (high pressure pump; 120/80 mmHg)
   b. Pumps blood to systemic circulation: everything except lungs
   c. LV chamber modeled as right cylinder:

      V (volume) = $\pi r^2 L$(note: radius raised to the second power).

Figure 16.14. The structure of the heart. (*a*) an anterior view; (*b*) a posterior view; (*c*) an internal view.

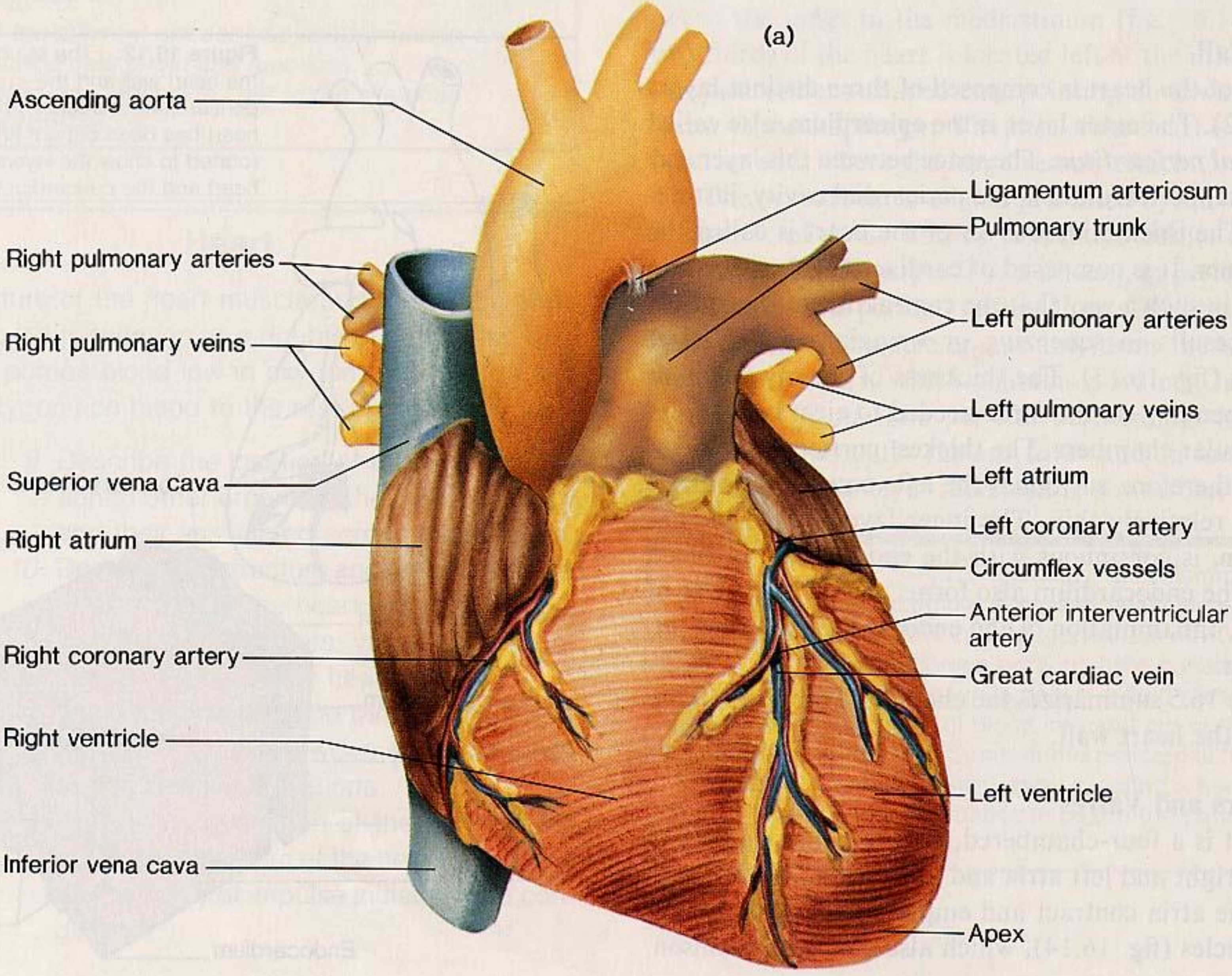
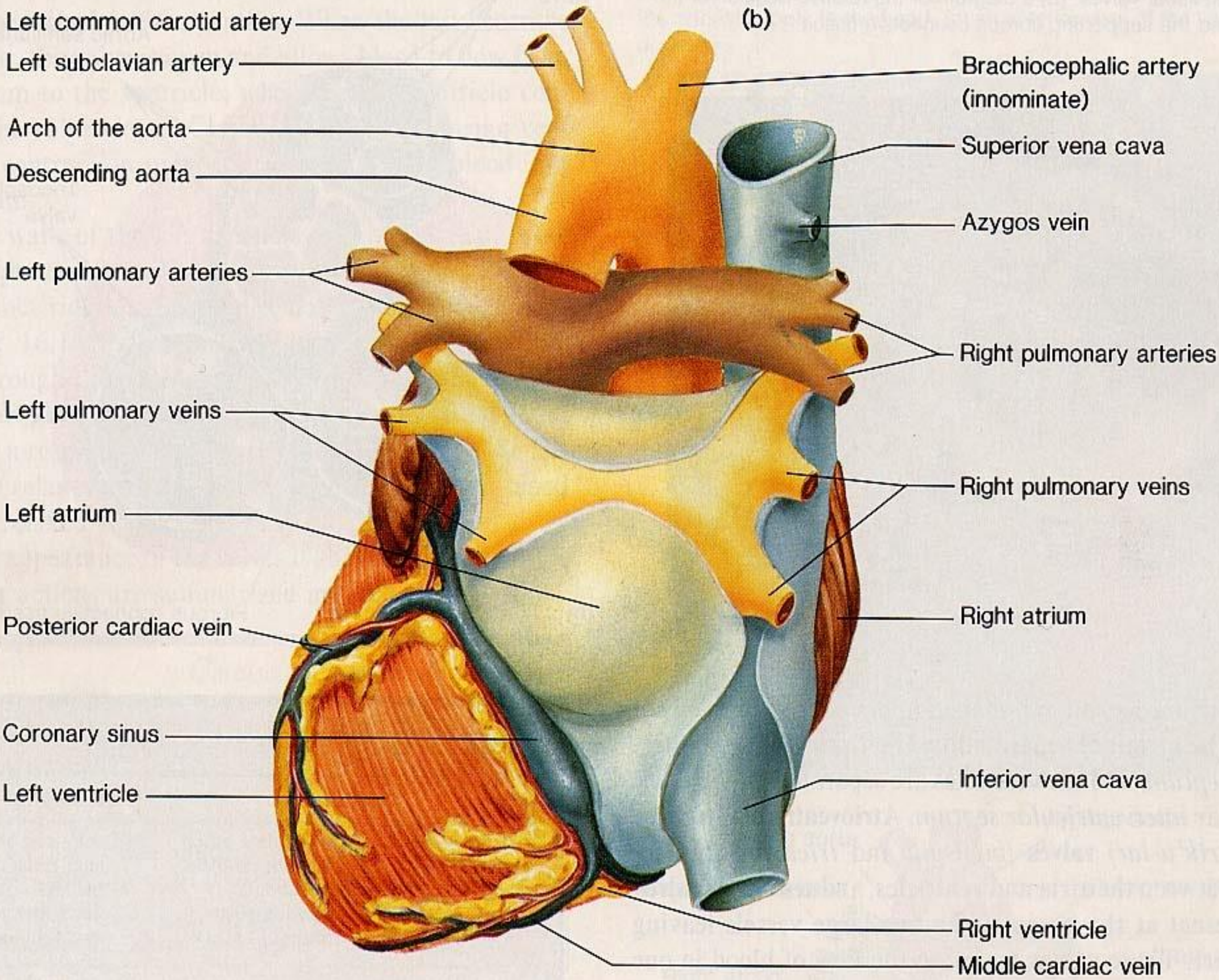
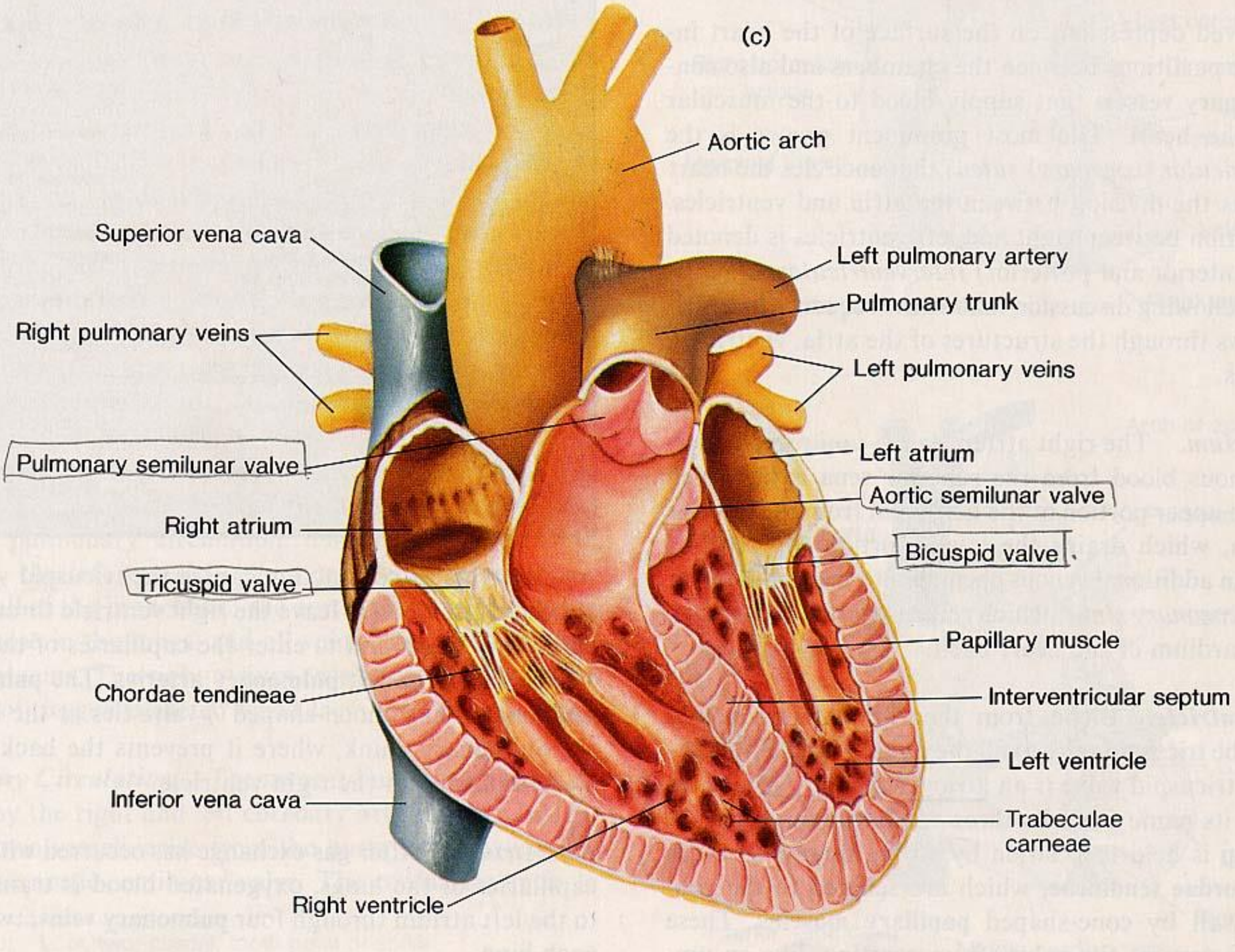


Figure 16.14—*Continued*




(c)
Aortic arch
Superior vena cava
Left pulmonary artery
Pulmonary trunk
Right pulmonary veins
Left pulmonary veins
Pulmonary semilunar valve
Left atrium
Aortic semilunar valve
Right atrium
Bicuspid valve
Tricuspid valve
Papillary muscle
Chordae tendineae
Interventricular septum
Left ventricle
Inferior vena cava
Trabeculae carneae
Right ventricle

B. Valves

- Open and close passively in response to differences in pressure in the two chambers(e.g. atrium vs. ventricle; ventricle vs. aorta)

1. Atrioventricular(AV) valves

a. Tricuspid valve,

: between RA and RV

three cusps(leaflets) which overlap to give complete closure.

b. Mitral valve,

:between LA and LV

two cusps,overlapping.

