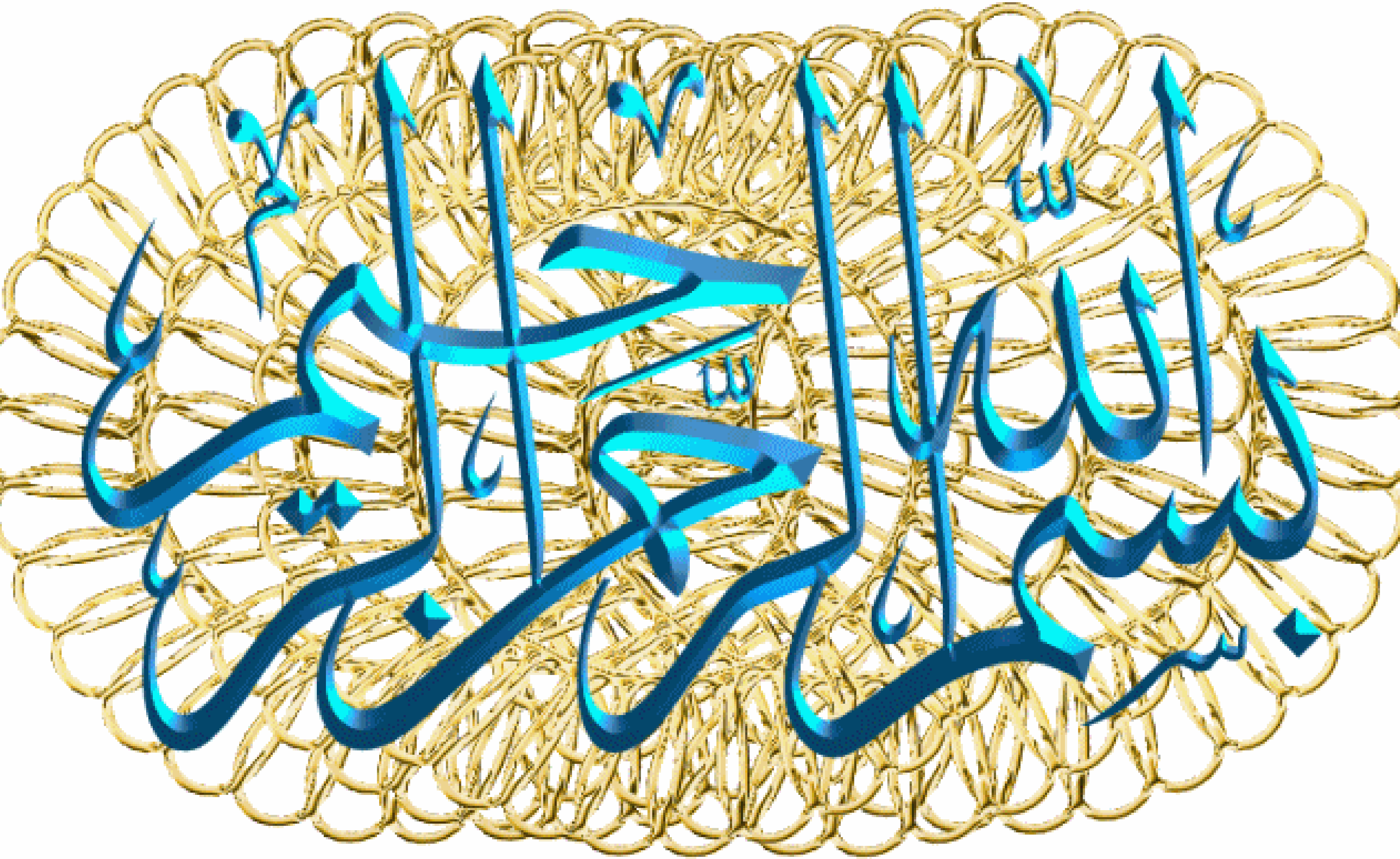
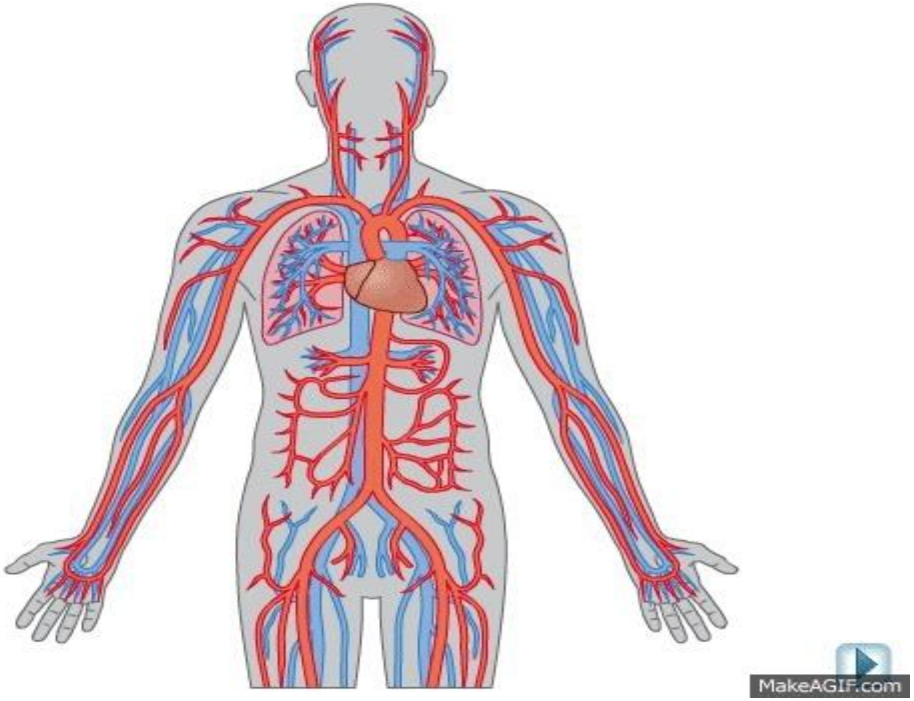
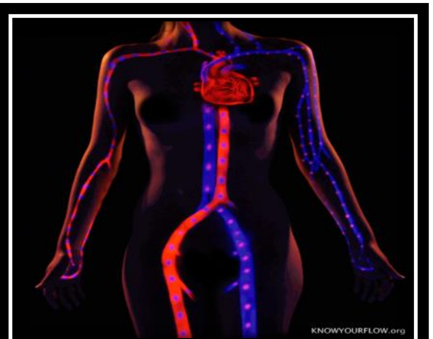

بسم الله الرحمن الرحيم

EXERCISES CAN ENHANCE CIRCULATION TO TARGETED ORGANS


Circulatory Adaptations to Exercise



Dr. Mustafa Qamar
Assistant Professor, SMC



The Circulatory System

- **Purposes of the cardiorespiratory system**
  - Transport O_2 and nutrients to tissues
  - Removal of CO_2 wastes from tissues
  - Regulation of body temperature
- **Two major adjustments of blood flow during exercise**
  - Increased cardiac output
  - Redistribution of blood flow

The Circulatory System

- **Heart**
  - Creates pressure to pump blood
- **Arteries and arterioles**
  - Carry blood away from the heart
- **Capillaries**
  - Exchange of O_2, CO_2, and nutrients with tissues
- **Veins and venules**
  - Carry blood toward the heart

Structure of the Heart

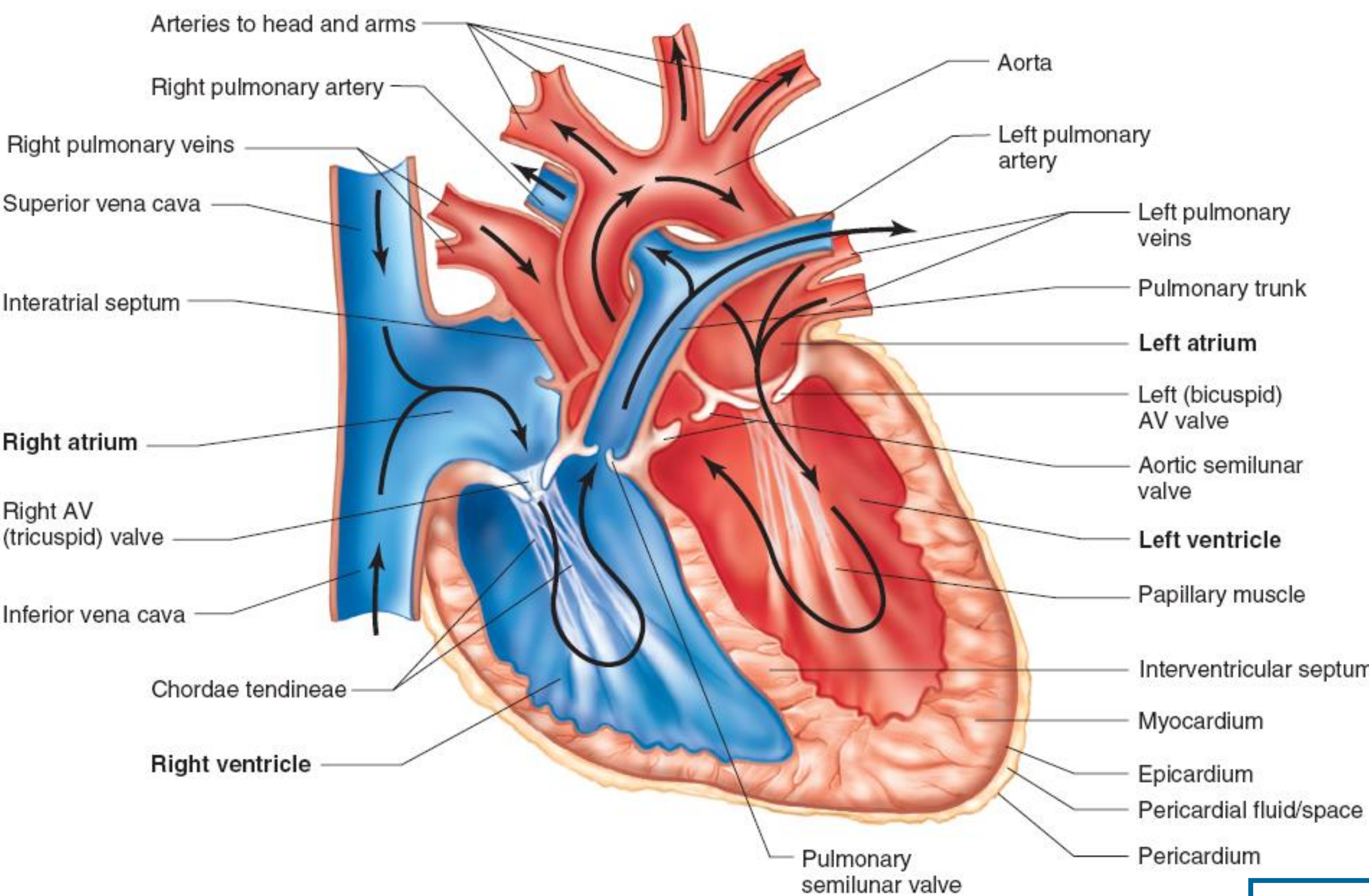


Figure 9.1


Active Heart Rate
100-120 BPM

Pulmonary and Systemic Circuits

- **Pulmonary circuit**
  - Right side of the heart
  - Pumps deoxygenated blood to the lungs via pulmonary arteries
  - Returns oxygenated blood to the left side of the heart via pulmonary veins
- **Systemic circuit**
  - Left side of the heart
  - Pumps oxygenated blood to the whole body via arteries
  - Returns deoxygenated blood to the right side of the heart via veins

Pulmonary and Systemic Circulations

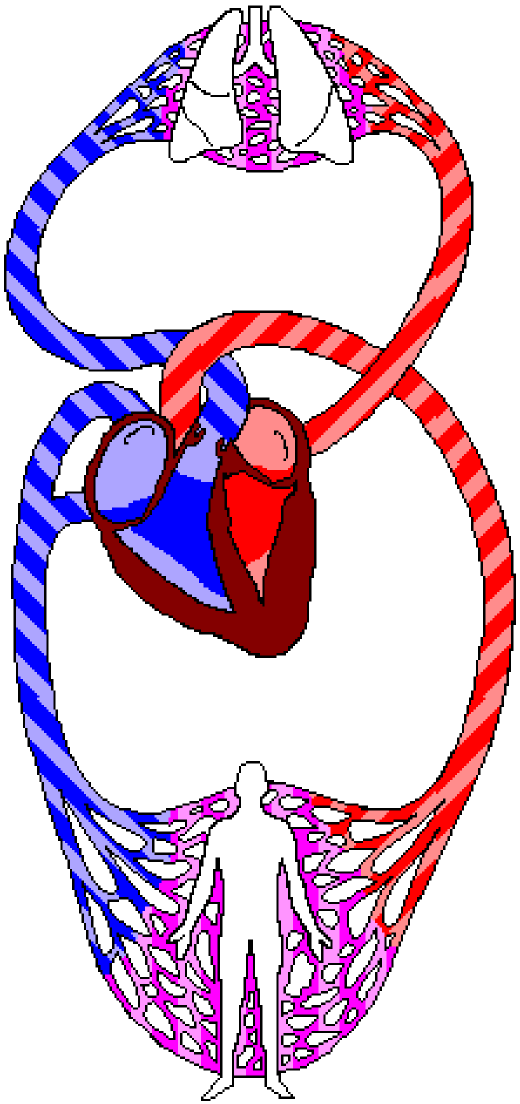


Figure 9.2

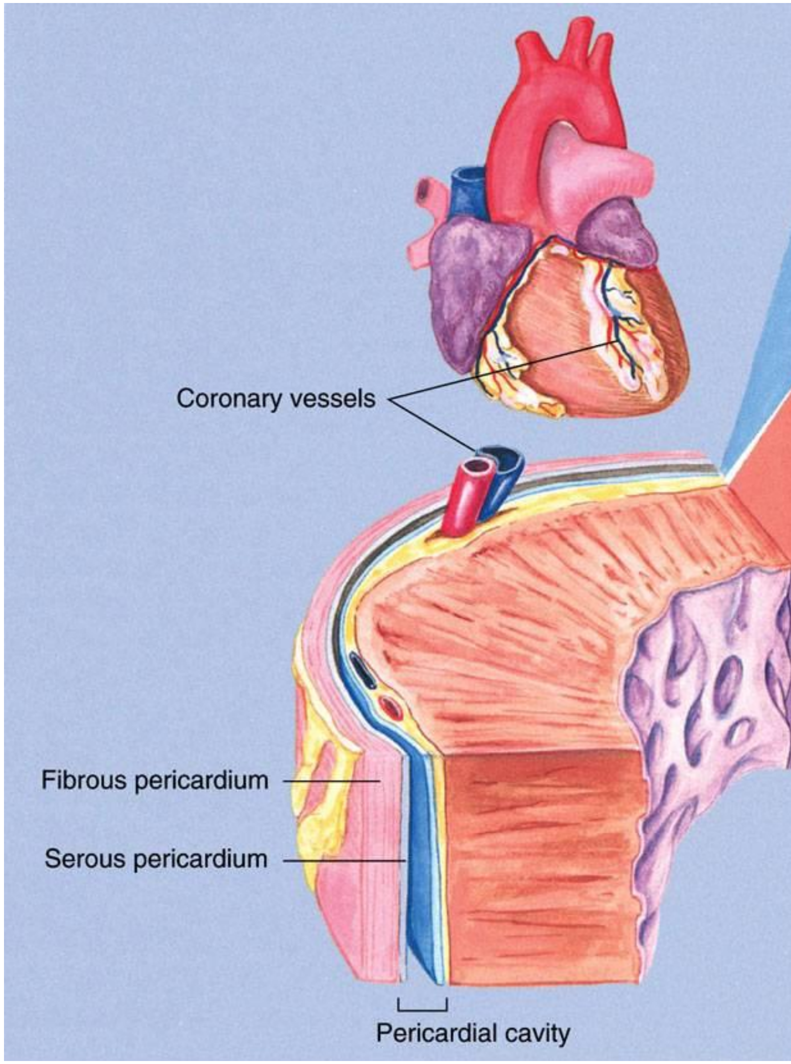
In Summary

- The purposes of the cardiovascular system are the following: (1) the transport of O_2 to tissues and removal of wastes, (2) the transport of nutrients to tissues, and (3) the regulation of body temperature.
- The heart is two pumps in one. The right side of the heart pumps blood through the pulmonary circulation, while the left side of the heart delivers blood to the systemic circulation.

Myocardium

- **The heart wall**
  - Epicardium
  - Myocardium
  - Endocardium
- **Receives blood supply via coronary arteries**
  - High demand for oxygen and nutrients
- **Myocardial infarction (MI)**
  - Blockage in coronary blood flow results in cell damage
  - Exercise training protects against heart damage during MI

The Heart Wall

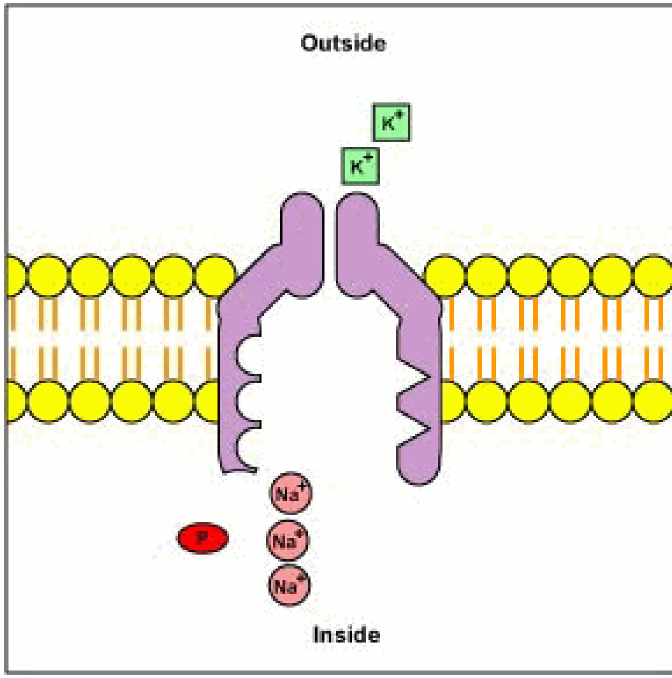


Layer	Characteristics	Function
Epicardium (visceral pericardium)	Serous membrane including blood capillaries, lymph capillaries, and nerve fibers	Serves as lubricative outer covering
Myocardium	Cardiac muscle tissue separated by connective tissues and including blood capillaries, lymph capillaries, and nerve fibers	Provides muscular contractions that eject blood from the heart chambers
Endocardium	Endothelial tissue and a thick subendothelial layer of elastic and collagenous fibers	Serves as protective inner lining of the chambers and valves

Figure 9.3

Exercise Training Protects the Heart

- **Regular exercise is cardioprotective**
  - Reduce incidence of heart attacks
  - Improves survival from heart attack
- **Exercise reduces the amount of myocardial damage from heart attack**
  - Improvements in heart's antioxidant capacity
  - Improved function of ATP-sensitive potassium channels



Endurance Exercise Protects Against Cardiac Injury During Heart Attack

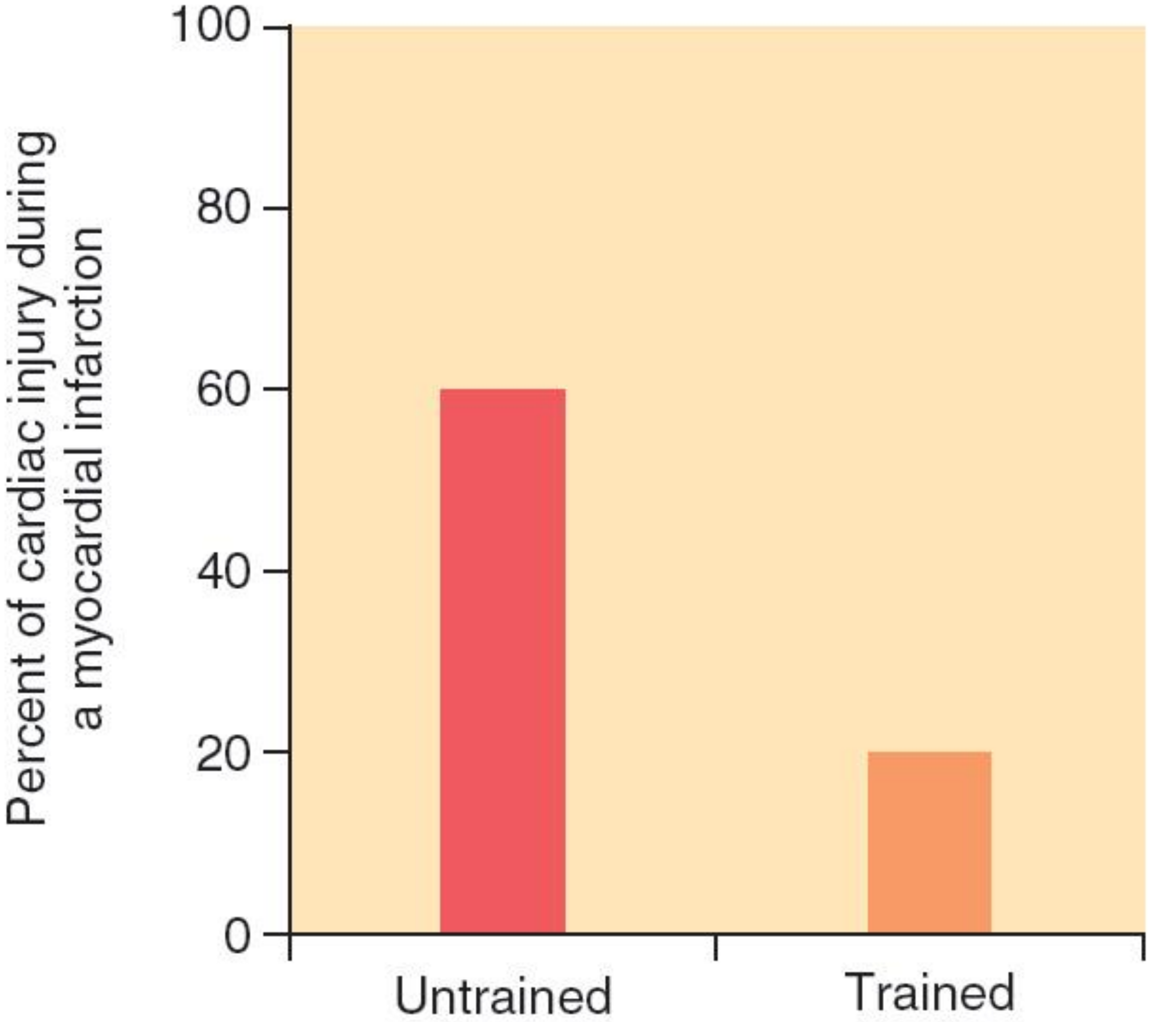


Figure 9.4

The Cardiac Cycle

- **Systole**
  - Contraction phase
  - Ejection of blood
- **Diastole**
  - Relaxation phase
  - Filling with blood
- **At rest, diastole longer than systole**
- **During exercise, both systole and diastole are shorter**

The Cardiac Cycle at Rest and During Exercise

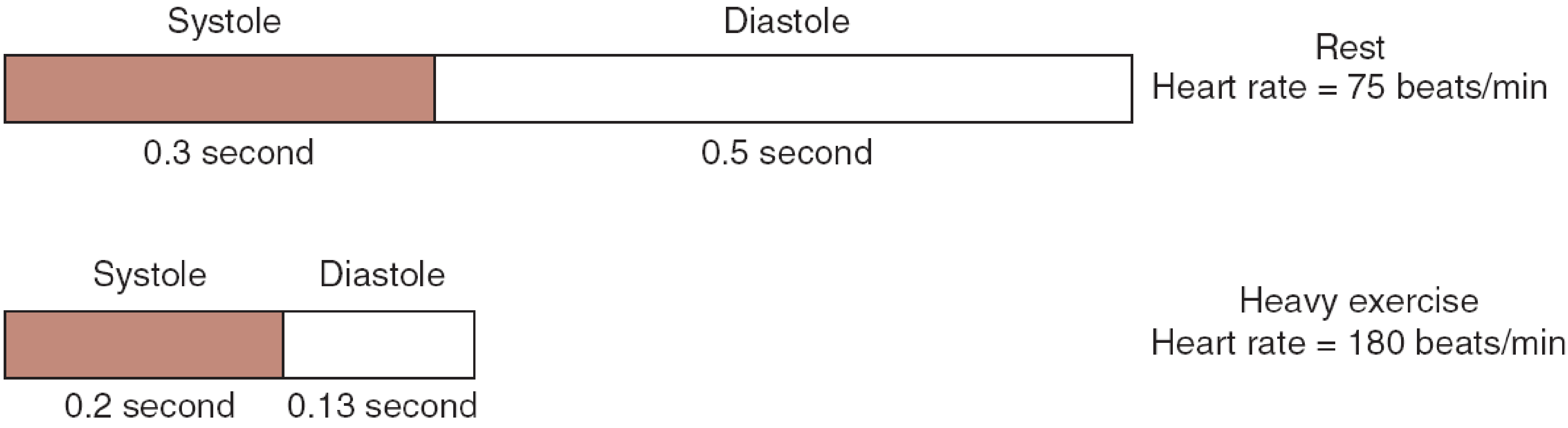


Figure 9.5

Pressure Changes During the Cardiac Cycle

- **Diastole**
  - Pressure in ventricles is low
  - Filling with blood from atria
    - AV valves open when ventricular P < atrial P
- **Systole**
  - Pressure in ventricles rises
  - Blood ejected in pulmonary and systemic circulation
    - Semilunar valves open when ventricular P > aortic P
- **Heart sounds**
  - First: closing of AV valves
  - Second: closing of aortic and pulmonary valves