Mitral and tricuspid valves :
cusps attached by tendons (chordae tendonae) to papillary muscles on the endocardial wall: contraction of the papillary muscles prevents cusps from bulging backwards into atrium during ventricular contraction.

2. Semilunar valves

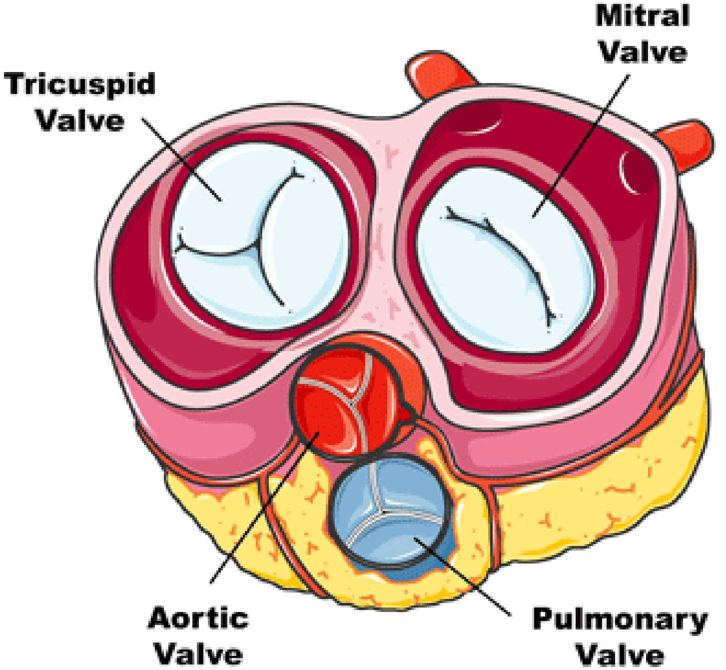
a. Pulmonary valves;

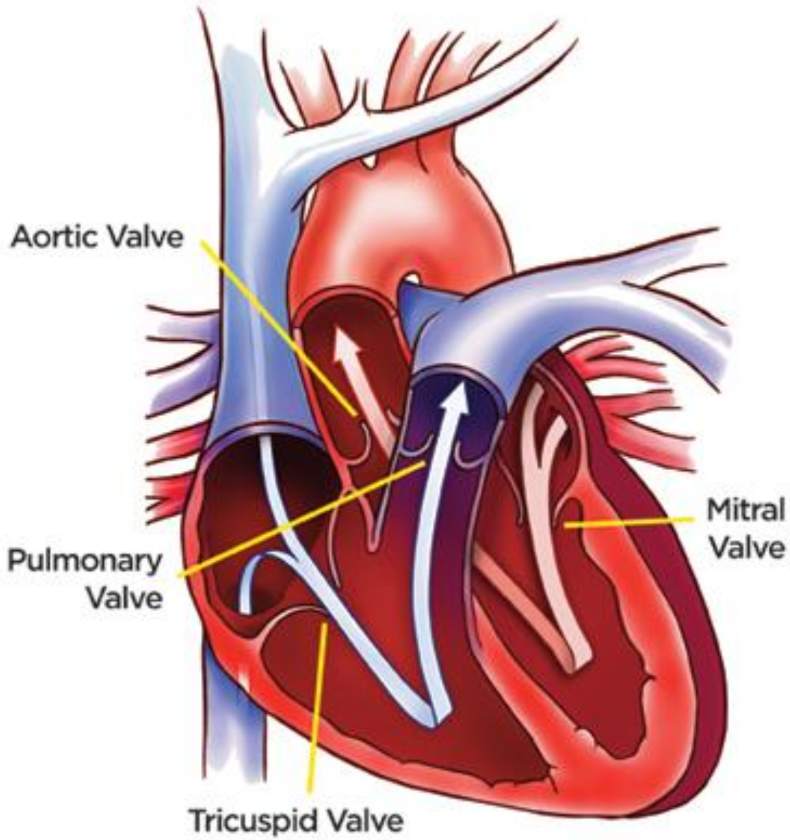
between RV and pulmonary artery

b. Aortic valve;

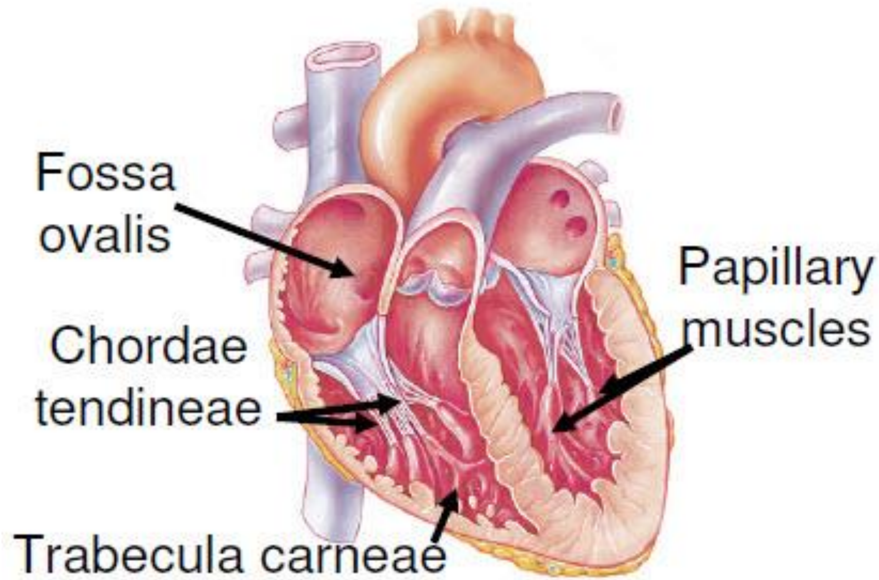
between LV and aorta

Smaller, tougher than AV valves, no tendons or papillary muscles necessary to prevent backward bulging.



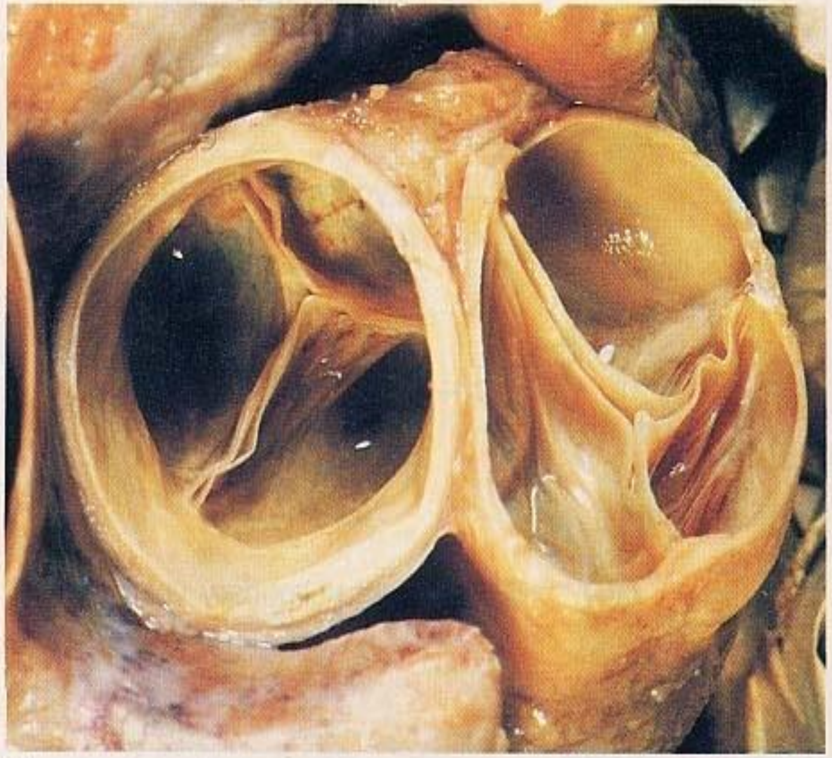


Aortic Valve
Pulmonary Valve
Mitral Valve
Tricuspid Valve

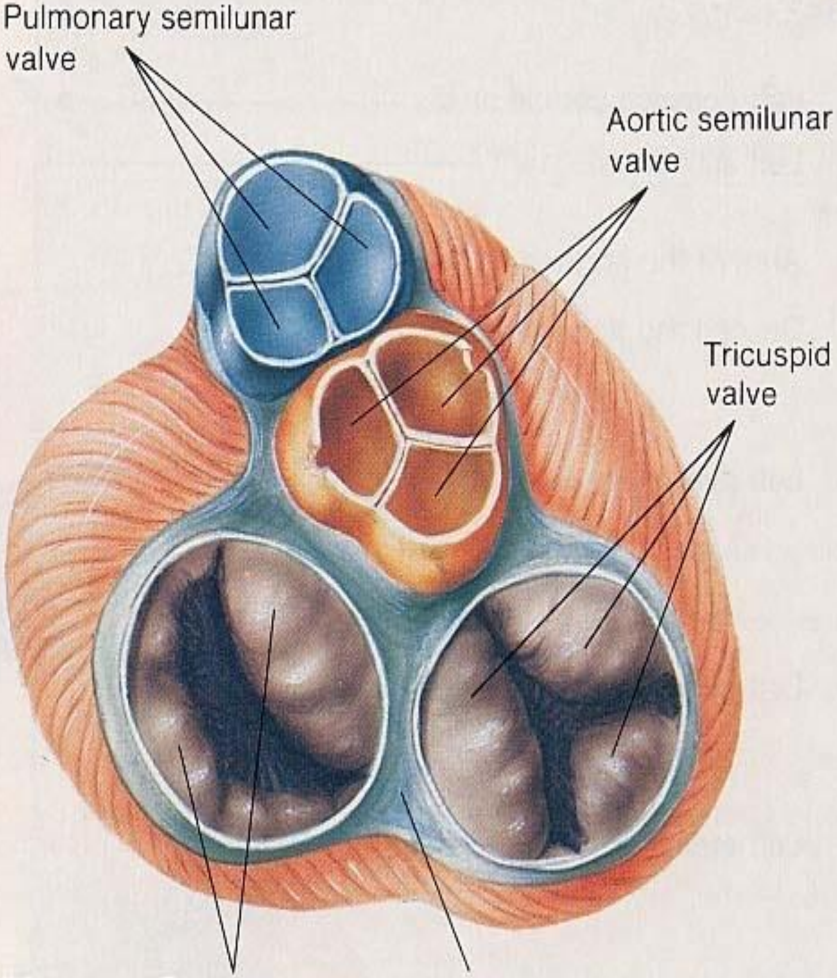


Fossa ovalis
Chordae tendineae
Papillary muscles
Trabecula carneae

Figure 16.15. A superior view of the heart valves. (*a*) a photograph of the semilunar valves. (*b*) a diagram of the relative position of the valves and the supporting fibrous connective tissue.



(a)

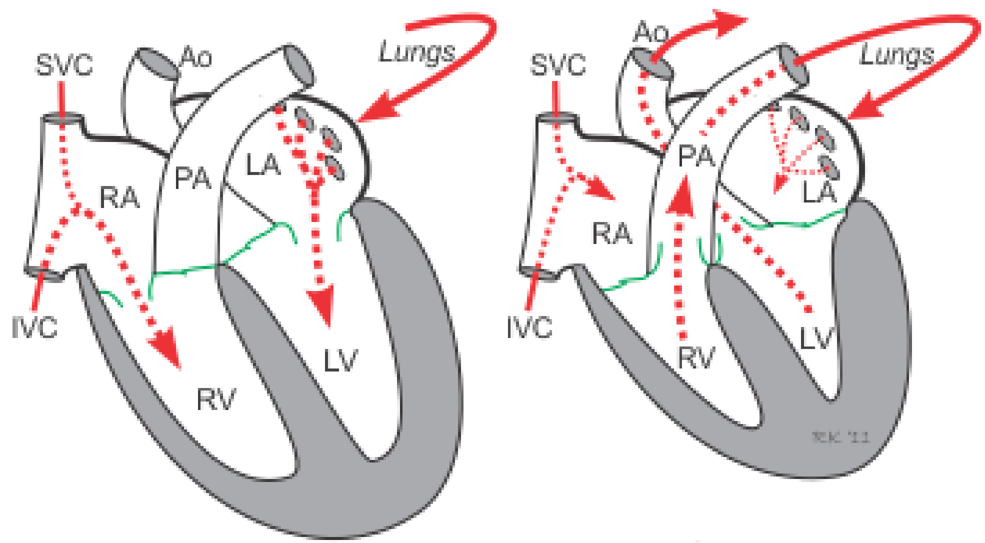


(b)

III. Cardiac Cycle

A single cycle of cardiac activity can be divided into two basic phases - **diastole** and **systole**.

- **Diastole** represents the period of time when the ventricles are relaxed (not contracting).
- **Systole** represents the time during which the left and right ventricles contract and eject blood into the aorta and pulmonary artery, respectively.

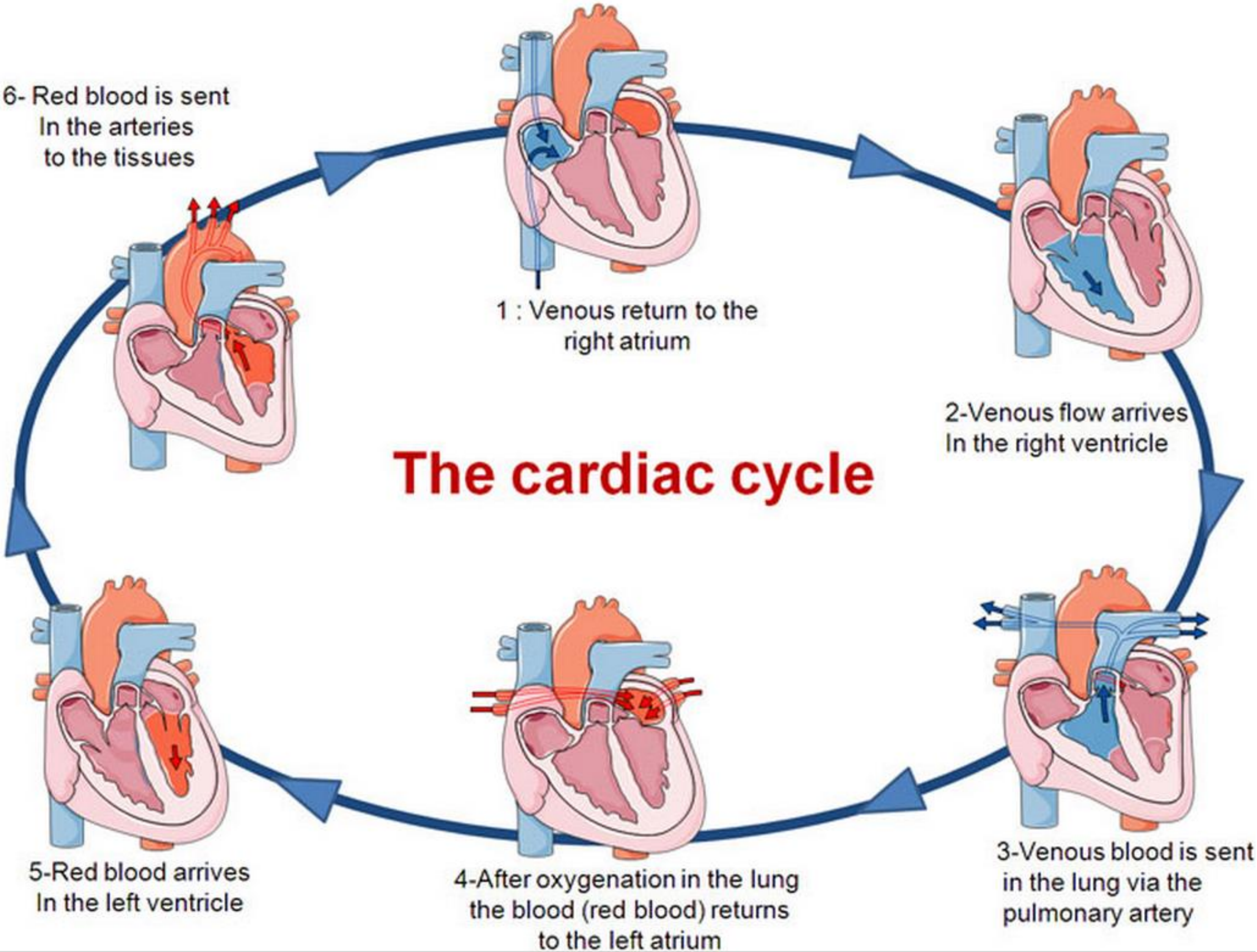


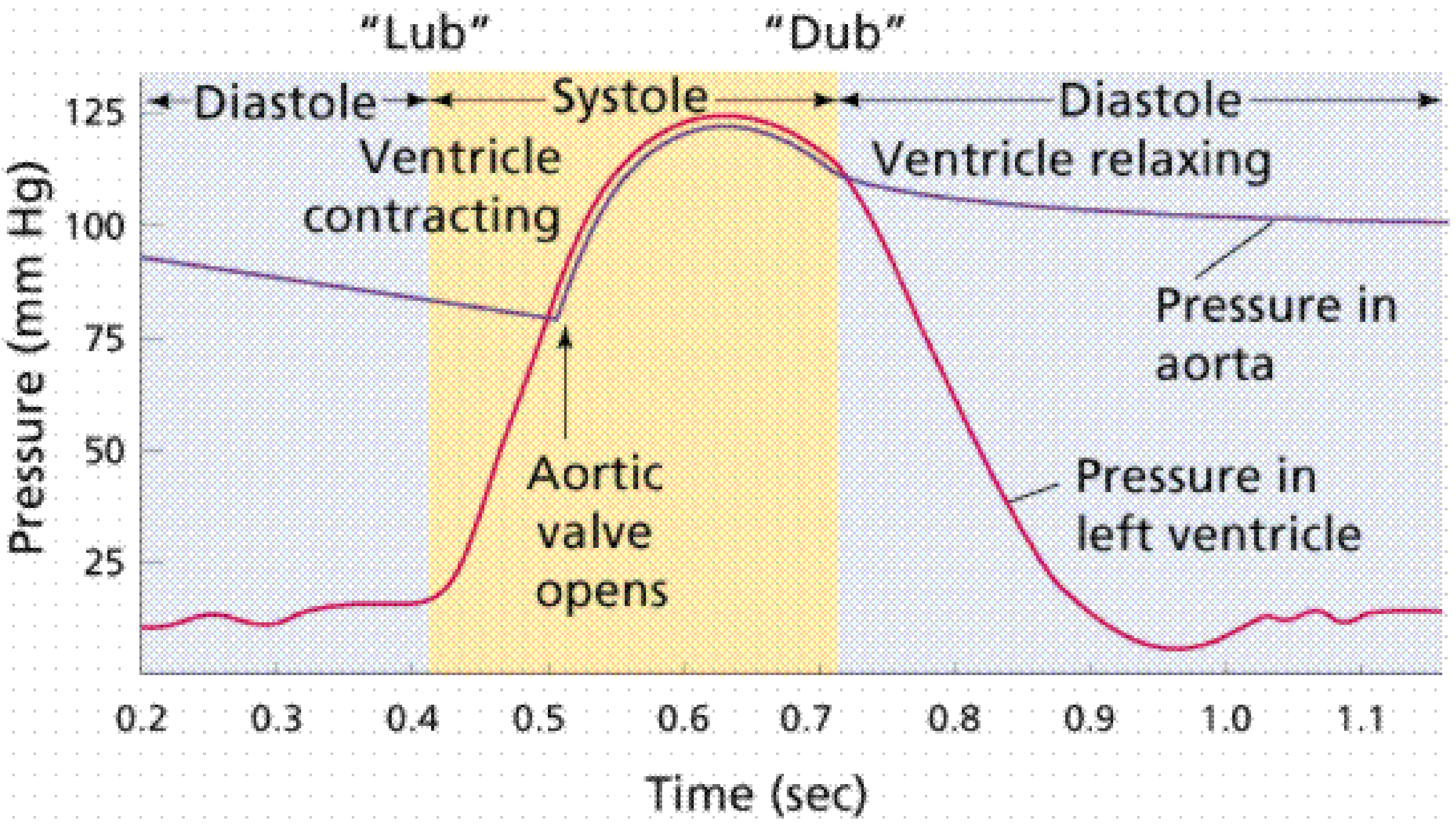
Diastole Systole

Sequence of events in left heart.

1. Ventricular contraction (systole) begins with **mitral valve** closing and **aortic valve** closed.
2. When ventricular pressure > atrial pressure, mitral valve closes.
3. During isovolumetric contraction, both valves are closed and no blood flows in or out of ventricle.
4. When ventricular press. > aortic press., aortic valve opens and ejection begins.
5. Rapid ejection phase is while ventricular pressure > aortic pressure.
6. Reduced ejection phase : vent. press. has actually fallen slightly below aortic press. but ejection into aorta continues due to inertia of blood flow.

7. When vent. press. falls even more, aortic valve snaps shut(aortic press. > vent. press.); this closing produces a notch on aortic press. trace called the incisura.
8. Isovolumetric relaxation phase is when both valves are close; the entire relaxation phase is called diastole.
9. When the ventricular pressure < atrial pressure, the mitral valve opens.
10. The period of rapid filling of the ventricle from the atrium occurs even before the atrium contracts.
11. Contraction of atrium helps to give extra filling of vent.; normally only 1/3 of total vent. volume, but more important during exercise where faster and larger volume filling times are required.
12. Ventricular contraction begins again.


6- Red blood is sent
In the arteries
to the tissues
1 : Venous return to the
right atrium
2-Venous flow arrives
In the right ventricle
The cardiac cycle
3-Venous blood is sent
in the lung via the
pulmonary artery
4-After oxygenation in the lung
the blood (red blood) returns
to the left atrium
5-Red blood arrives
In the left ventricle



The cardiac cycle.

Bioelectric Phenomema

I. Structure of heart muscle.

A. Functional syncytium (기능적 세포결합체):

- ✓ Separate cells connected to each other by intercalated discs which are regions of low electrical resistance thus providing electric current to flow easily between cells.

B. The two atria are electrically continuous as are the ventricles however, the atria are not continuous with the ventricles. Atria and ventricles are linked by a specialized structure called the atrioventricular node(AV node).