Pressure, Volume, and Heart Sounds During the Cardiac Cycle

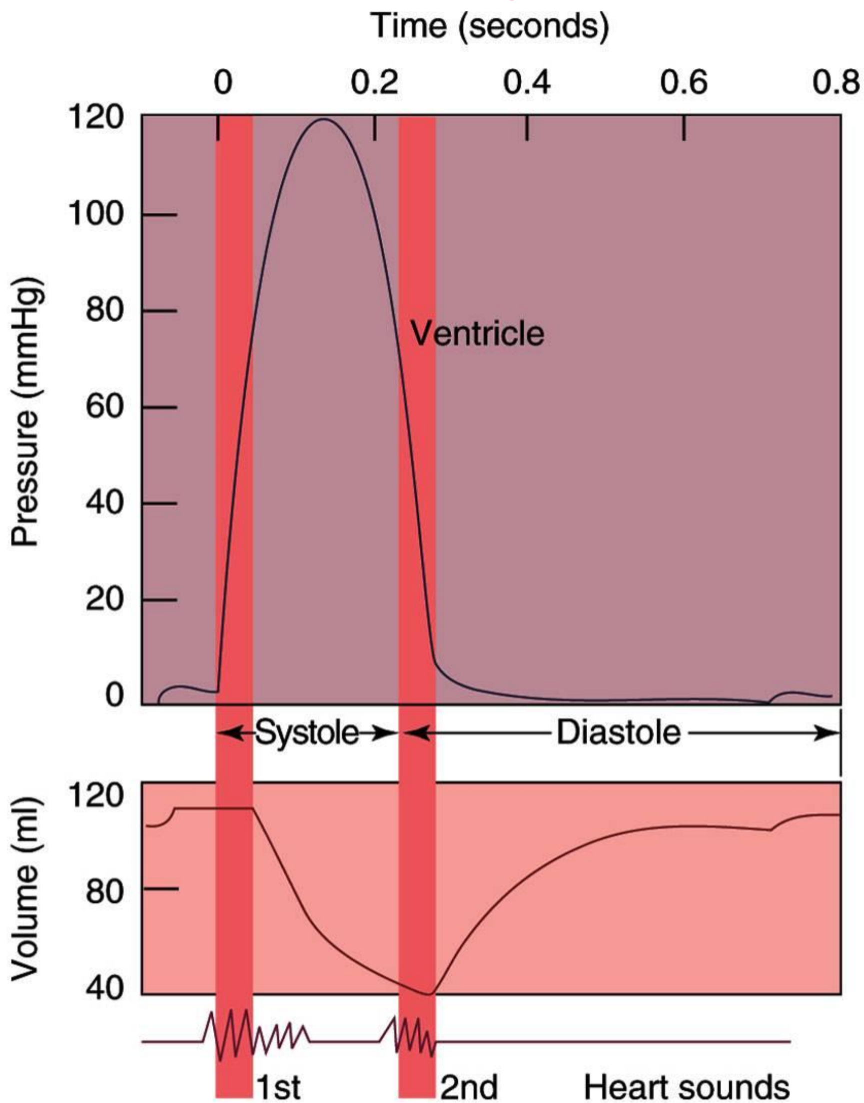
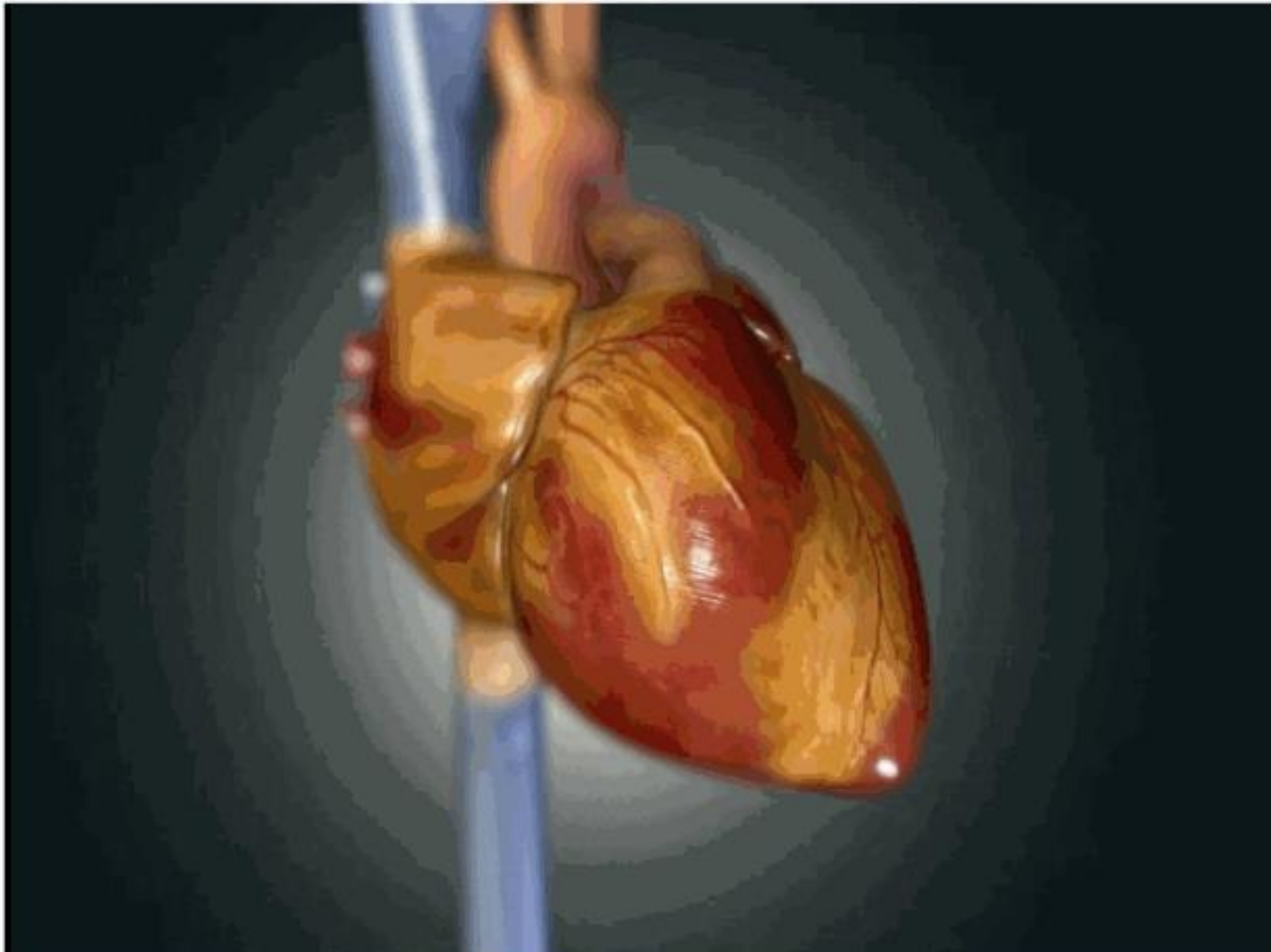


Figure 9.6

Arterial Blood Pressure

- **Expressed as systolic/diastolic**
  - Normal is 120/80 mmHg
- **Systolic pressure**
  - Pressure generated during ventricular contraction
- **Diastolic pressure**
  - Pressure in the arteries during cardiac relaxation
- **Pulse pressure**
  - Difference between systolic and diastolic
- **Mean arterial pressure (MAP)**
  - Average pressure in the arteries

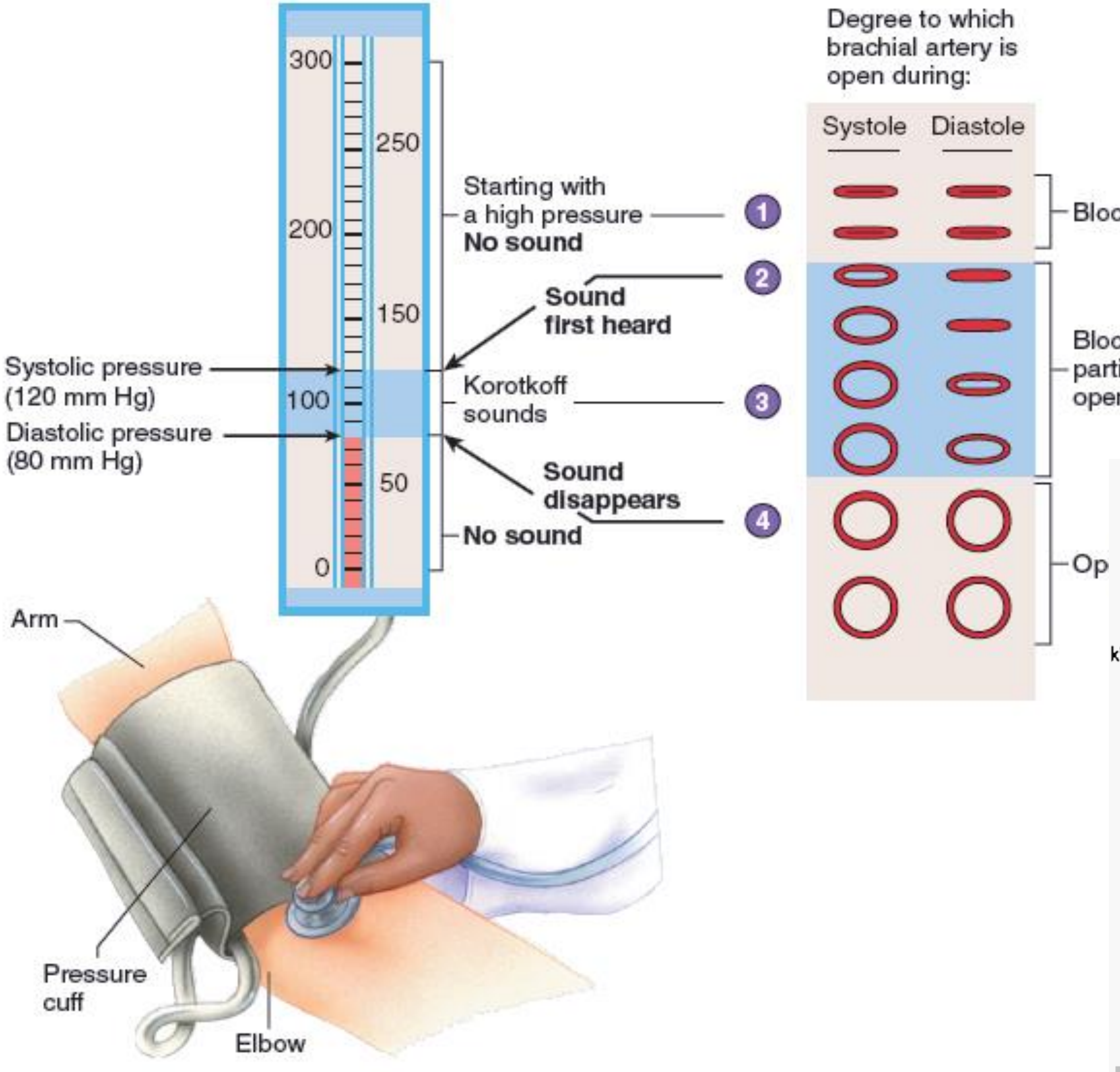
    MAP = DBP + 0.33(PP)



Hypertension

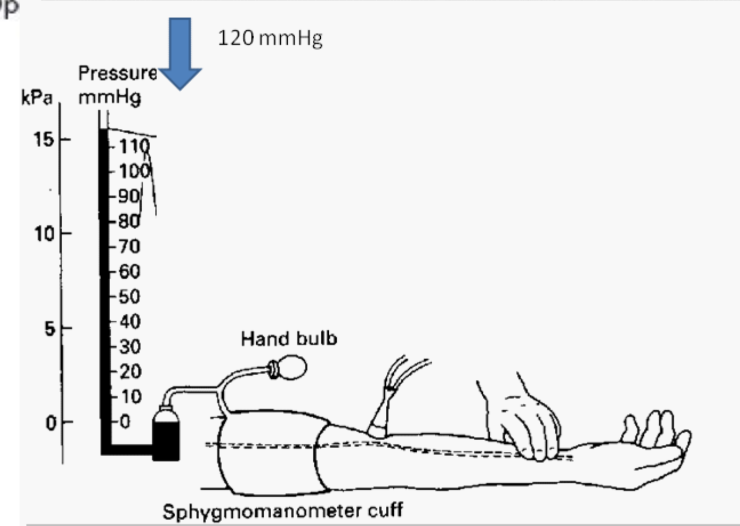
- **Blood pressure above 140/90 mmHg**
- **Primary (essential) hypertension**
  - Cause unknown
  - 90% cases of hypertension
- **Secondary hypertension**
  - result of some other disease process
- **Risk factor for:**
  - Left ventricular hypertrophy
  - Atherosclerosis and heart attack
  - Kidney damage
  - Stroke

Measurement of Arterial Blood Pressure



Try palpating the diastolic blood pressure

It is not unscientific !



Tactile impulses can be more sensitive, further it is immune from ambient noise contamination !

Factors that Influence Arterial Blood Pressure

- **Determinants of mean arterial pressure**
  - Cardiac output
  - Total vascular resistance

MAP = cardiac output x total vascular resistance

- **Short-term regulation**
  - Sympathetic nervous system
  - Baroreceptors in aorta and carotid arteries
- **Long-term regulation**
  - Kidneys
    - Via control of blood volume