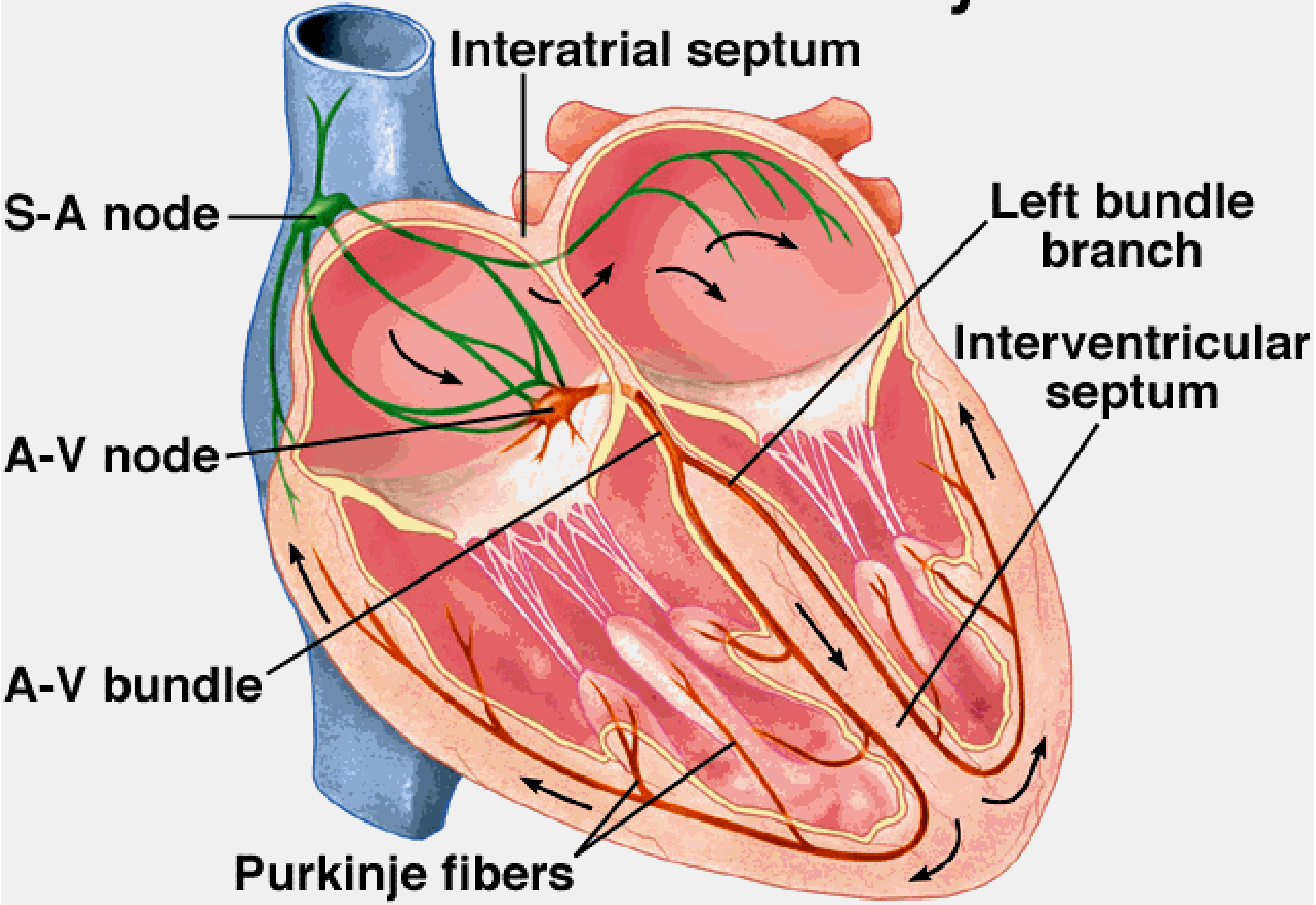
Sinoatrial node (SA node)

- The natural pacemaker of the heart.
- The sinoatrial (SA) node consists of a cluster of specialized muscle cells within the wall of the right atrium (upper chamber) of the heart.
- Without any external influence, these cells emit electrical impulses at a rate of 100 per minute, which initiate the contractions (beats) of the heart.

Atrioventricular node (AV node)

- The **atrioventricular node** (abbreviated **AV node**) is a part of the electrical control system of the heart that coordinates heart rate.
- It electrically connects atrial and ventricular chambers.

Cardiac Conduction System



II. Propagation of action potential (AP)

A. The heart beats spontaneously i.e. initiation of the heart beat is myogenic : heart rate modulated by cardiac nerves.

B. AP propagates sequentially through heart to produce an effective pump.

1. Sinoatrial node(SA node) : near superior vena cava is the primary pacemaker region where cardiac APs normally originates. These cells spontaneously depolarize to elicite APs.
2. The AP then propagates through both right and left atria rapidly.
3. Then propagates slowly through the AV node.
4. Then very rapidly down the His-Purkinje system, a system of specialized conducting tissue that quickly propagates APs down to the apex of the ventricle and to all vent. regions. This ensures simultaneous excitation and contraction of all ventricle tissue.

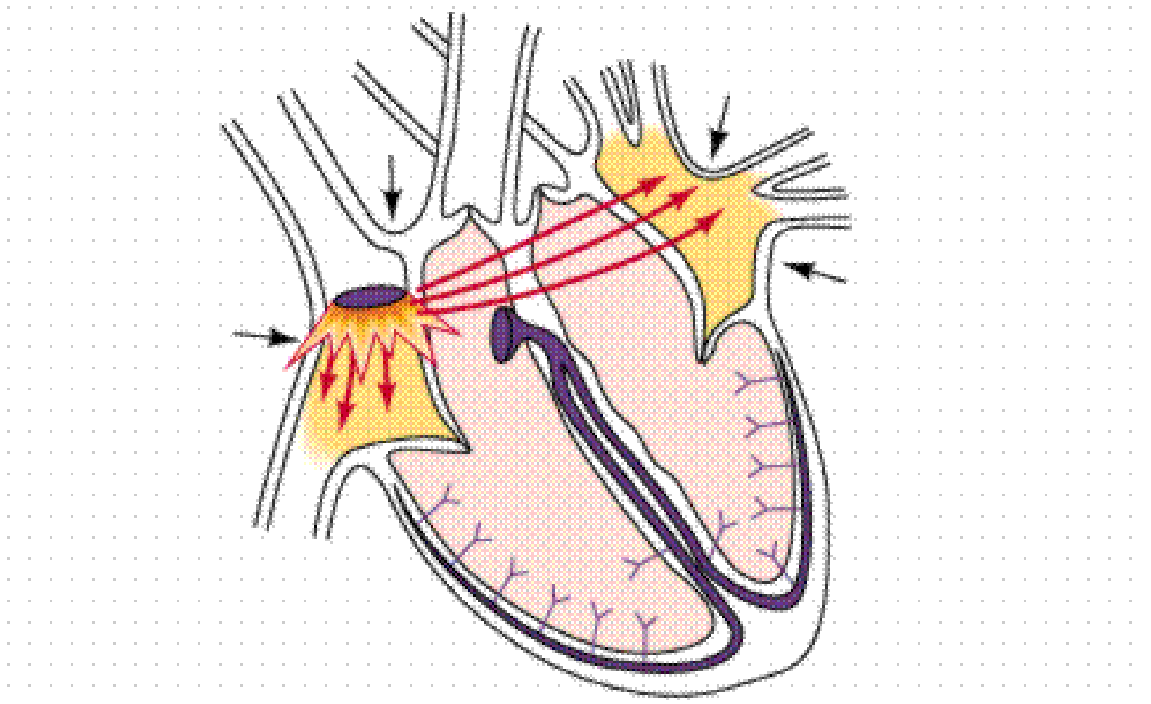
III. Form and function of the cardiac action potential

A. Sinoatrial node (SA node)

1. Spontaneously depolarizes due to a decrease of a K current, an increase of a Ca current, and a steady-inward Na background current.
2. Slow upstroke of AP due to calcium current.
3. Repolarization by potassium current.

B. Atrium

1. No spontaneous activity ; ~is excited by SA node.
2. Rapid upstroke of AP : Na current (like nerve) : rapid propagation.
3. Moderate plateau : Ca current to initiate contraction.



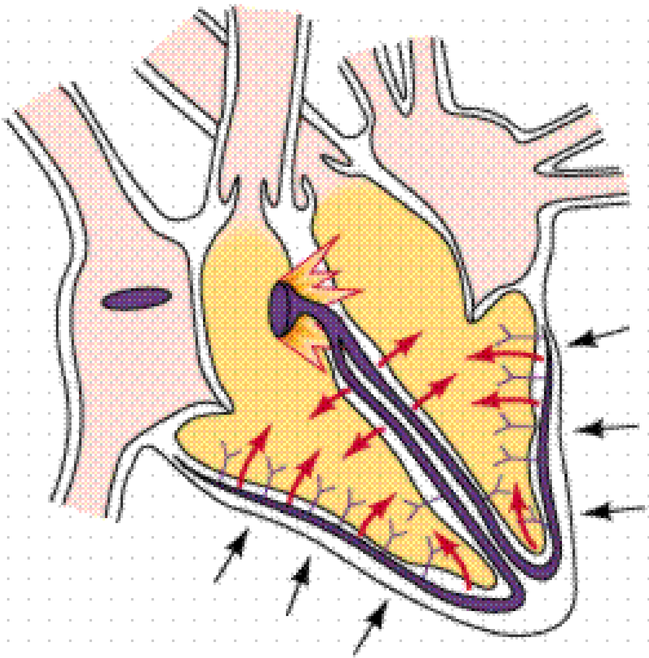
Sinoatrial node fires, action potentials spread through atria which contract

C. AV node

1. Like SA node, but slower spontaneous activity (slower pacing rate).
2. Slow upstroke of AP due to calcium current.
3. Slow propagation to provide AV delay ; slowest conduction in heart.

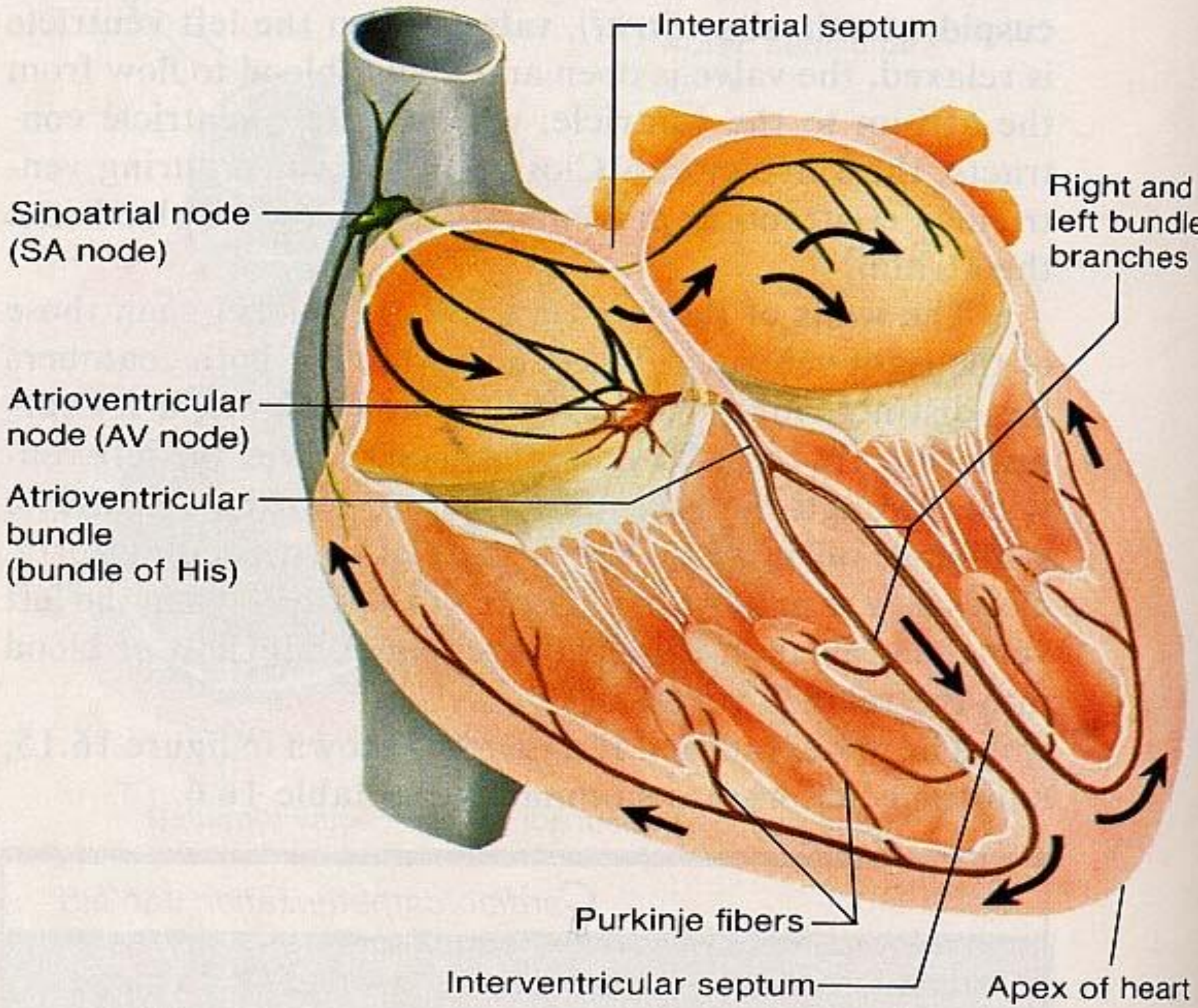
D. Purkinje fibers and ventricular cells

1. Purkinje fibers can show spontaneous activity ; ventricular cells do not.
2. Rapid Na-current upstroke ; rapid propagation ; fastest conduction time in heart.
3. Long plateau : calcium current flow to stimulate contraction.
4. Repolarization by potassium current.
5. Long plateau producing a long refractory period (time during which another AP cannot be elicited): prevents reexcitation by neighboring cells.