Factors That Influence Arterial Blood Pressure

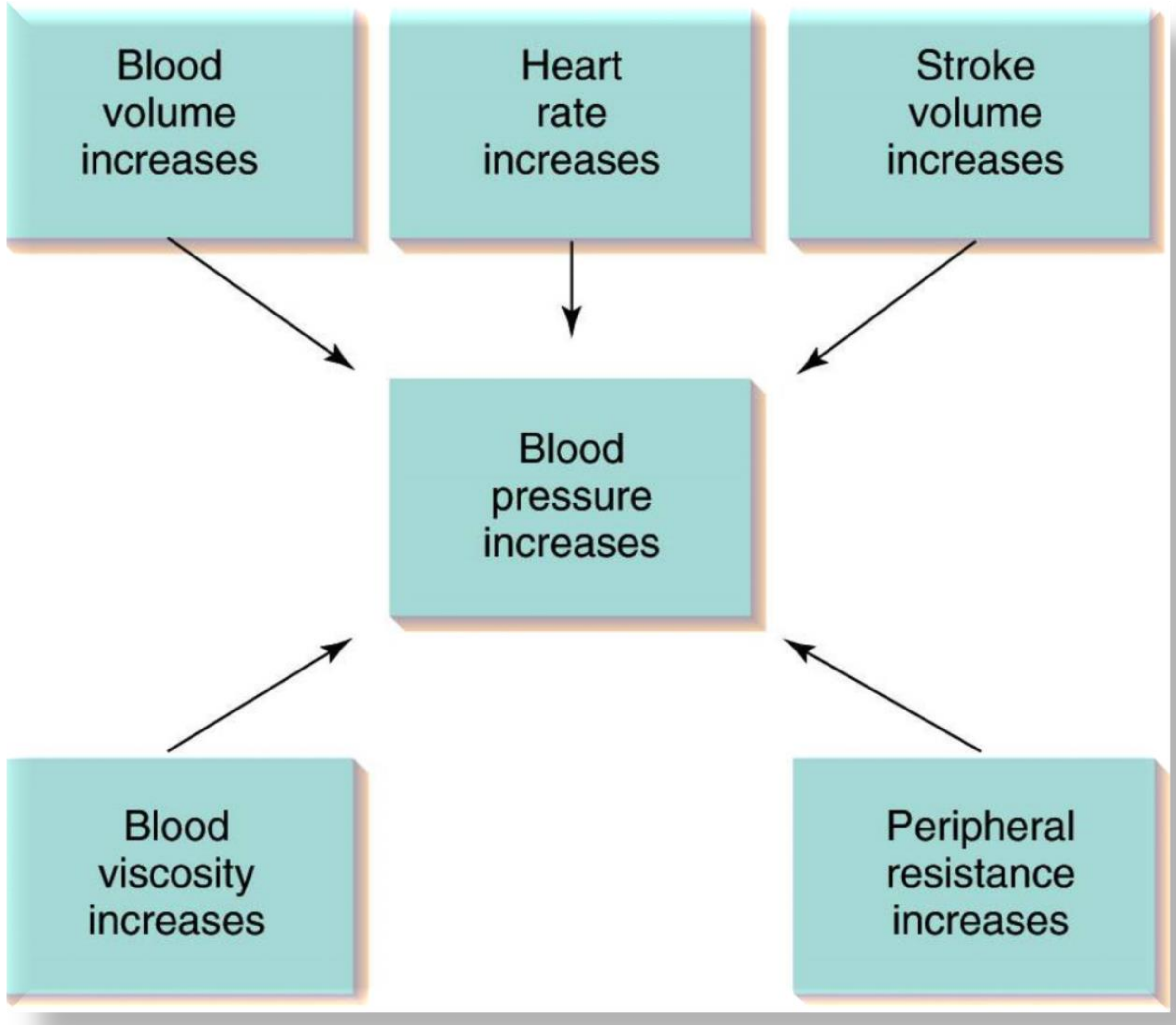
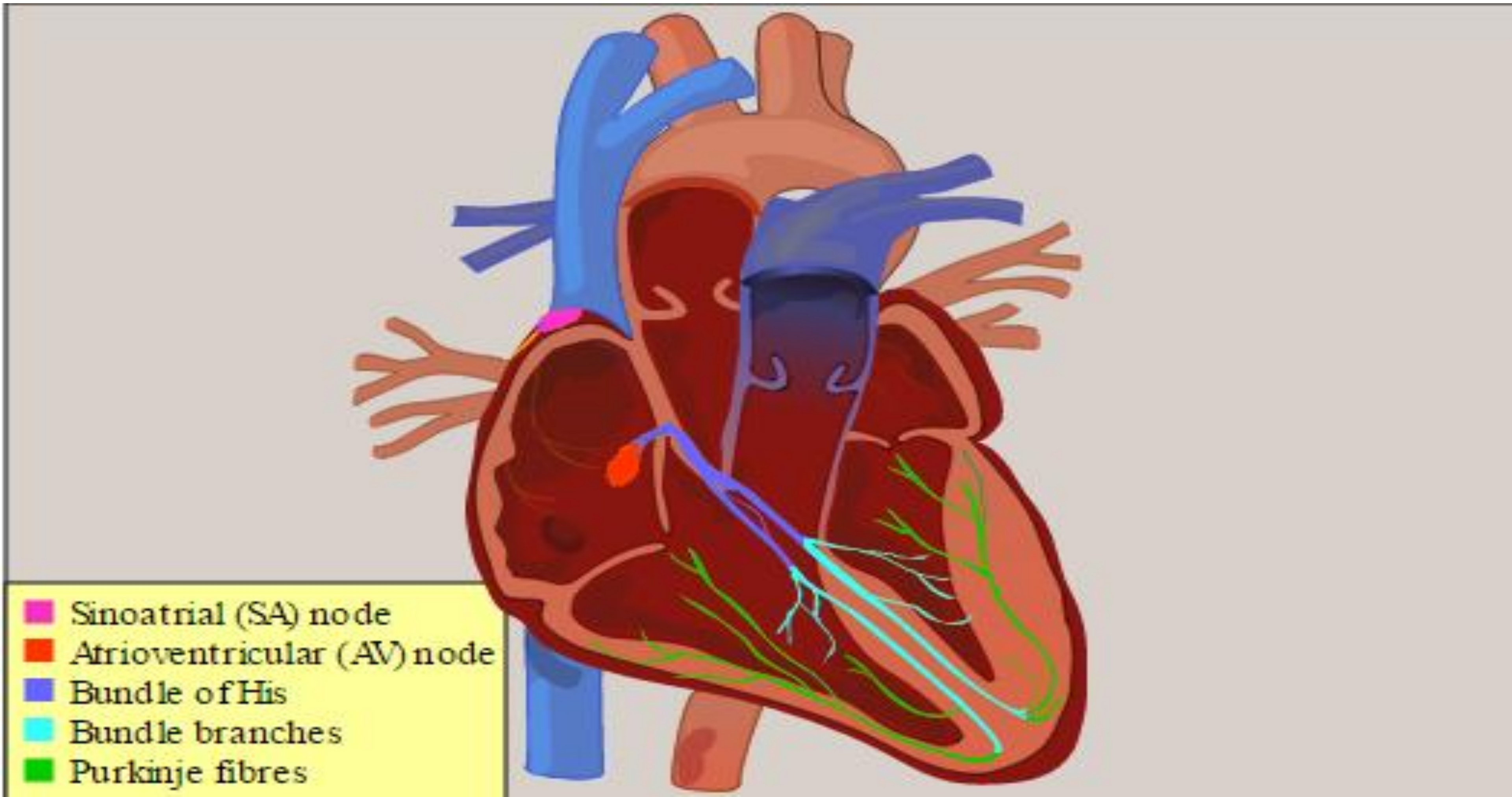
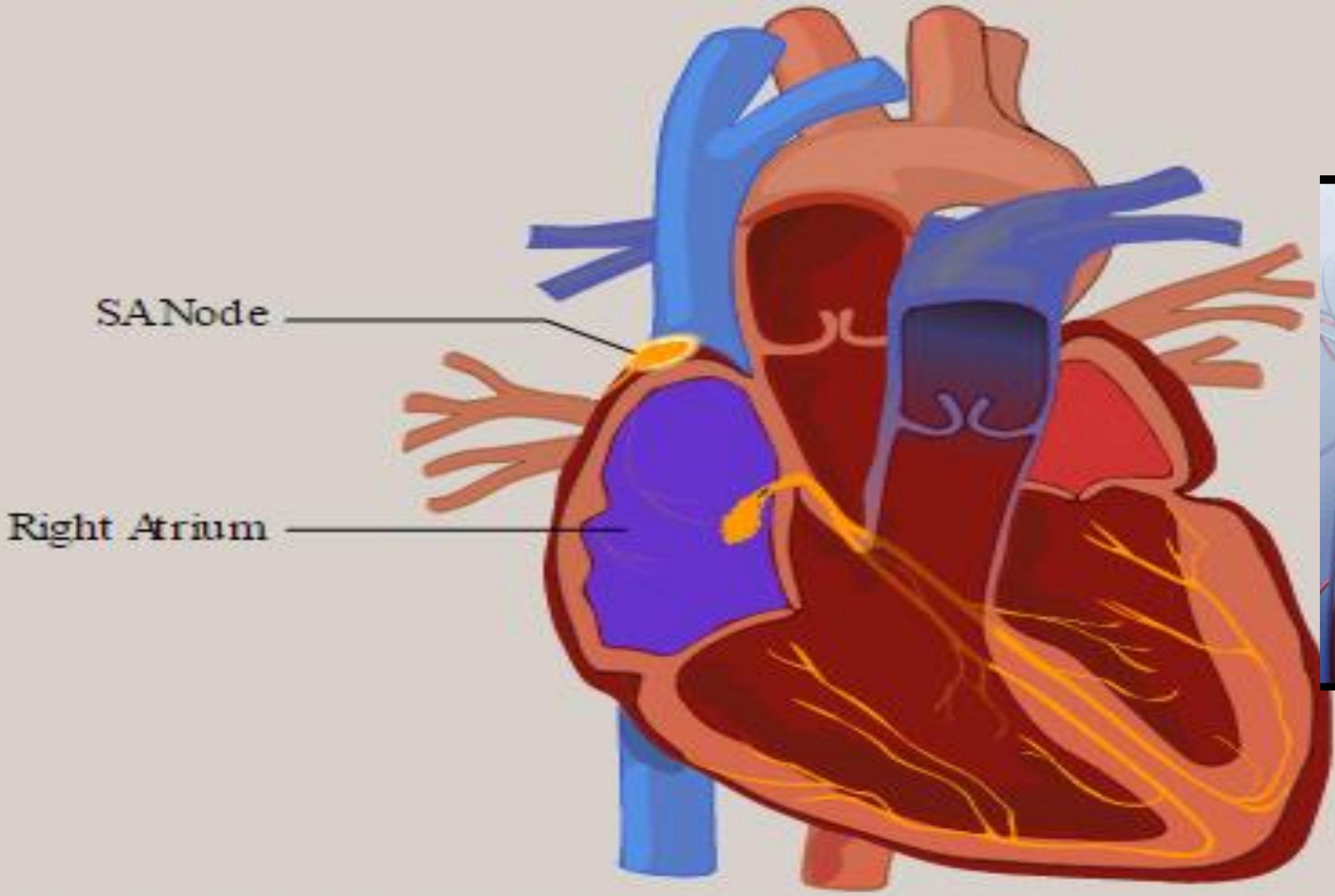


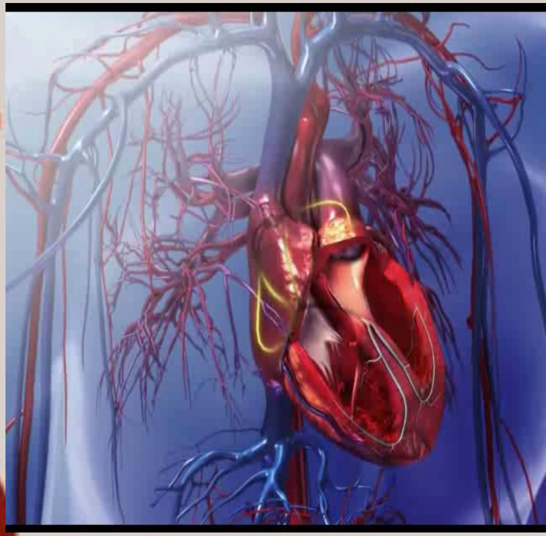
Figure 9.8

Electrical Activity of the Heart

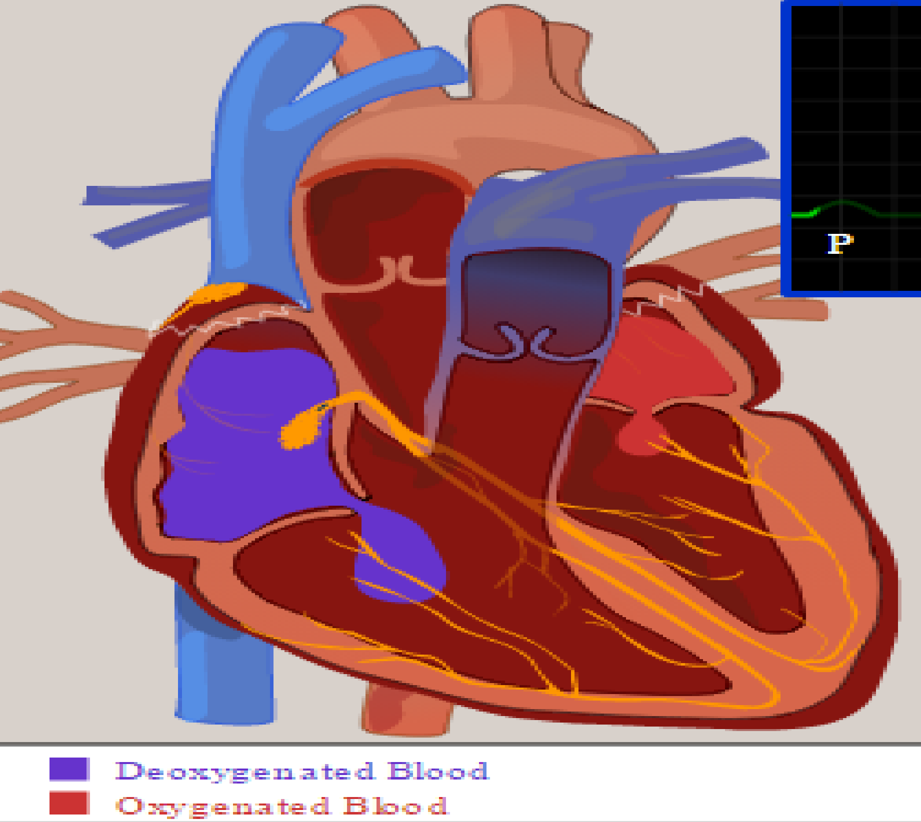
Contraction of the heart depends on electrical stimulation of the myocardium Conduction system

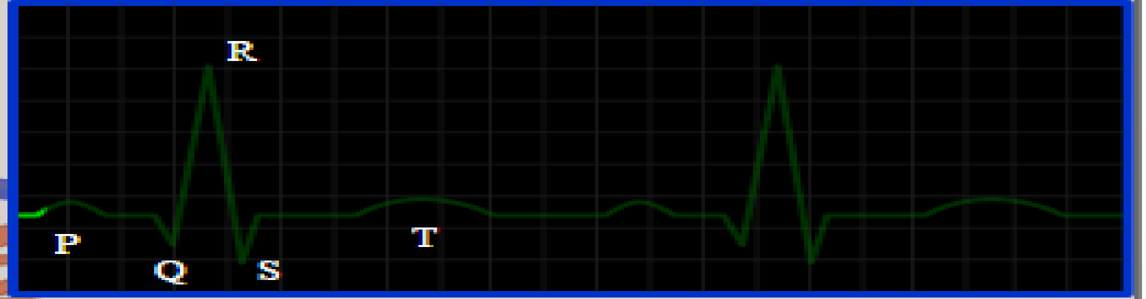


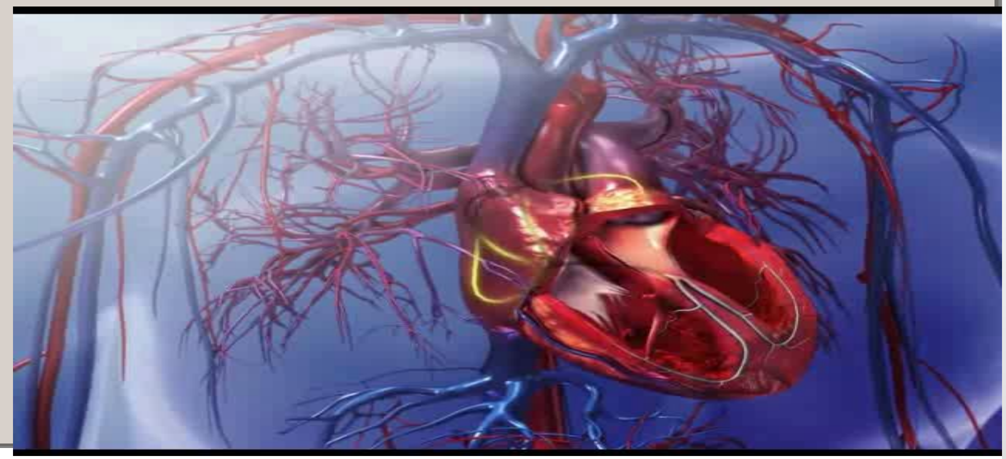




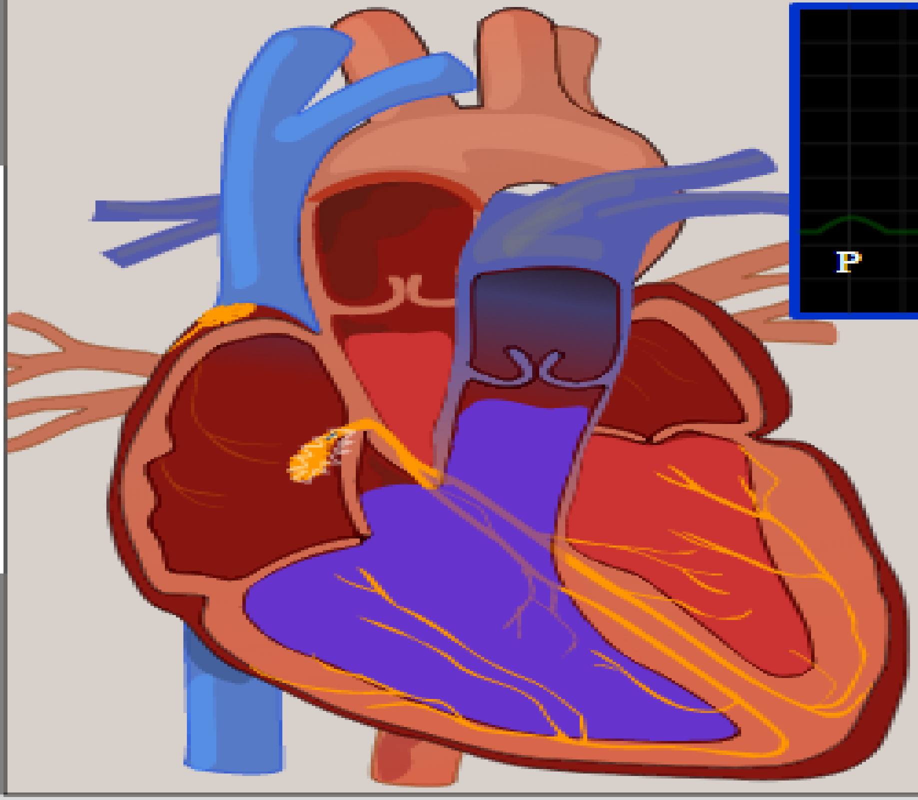
Contractions in the heart begin when electrical impulses are sent from the SA node which is located in the right atrium.