Atrioventricular node fires, sending impulses along conducting fibers; ventricles contract

Figure 16.17. The conduction system of the heart.



IV. Hierarchy of pacemaker region.

A. SA node, AV node, Purkinje fibers are all capable of spontaneous activity.

B. SA node normal pacemaker ; if blocked, then AV node takes over; if blocked, then Purkinje cells take over.

Electrocardiography (ECG)

- **Electrocardiography** (**ECG** or **EKG** from the German *Elektrokardiogramm*) is a transthoracic (across the thorax or chest) interpretation of the electrical activity of the heart over a period of time, as detected by electrodes attached to the outer surface of the skin and recorded by a device external to the body.
- The recording produced by this noninvasive procedure is termed as **electrocardiogram** (also ECG or EKG). An electrocardiogram (ECG) is a test that records the electrical activity of the heart.

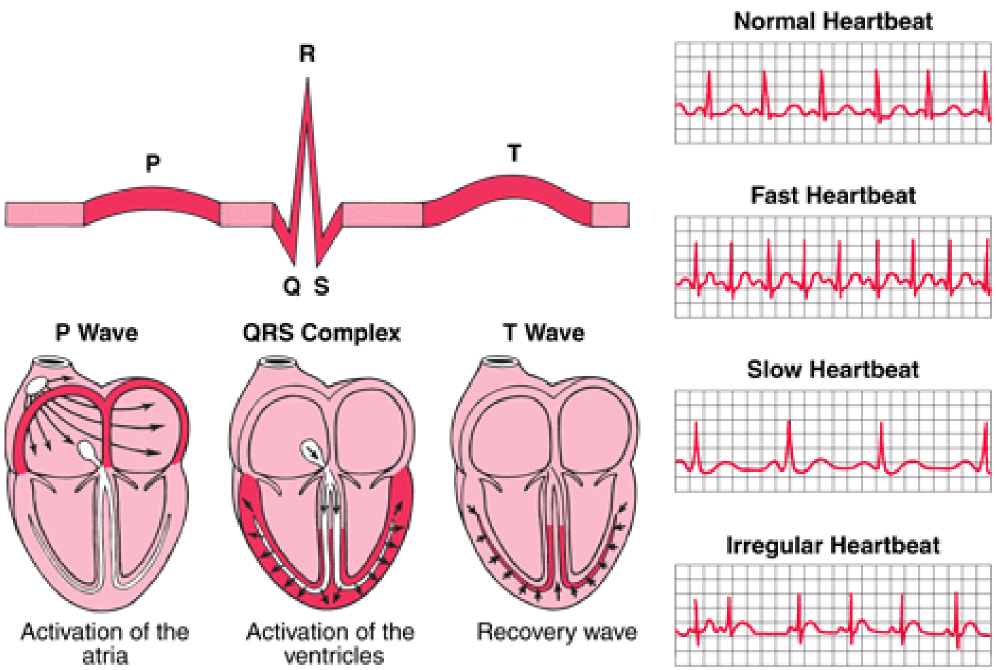
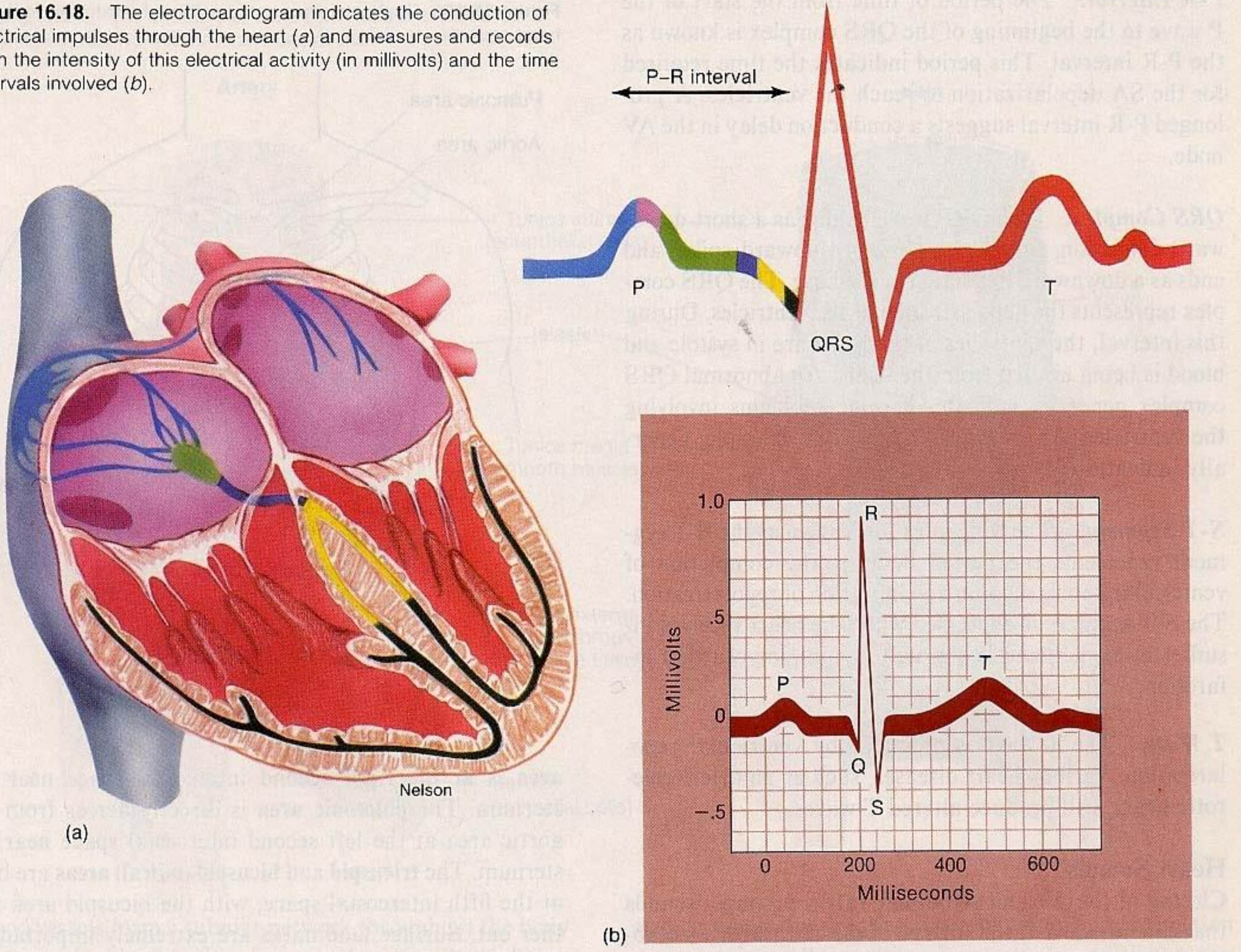
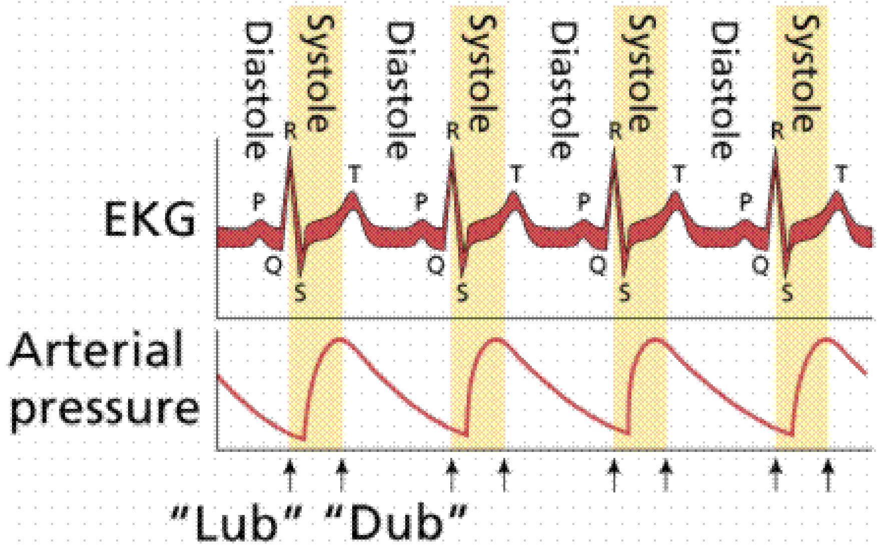


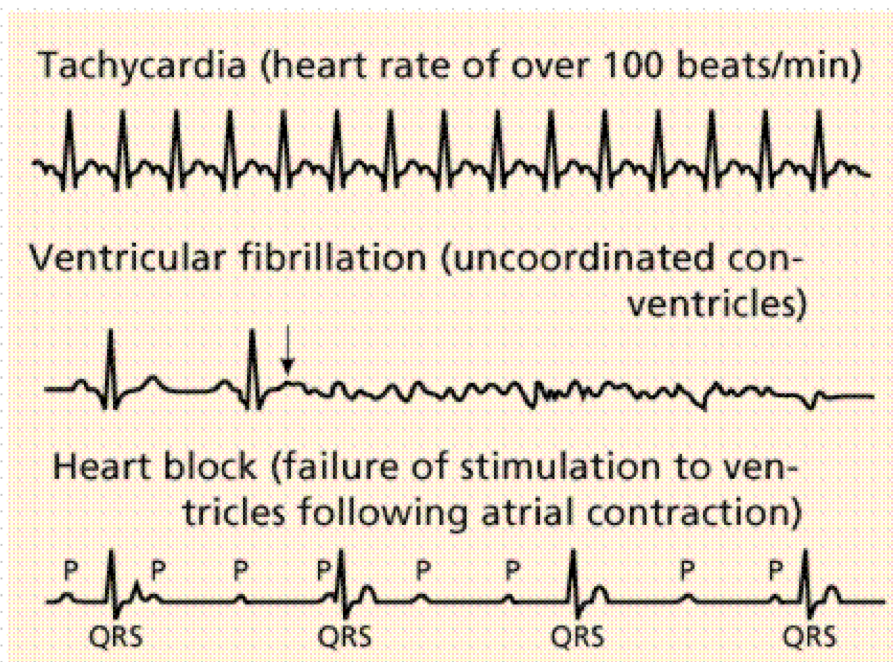
Figure 16.18. The electrocardiogram indicates the conduction of electrical impulses through the heart (*a*) and measures and records both the intensity of this electrical activity (in millivolts) and the time intervals involved (*b*).