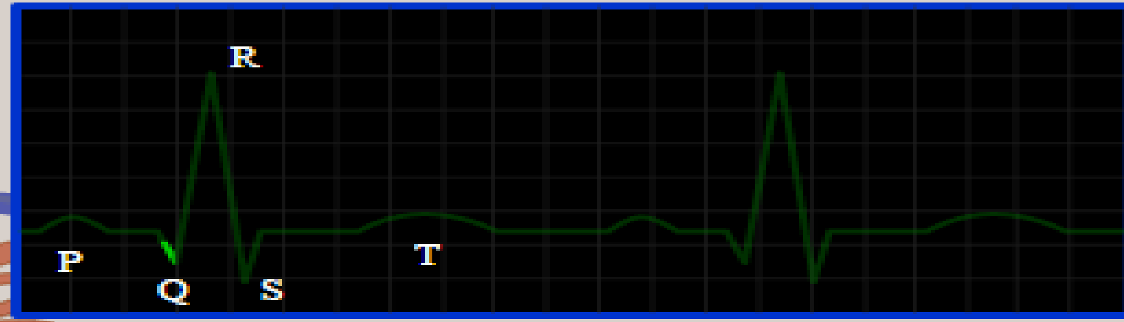


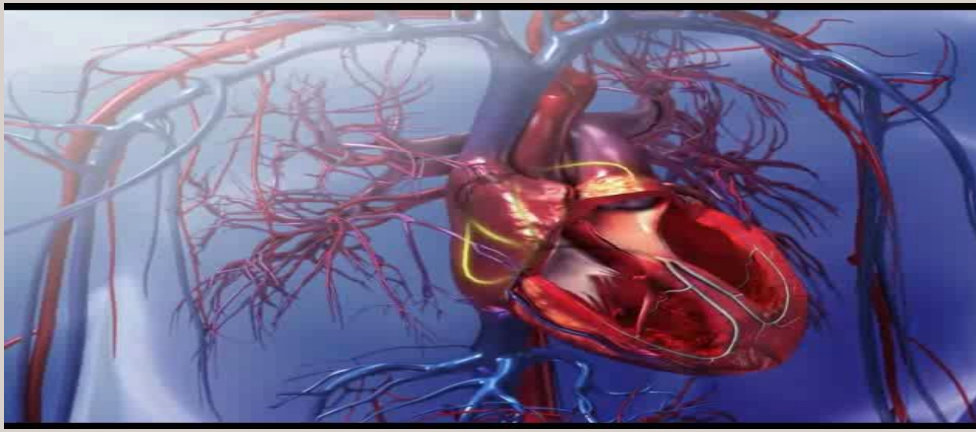




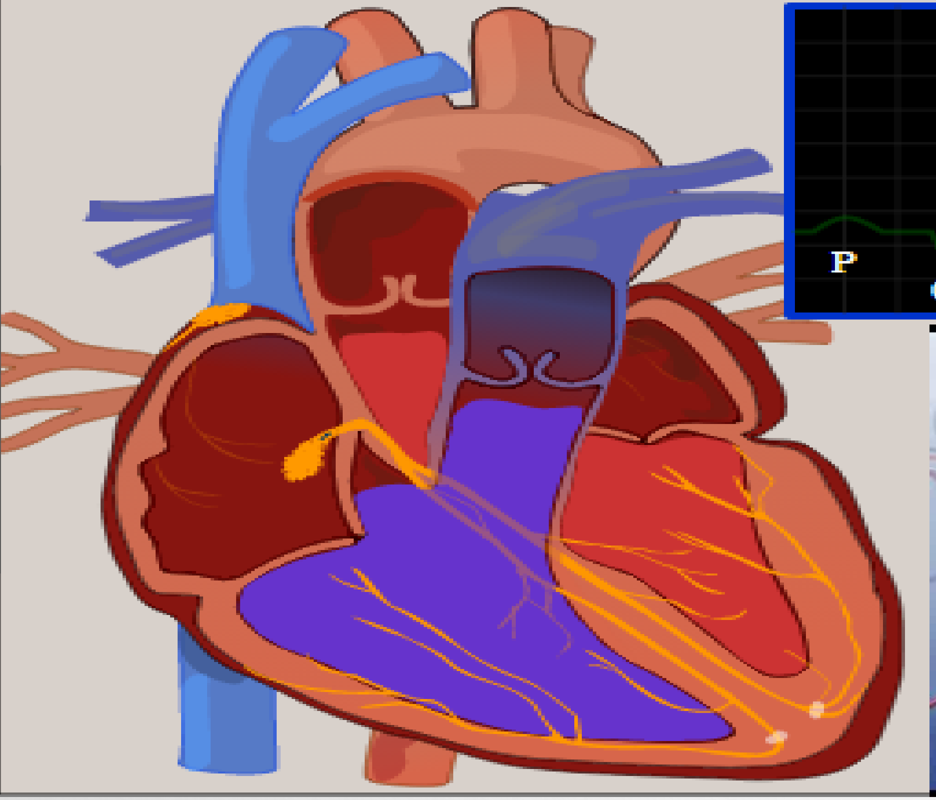
When the right atrium is filled with blood the electrical impulse spreads across the cells in the right and left atria. This causes the atria to contract. Pushing blood through the open valves into the ventricles. The contraction of the atria is represented by the **P wave on the ECG**.

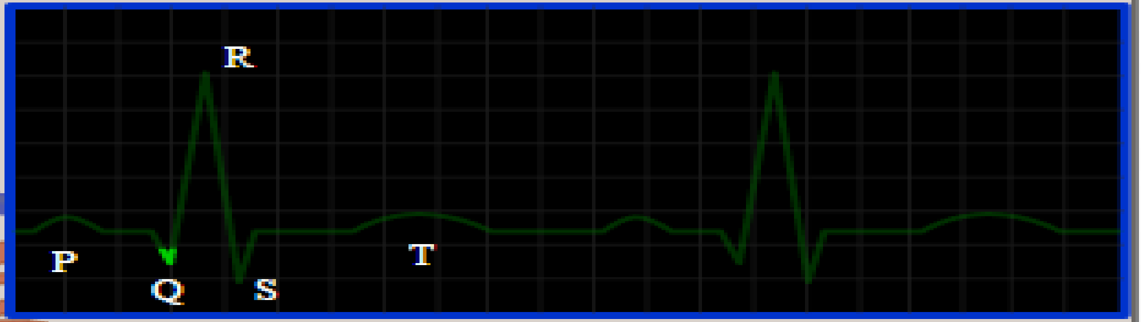


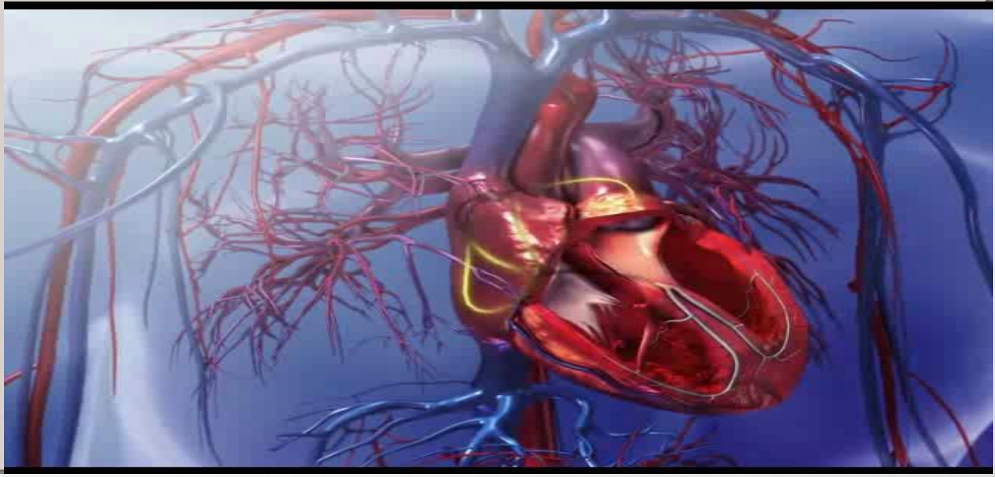




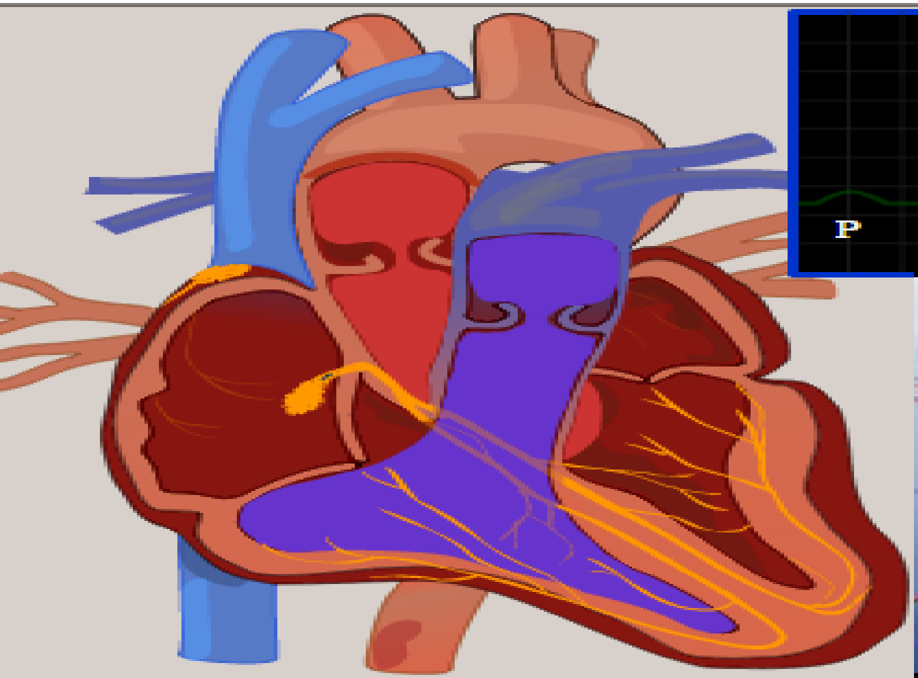
The electric impulse arrives at the AV node which is located between the two atria. ‘The impulse slows down slightly to allow the ventricles to fill with blood. This is marked by the line between the **P and Q wave**.

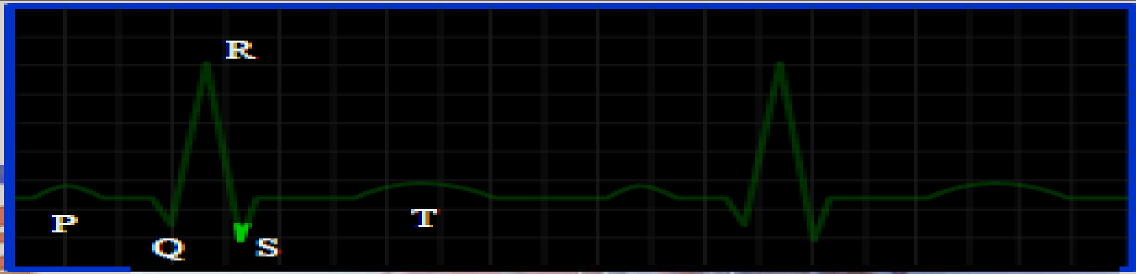


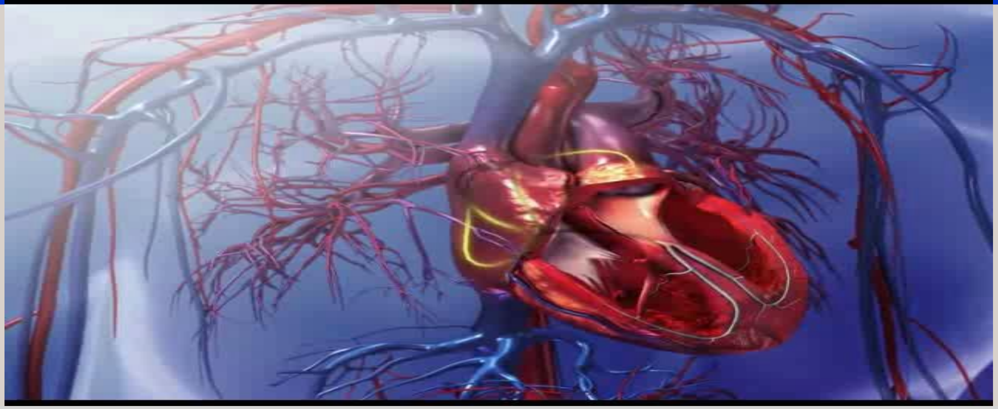




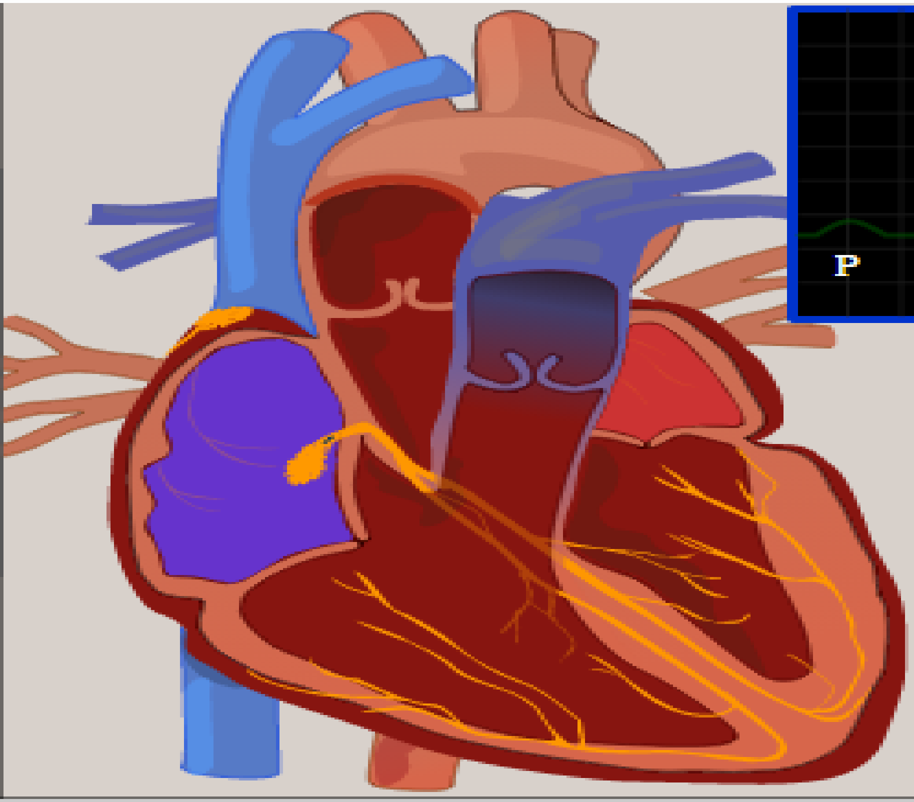
The electrical impulse travels through **the bundle of his** which is located in the ventricles. The bundle of his divides into the left and right bundle branches and the impulse travels down these. On the ECG this is marked by the **Q wave**.