A normal electrocardiogram (EKG)



Some abnormal EKGs

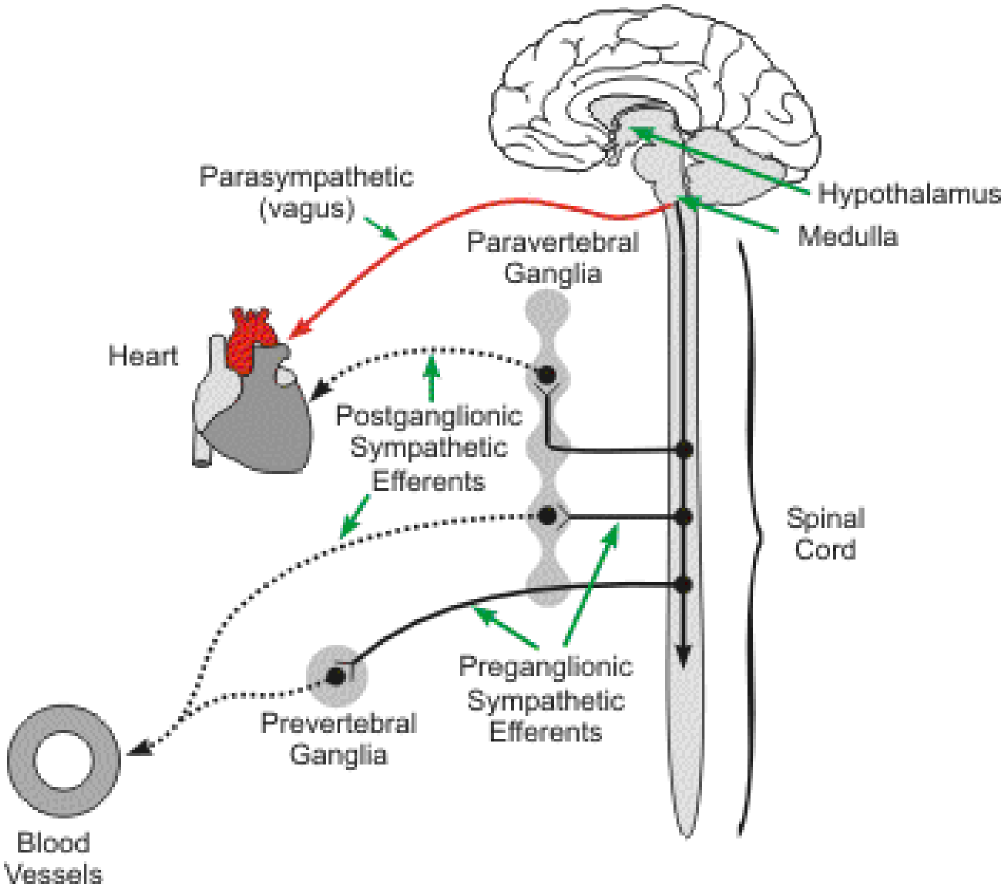


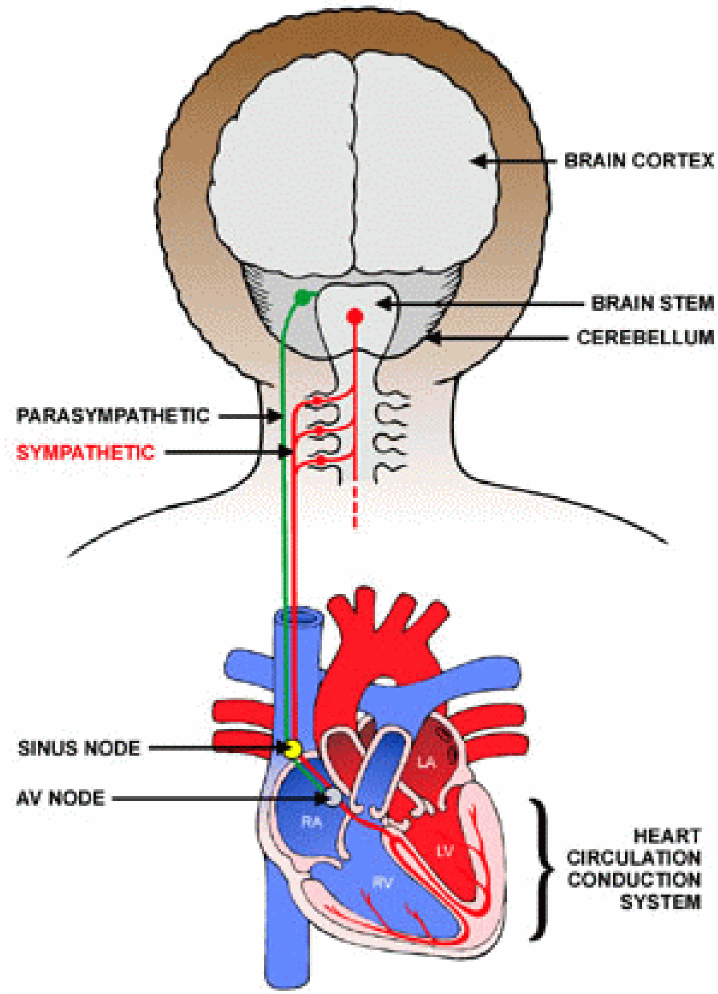
Neural and hormonal regulation.

A. Autonomic nervous system

1. Sympathetic nervous system.

a. Transmitter is norepinephrine(NE).
b. SA node rate increases (+ chronotropic effect) ; NE increases the Ca current that depolarizes the tissue which leads to the AP.
c. Faster conduction through AV node : Increased Ca current.
d. More forceful contraction by ventricles (+ inotropic effect).





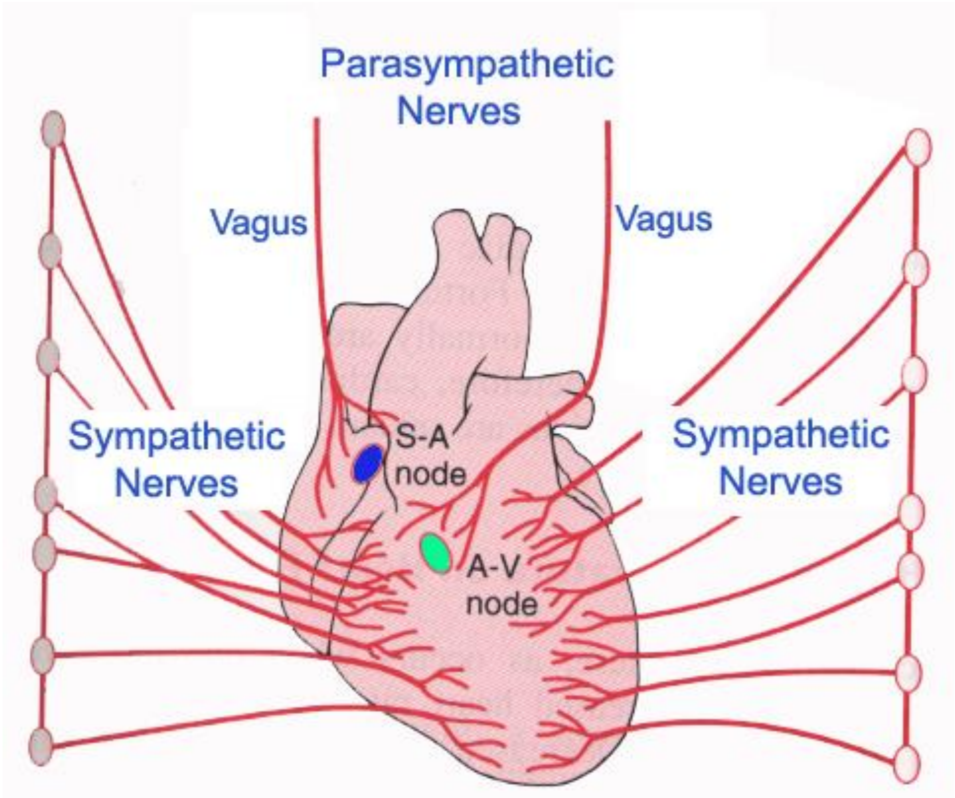
Your nervous system speeds up your heart rate.

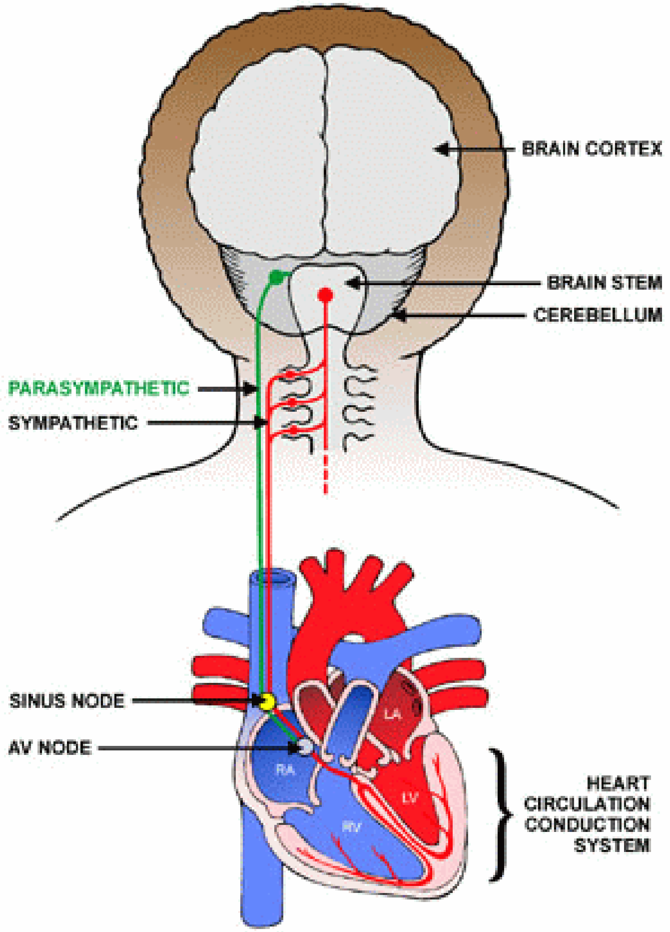
2. Parasympathetic nervous system

   a. Vagus nerve ; transmitter is acetylcholine (ACh).
   b. Slows SA node rate (negative chronotropic effect).
   c. ACh opens new K channels which hyperpolarizes cells ; Ca current is decreased.
   d. Slows conduction through AV node.
   e. Decreases force of contraction (negative inotropic effect).

3. Parasymp. tone predominates ; cutting all nerves lead to faster heart rate.

4. During exercise, symp. stim. causes positive inotropic and chronotoropic effects.





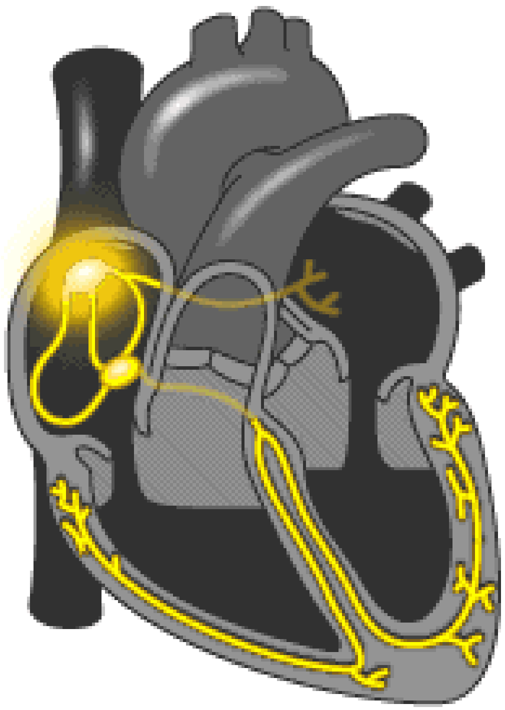
Your nervous system slows down your heart rate.