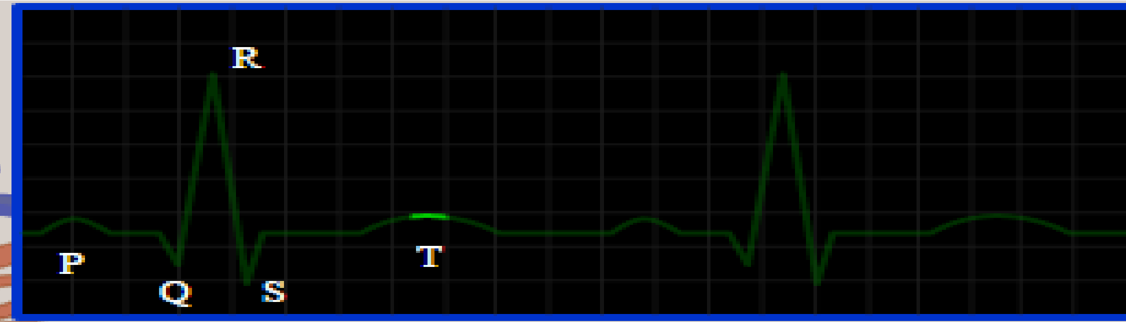


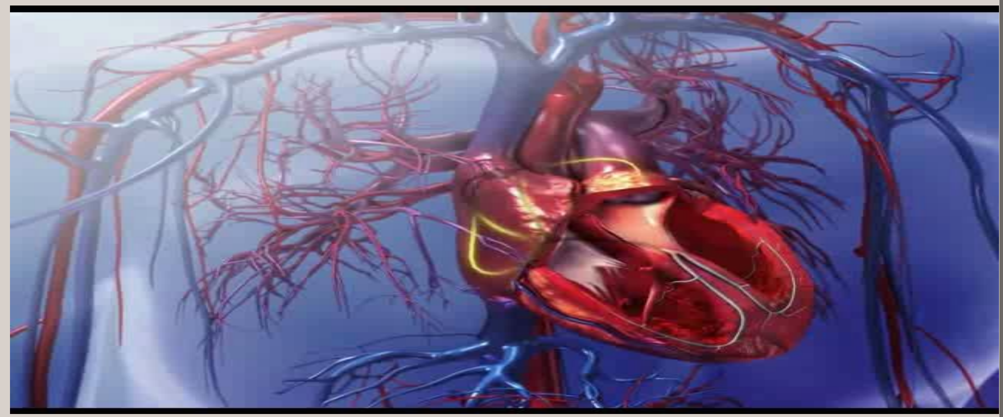




Purkinje fibers causes the ventricles to contract. Both ventricles do not contract at precisely the same time. The left ventricle contracts slightly before the right. On ECG the contraction of the left ventricle is represented by the R wave and the contraction oft he **right ventricle is represented by the S wave**.







Once the impulse has passed the ventricles relax and wait for the next electric impulse. **The T wave in the ECG marks ventricles relaxing**.

Diagnostic Use of the ECG During Exercise

- **Graded exercise test to evaluate cardiac function**
  - Observe ECG during exercise
  - Also observe changes in blood pressure
- **Atherosclerosis**
  - Fatty plaque that narrows coronary arteries
  - Reduces blood flow to myocardium
    - Myocardial ischemia
- **S-T segment depression**
  - Suggests myocardial ischemia

S-T Segment Depression on the Electrocardiogram

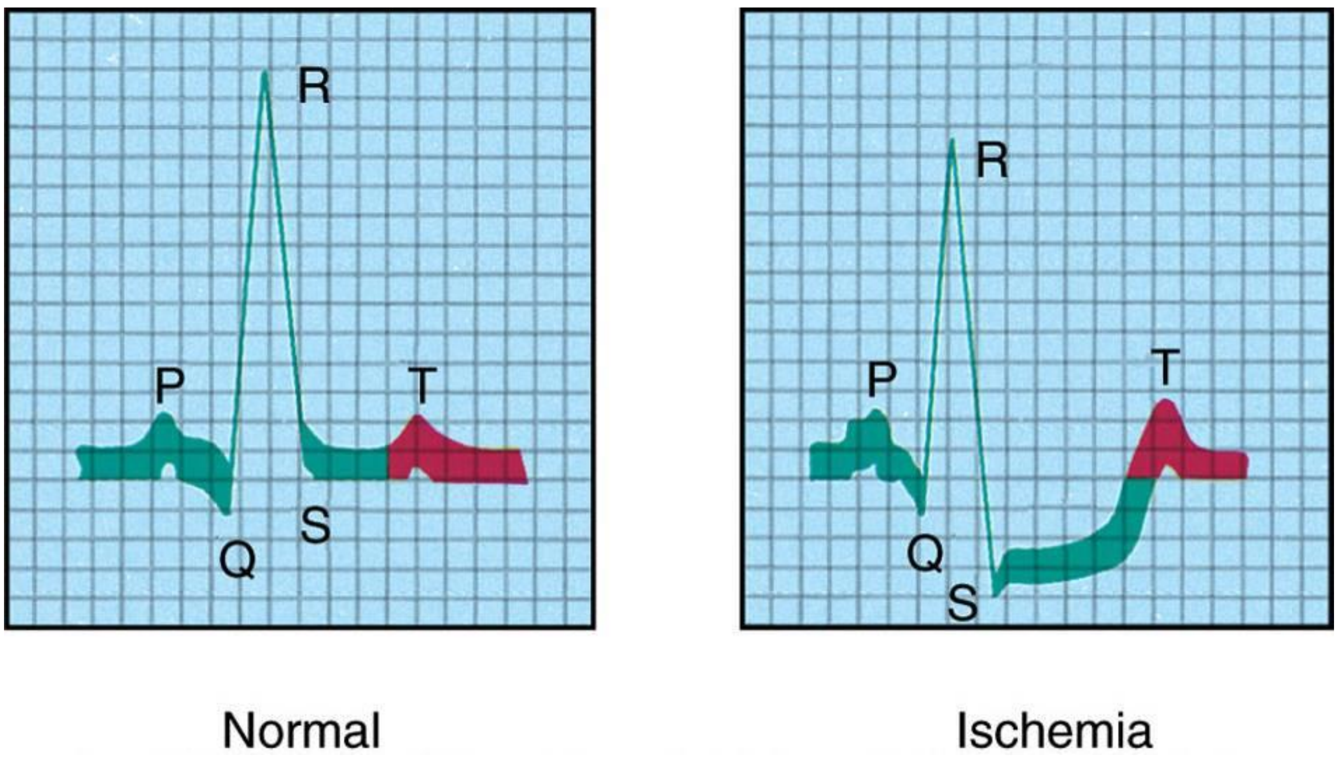


Figure 9.10

In Summary

- The contraction phase of the cardiac cycle is called *systole* and the relaxation period is called *diastole*.
- The pacemaker of the heart is the SA node.
- The average blood pressure during a cardiac cycle is called *mean arterial pressure*.

In Summary

- Blood pressure can be increased by one or all of the following factors:
  - a. increase in blood volume
  - b. increase in heart rate
  - c. increased blood viscosity
  - d. increase in stroke volume
  - e. increased peripheral resistance
- A recording of the electrical activity of the heart during the cardiac cycle is called the *electrocardiogram* (ECG).

Cardiac Output

- **The amount of blood pumped by the heart each minute**
- **Product of heart rate and stroke volume**
  - Heart rate
    - Number of beats per minute
  - Stroke volume
    - Amount of blood ejected in each beat

Q = HR x SV

- **Depends on training state and gender**

Typical Values for Cardiac Output

TABLE 9.2 Typical Resting and Maximal Exercise Values for Stroke Volume (SV), Heart Rate (HR), and Cardiac Output ($\dot{Q}$) for College-Age Untrained Subjects and Trained Endurance Athletes (Body Weights: Male = 70 kg; Female = 50 kg)

Subject	HR (beats/min)		SV (ml/beat)		$\dot{Q}$ (l/min)
Rest					
Untrained male	72	×	70	=	5.00
Untrained female	75	×	60	=	4.50
Trained male	50	×	100	=	5.00
Trained female	55	×	80	=	4.40
Max Exercise					
Untrained male	200	×	110	=	22.0
Untrained female	200	×	90	=	18.0
Trained male	190	×	180	=	34.2
Trained female	190	×	125	=	23.8

Note that values are rounded off. Data from references 3, 22, and 68.

Regulation of Heart Rate

- **Parasympathetic nervous system**
  - Via vagus nerve
  - Slows HR by inhibiting SA and AV node
- **Sympathetic nervous system**
  - Via cardiac accelerator nerves
  - Increases HR by stimulating SA and AV node
- **Low resting HR due to parasympathetic tone**
- **Increase in HR at onset of exercise**
  - Initial increase due to parasympathetic withdrawal
    - Up to ~100 beats/min
  - Later increase due to increased SNS stimulation

Nervous System Regulation of Heart Rate

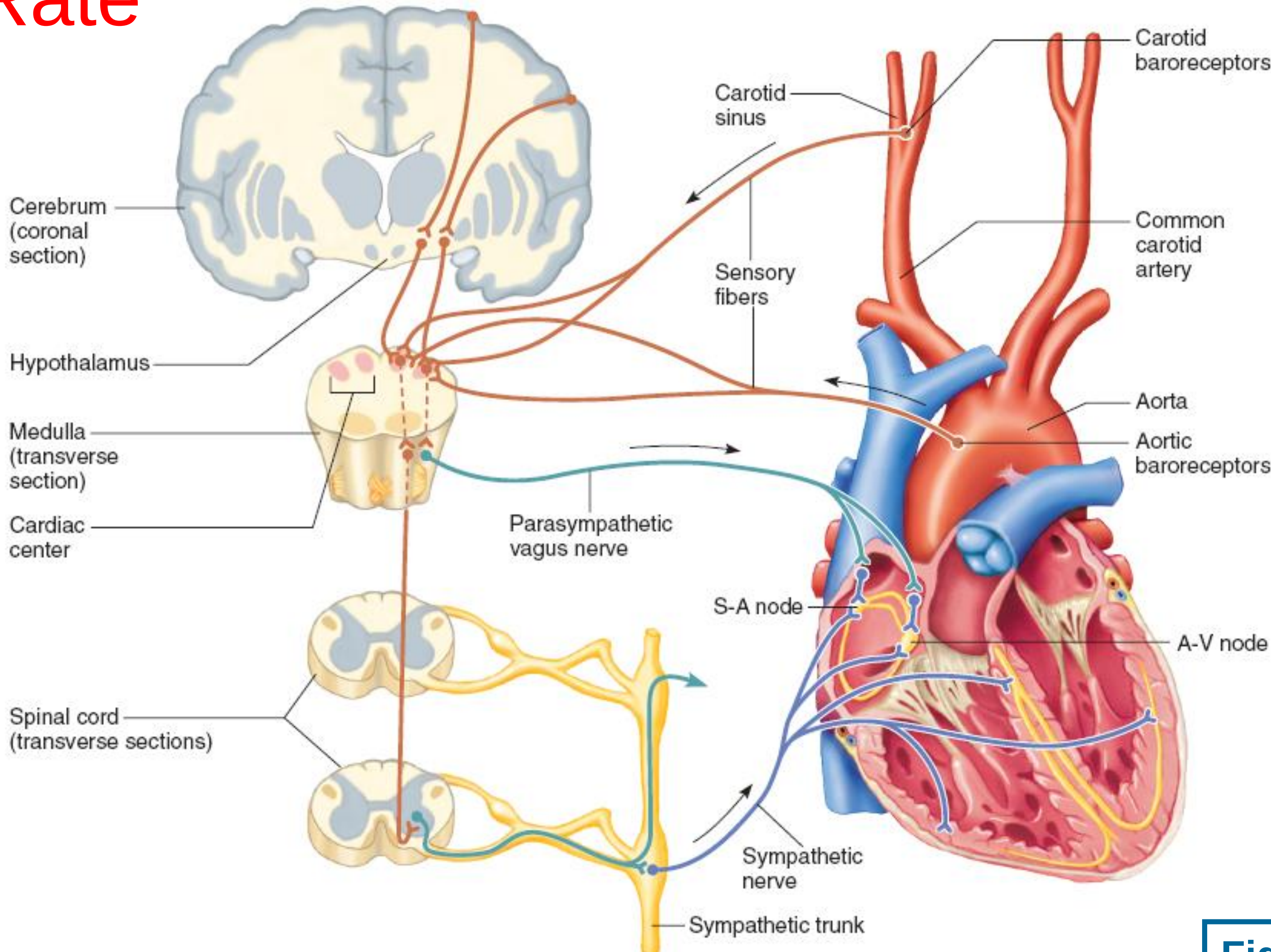


Figure 9.14

Clinical Applications 9.2
Beta-Blockade and Heart Rate

- **Beta-adrenergic blocking drugs (beta-blockers)**
  - Reduce heart rate and contractility
    - Lower the myocardial oxygen demand
- **Prescribed for patients with coronary artery disease and hypertension**
- **Will lower heart rate during submaximal and maximal exercise**
  - Important for exercise prescription

Regulation of Stroke Volume

- **End-diastolic volume (EDV)**
  - Volume of blood in the ventricles at the end of diastole ("preload")
- **Average aortic blood pressure**
  - Pressure the heart must pump against to eject blood ("afterload")
    - Mean arterial pressure
- **Strength of the ventricular contraction (contractility)**
  - Enhanced by:
    - Circulating epinephrine and norepinephrine
    - Direct sympathetic stimulation of heart

End-Diastolic Volume

- **Frank-Starling mechanism**
  - Greater EDV results in a more forceful contraction
    - Due to stretch of ventricles
- **Dependent on venous return**
- **Venous return increased by:**
  - Venoconstriction
    - Via SNS
  - Skeletal muscle pump
    - Rhythmic skeletal muscle contractions force blood in the extremities toward the heart
    - One-way valves in veins prevent backflow of blood
  - Respiratory pump
    - Changes in thoracic pressure pull blood toward heart

Relationship Between End-Diastolic Volume and Stroke Volume

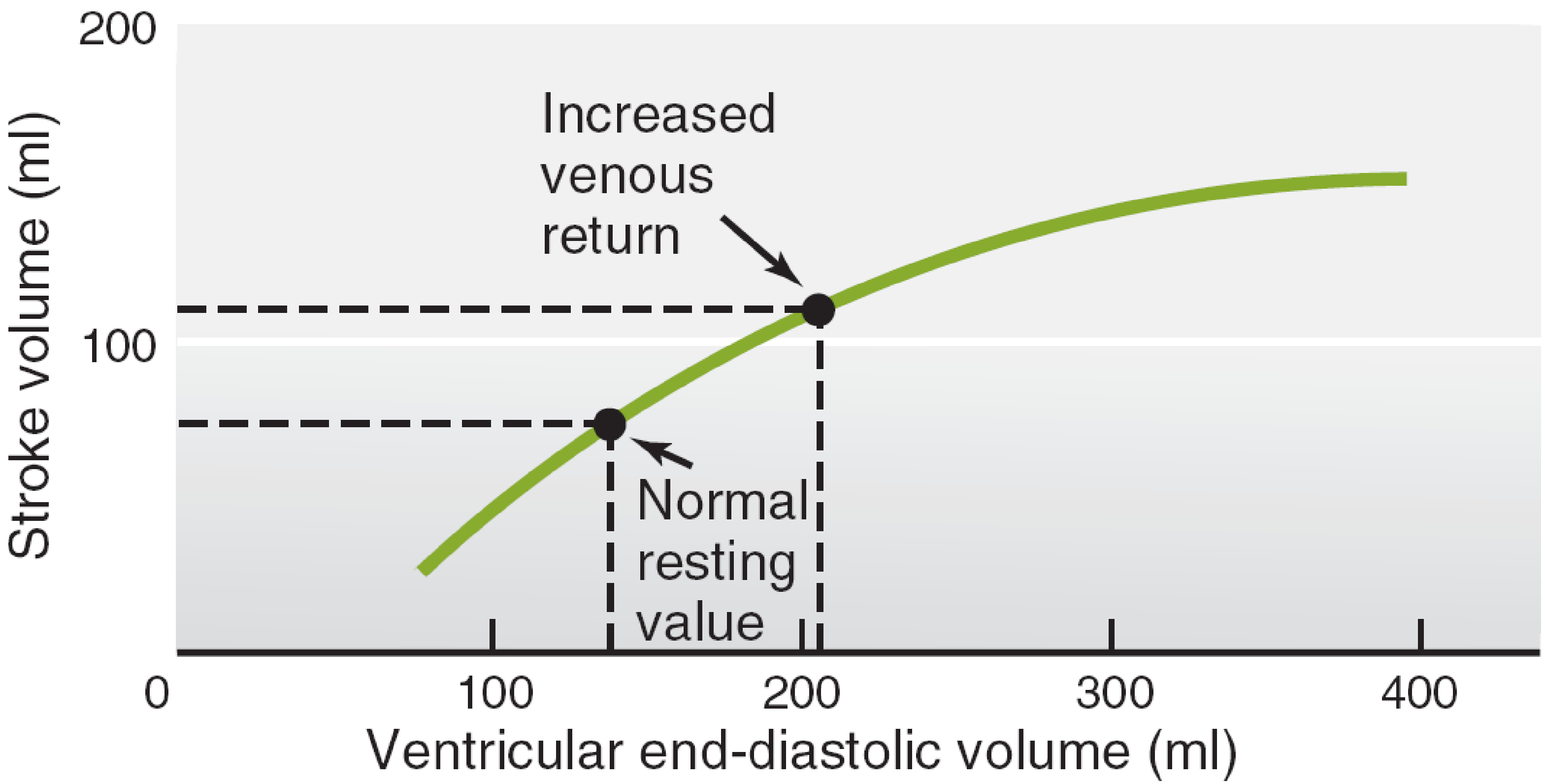


Figure 9.15

Skeletal Muscle Pump

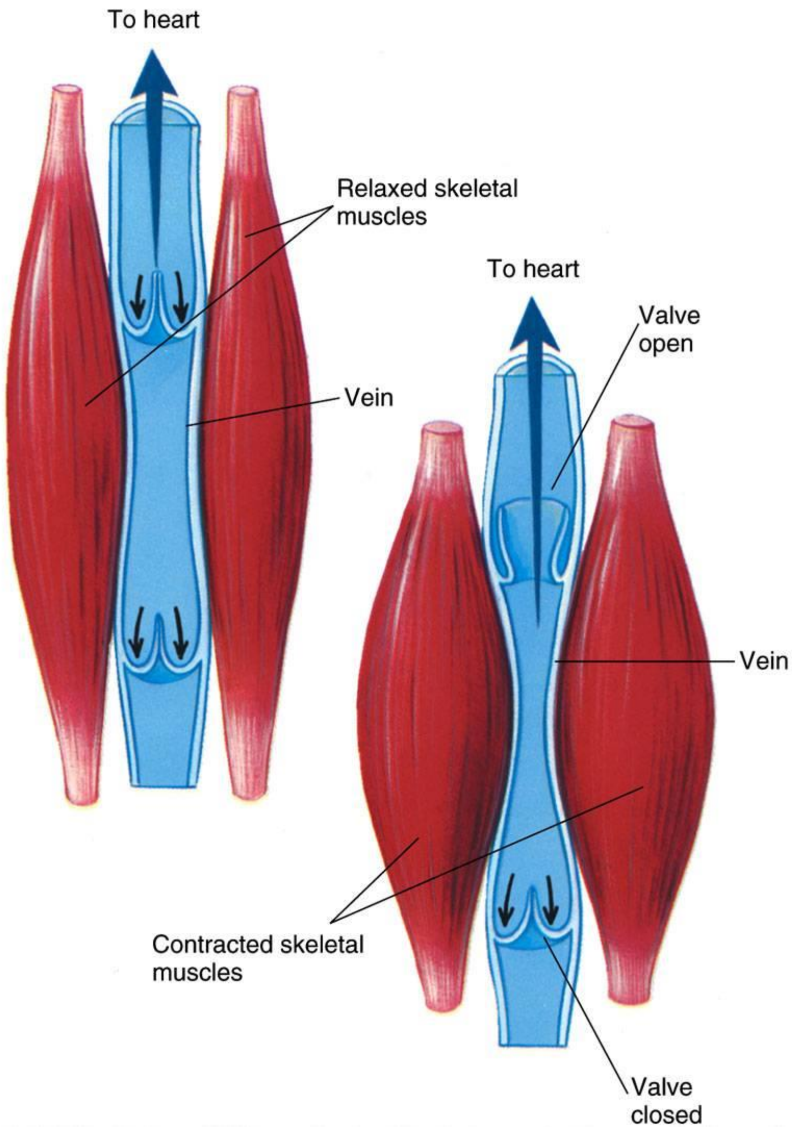


Figure 9.16

Effects of Sympathetic Stimulation on Stroke Volume

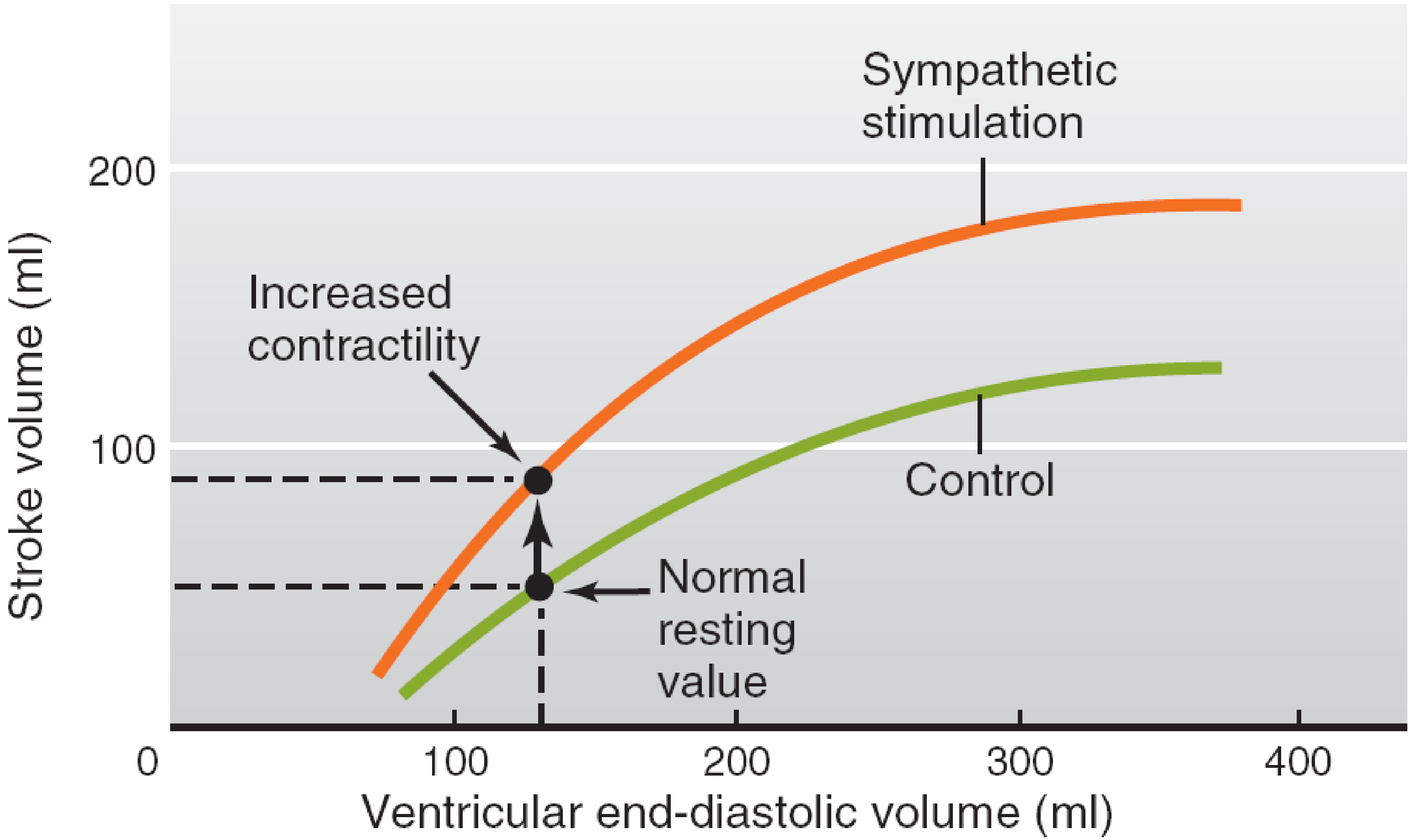


Figure 9.17

Factors that Regulate Cardiac Output

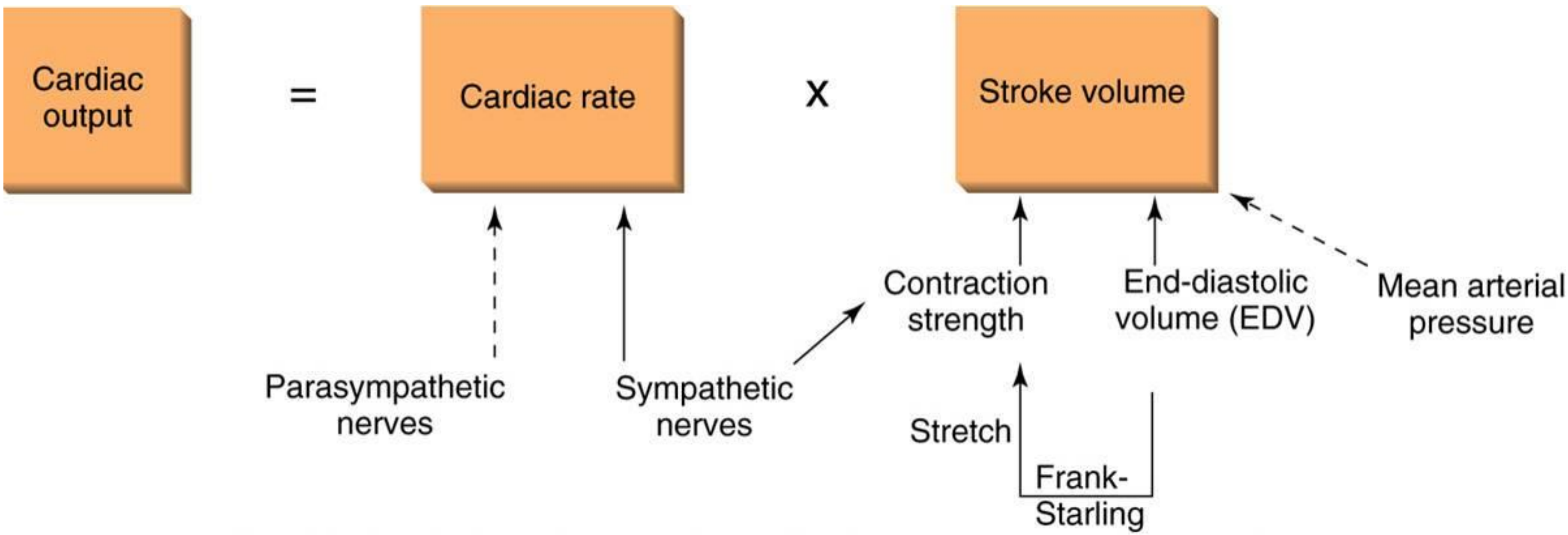


Figure 9.18

In Summary

- Cardiac output is the product of heart rate and stroke volume (Q = HR x SV). Figure 9.18 summarizes those variables that influence cardiac output during exercise.
- The pacemaker of the heart is the SA node. SA node activity is modified by the parasympathetic nervous system (slows HR) and the sympathetic nervous system (increases HR).
- Heart rate increases at the beginning of exercise due to a withdrawal of parasympathetic tone. At higher work rates, the increase in heart rate is achieved via an increased sympathetic outflow to the SA node.