B. Hormones.

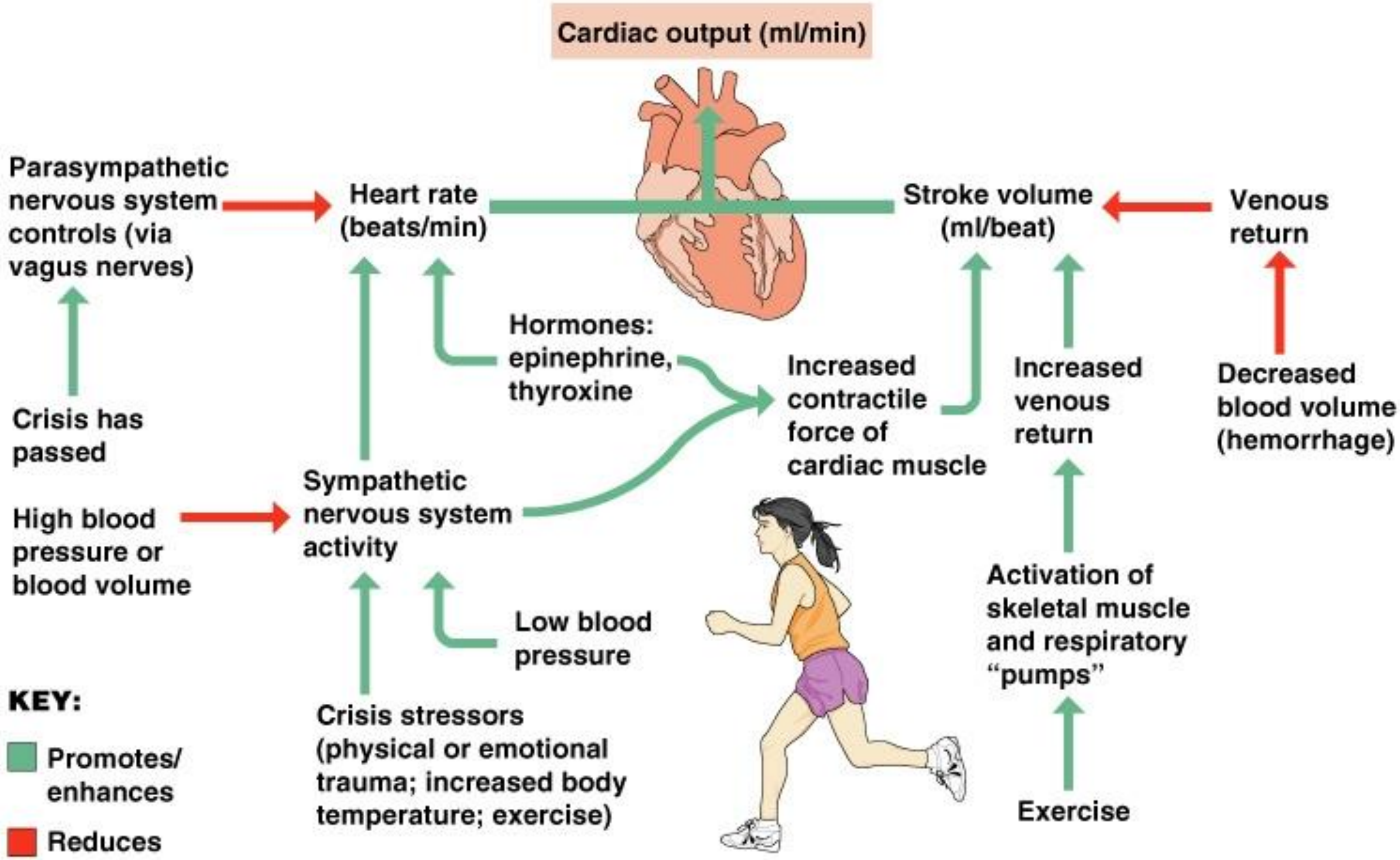
1. Epinephrine(adrenaline) ; released by adrenal medulla : has same effect as NE.
2. Angiotensin II : important hormone for regulating blood pressure ; same effect as EPI and NE in heart muscle.

Cardiac Output

- Cardiac output is the volume of blood being pumped by the heart in a minute.
- It is equal to the heart rate multiplied by the stroke volume.



Factors Influencing Cardiac Output:



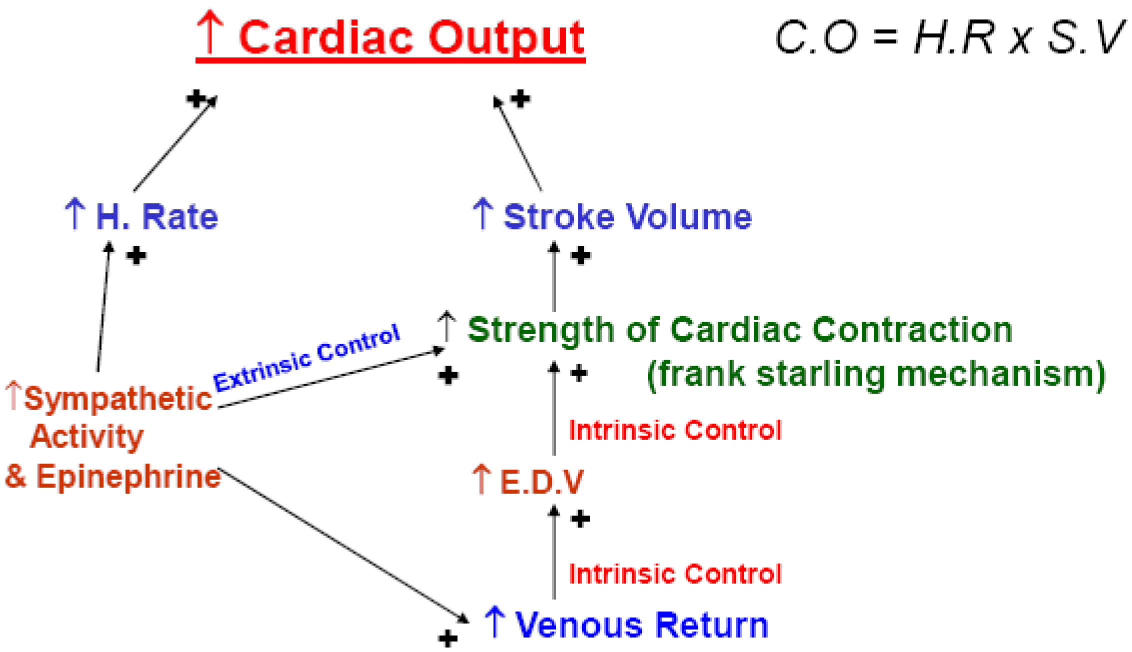
Factors Affecting Cardiac Output

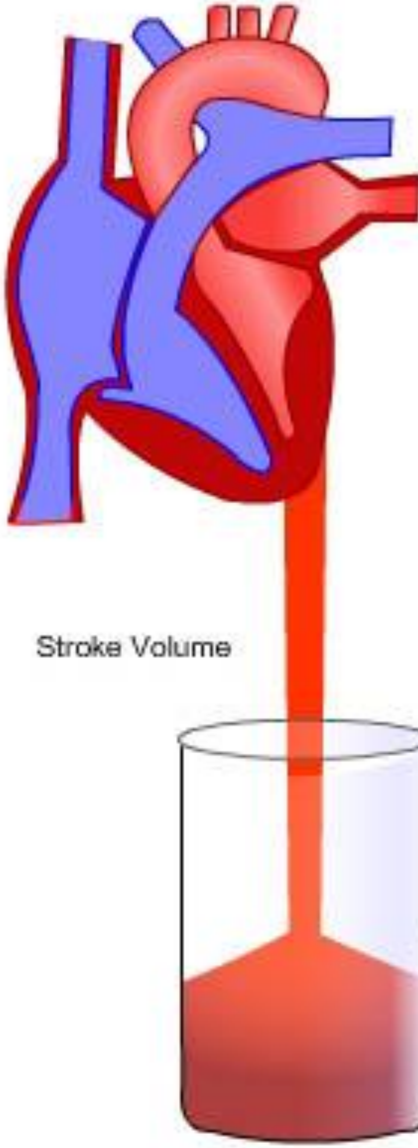
- Increase/ decreased in heart rate
- Change of posture
- Sympathetic nervous system activity
- Parasympathetic nervous system activity can also affect cardiac output.

Stroke volume

- Stroke volume is the amount of blood pumped by the left ventricle of the heart in one contraction.
- The stroke volume is not all of the blood contained in the left ventricle.
- The heart does not pump all the blood out of the ventricle.
- Normally, only about two-thirds of the blood in the ventricle is put out with each beat.

Regulation of Cardiac Output





To increase cardiac output

Increase stroke volume

or

Increase heart rate

or

increase both

I. Definitions

volume pumped per minute (ml/min).

1. Same volume is pumped by R. and L. vent. (normally about 5,000 ml/min).

2. Cardiac output = stroke volume x heart rate. (CO=SV x HR)

3. Factors controlling heart rate :

   a. Intrinsic rate of SA node.

   b. 2 important outside influences from autonomic nervous system :

   i. (+) chronotropic effects (β-receptors).

   ii. (-) chronotropic effects (muscarinic receptors).

4. Ejection fraction = SV/EDV.

If ventricle has 140 ml of blood just before systole (end diastolic volume(EDV) = 140 ml) and 80ml is pumped during systole(SV = 80ml) then the ejection fraction = (80/140) = 0.57

5. End systolic volume(ESV) is volume remaining in the ventricle after systole(but before filling); e.g. ESV = 140-80 = 60ml.

6. SV = EDV - ESV ; this can be changed by changing either EDV or ESV ; normally, ESV can change appreciably(e.g. with exercise) while EDV changes much less.
   a. ESV increases if pressure in the aorta increases ; pressure load(afterload) increases ; SV decreases.
   b. ESV decreases if contractility of the ventricular muscle increases ; a more forceful contraction and therefore a more complete emptying of the ventricle.

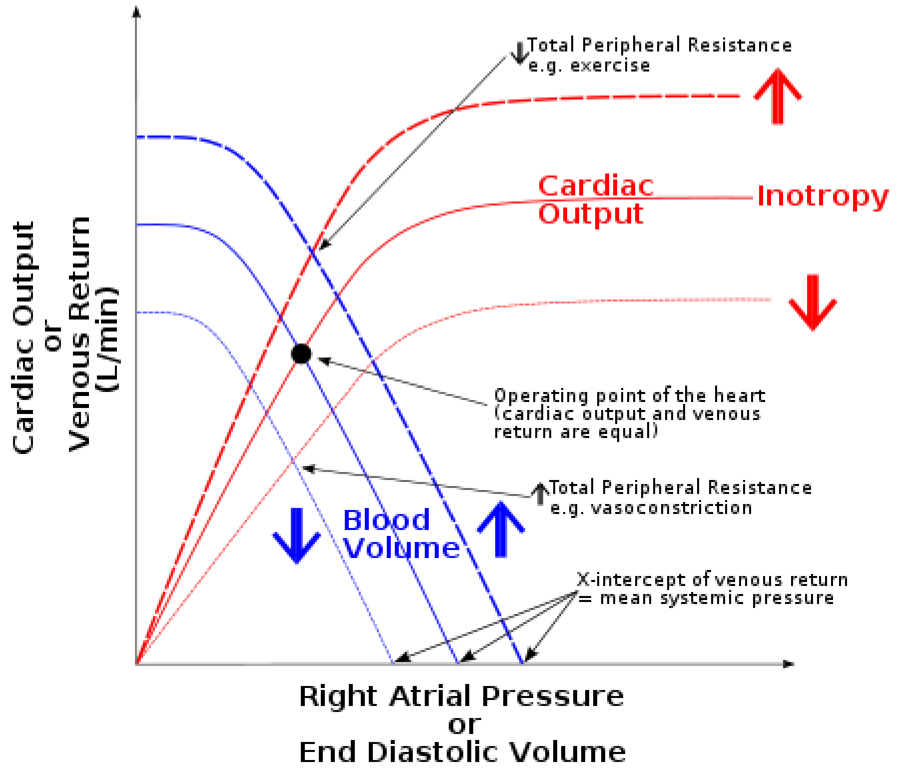
II. Starling's Law of the heart.

Starling's Law of the heart says that the heart pumps all the blood that comes to it. Also called the Frank-Starling Law.

1. The heart pumps more forcefully if it is filled more during diastole.
2. A simple mechanical pump will pump a constant volume regardless of how much fluid returns.
3. Two important factors which control SV : Intrinsic mechanical factors (Frank-Starling mechanism) : (1) preload and (2) afterload.

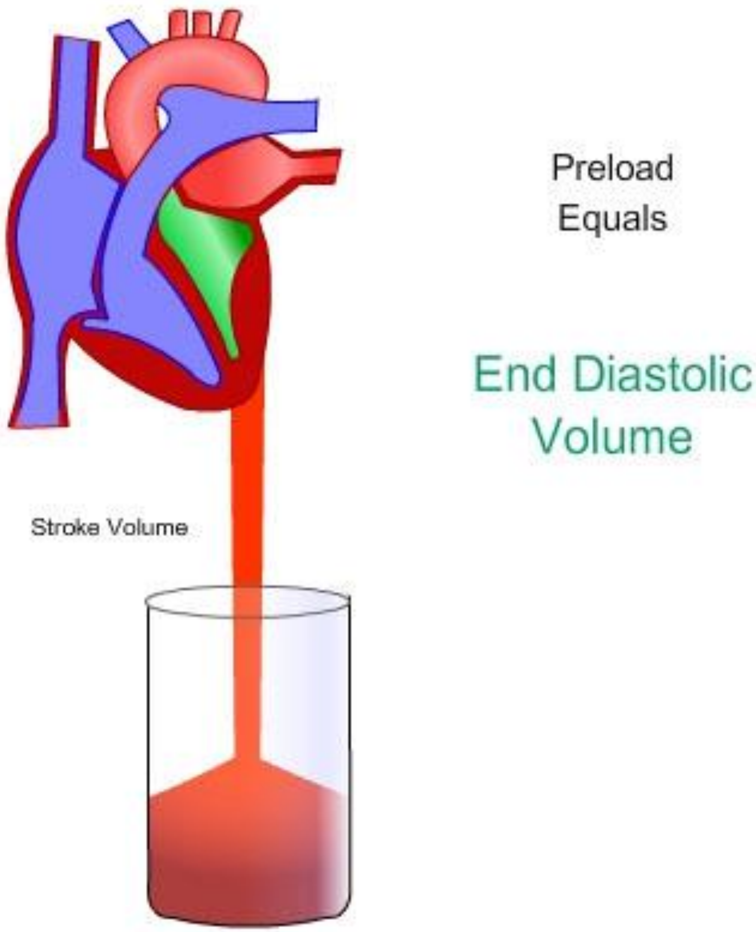
4. Starling's law is based on length-tension relationship for skeletal muscle :

- At resting length increases, contractile tension increases due to relation between thin and thick filaments; better interdigitation with thick filaments at moderate lengths thus more force generated.
- At short lengths, thin filaments interfere with each other.



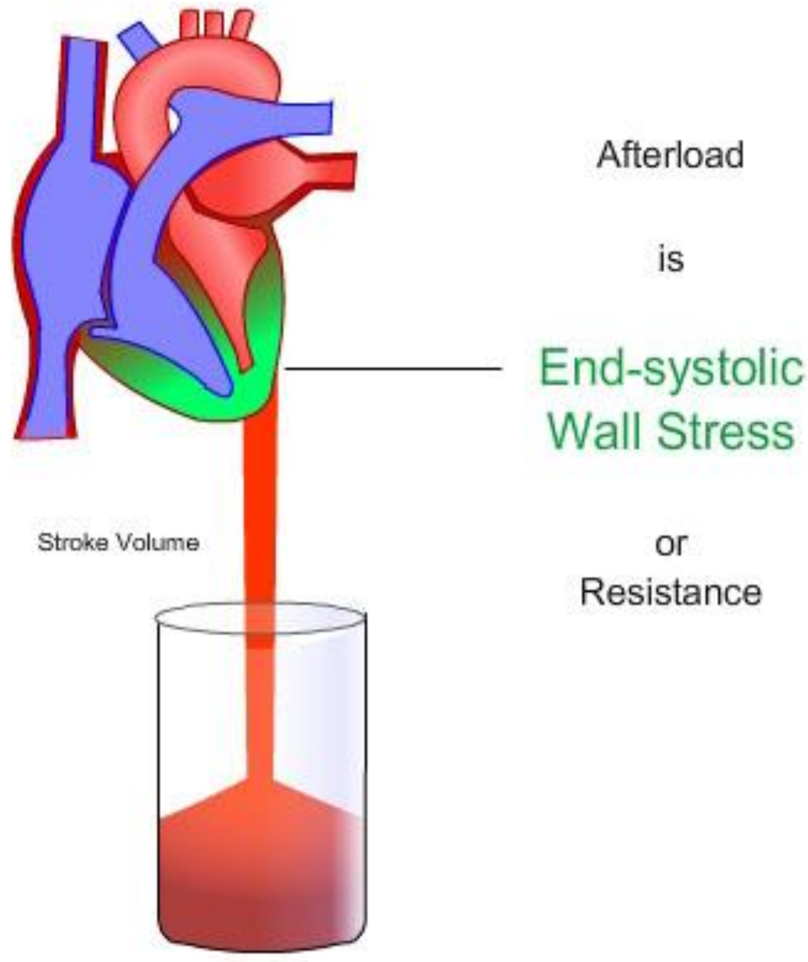
Preload

In cardiac physiology, preload is the volume of blood present in a ventricle of the heart, after passive filling and atrial contraction. If the chamber is not mentioned, it is usually assumed to be the left ventricle.



Afterload

In cardiac physiology, afterload is the tension produced by a chamber of the heart in order to contract.



Cardiac output reserves

A. Increase in rate

1. stimulation by sympathetic nervous system
2. from 70 bpm to 180 bpm possible
3. changes in heart rate is major factor in controlling cardiac output

B. Increase in SV

1. from normal value of about 60 ml/min to about 140 ml/min

To increase cardiac output

increase stroke volume

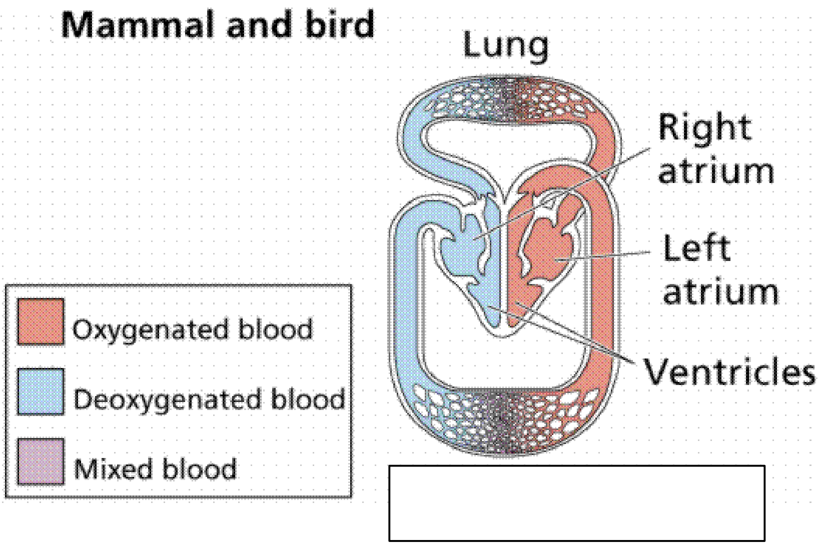
or

increase heart rate

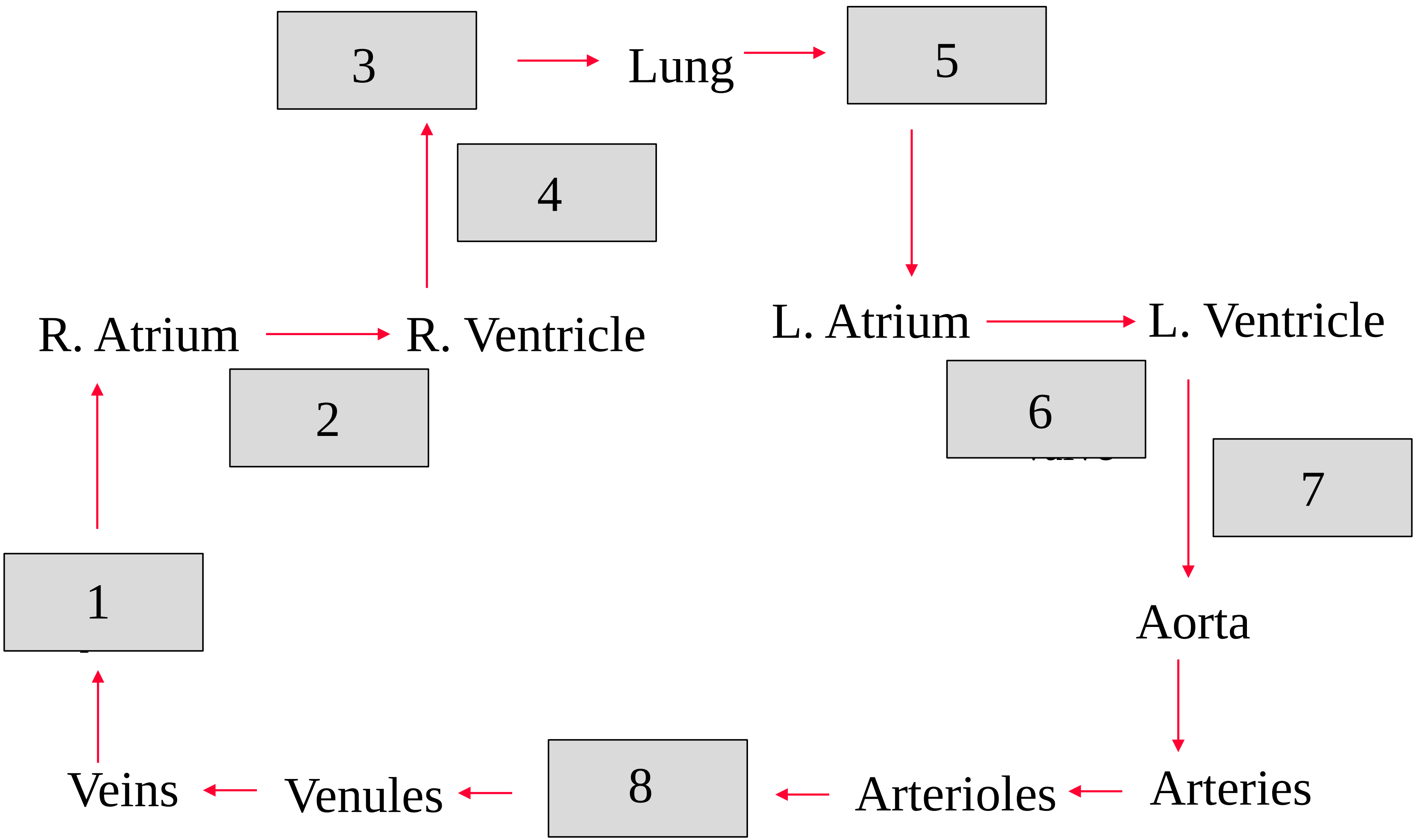
or

increase both

순환 체계


Mammal and bird
Lung
Right
atrium
Left
atrium
Ventricles
Oxygenated blood
Deoxygenated blood
Mixed blood

Quiz 3


3
Lung
5
4
R. Atrium
R. Ventricle
L. Atrium
L. Ventricle
2
6
7
1
Aorta
Veins
Venules
8
Arterioles
Arteries