In Summary

- Stroke volume is regulated by: (1) end-diastolic volume, (2) aortic blood pressure, and (3) the strength of ventricular contraction.
- Venous return increases during exercise due to: (1) venoconstriction, (2) the muscle pump, and (3) the respiratory pump.

Physical Characteristics of Blood

- **Physical characteristics of blood**
  - Plasma
    - Liquid portion of blood
    - Contains ions, proteins, hormones
  - Cells
    - Red blood cells
      - Contain hemoglobin to carry oxygen
    - White blood cells
      - Important in preventing infection
    - Platelets
      - Important in blood clotting
- **Hematocrit**
  - Percentage of blood composed of cells

Hematocrit

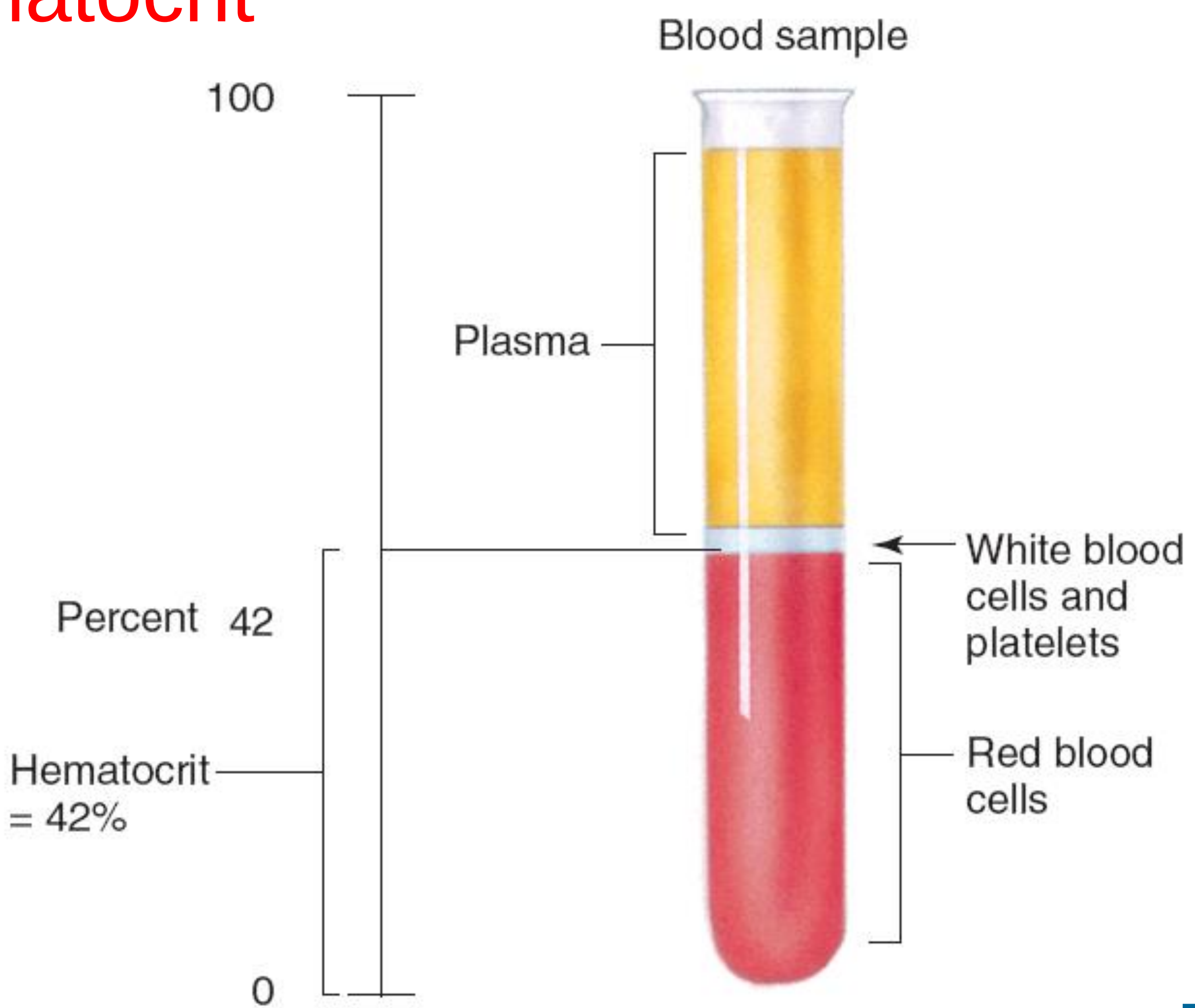


Figure 9.19

Relationships Among Pressure, Resistance, and Flow

- **Blood flow**
  - Directly proportional to the pressure difference between the two ends of the system
  - Inversely proportional to resistance

$$\textbf{Blood flow} = \frac{\Delta \textbf{ Pressure}}{\textbf{Resistance}}$$

- **Pressure**
  - Proportional to the difference between MAP and right atrial pressure (Δ Pressure)

Blood Flow Through the Systemic Circuit

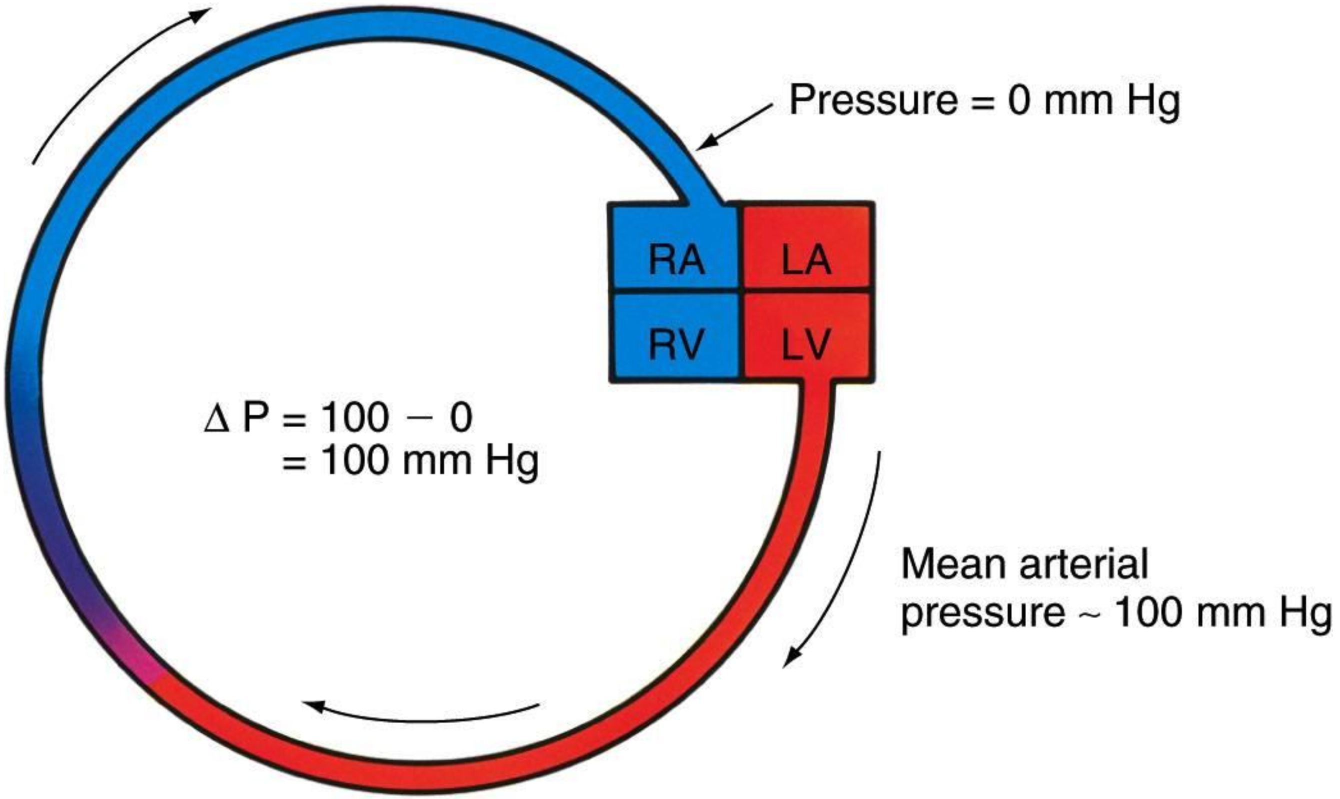


Figure 9.20

Hemodynamics

- **Resistance**
  - Depends upon:
    - Length of the vessel
    - Viscosity of the blood
    - Radius of the vessel

$$\text{Resistance} = \frac{\text{Length x viscosity}}{\text{Radius}^4}$$

- **Sources of vascular resistance**
  - MAP decreases throughout the systemic circulation
  - Largest drop occurs across the arterioles
    - Arterioles are called "resistance vessels"

Pressure Changes Across the Systemic Circulation

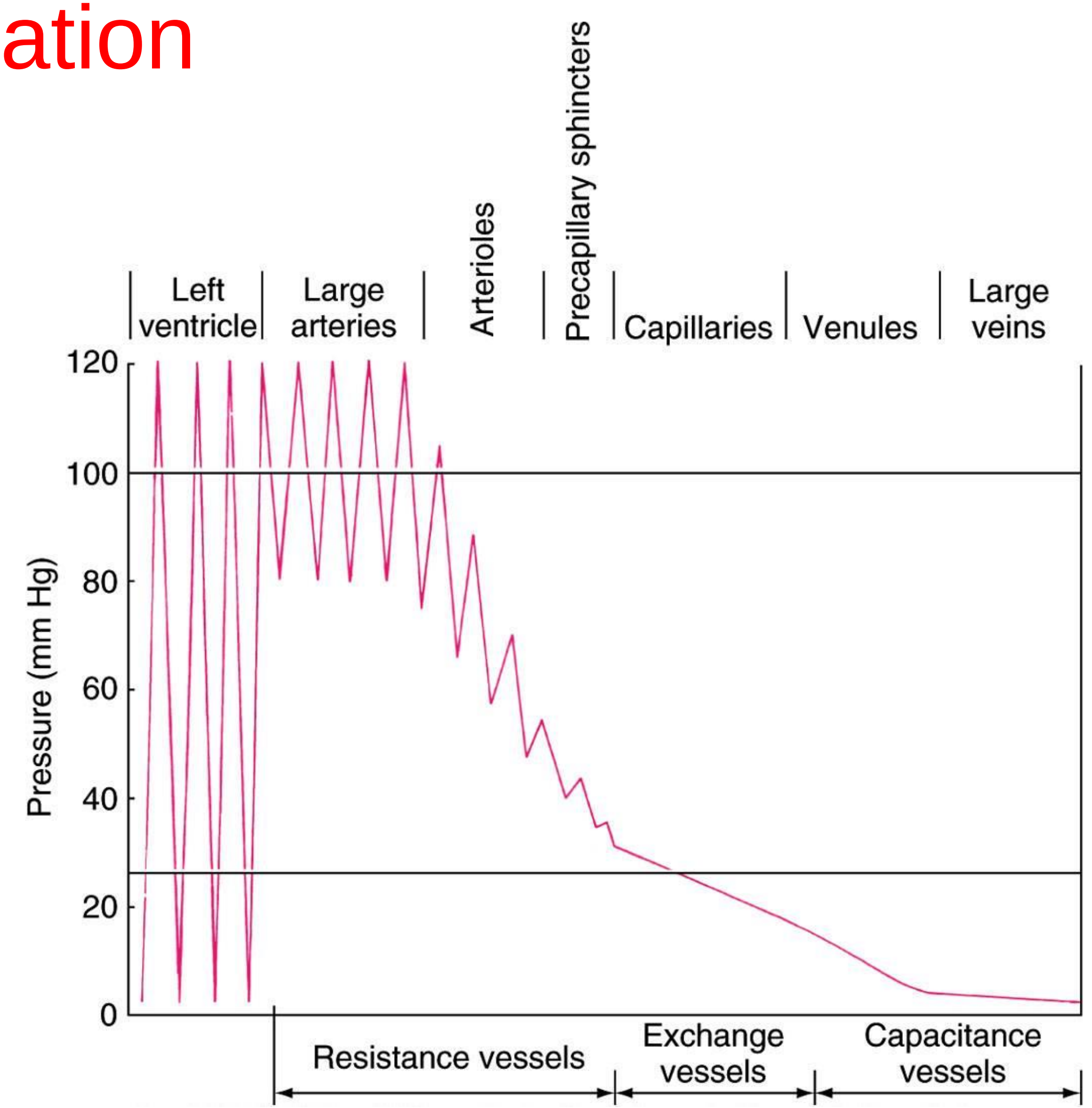


Figure 9.20

In Summary

- Blood is composed of two principle components, plasma and cells.
- Blood flow through the vascular system is directly proportional to the pressure at the two ends of the system, and inversely proportional to resistance.
- The most important factor determining resistance to blood flow is the radius of the blood vessel.
- The greatest vascular resistance to blood flow is offered in the arterioles.

Oxygen Delivery During Exercise

- **Oxygen demand by muscles during exercise is 15–25x greater than at rest**
- **Increased O_2 delivery accomplished by:**
  - Increased cardiac output
  - Redistribution of blood flow
    - From inactive organs to working skeletal muscle

Changes in Cardiac Output During Exercise

- **Cardiac output increases due to:**
  - Increased HR
    - Linear increase to max

      Max HR = 220 – age (years)
  - Increased SV
    - Increase, then plateau at ~40% VO_2 max
    - No plateau in highly trained subjects

Changes in Arterial-Mixed Venous O_2 Content During Exercise

- **Higher arteriovenous difference (a-vO_2 difference)**
  - Amount of O_2 that is taken up from 100 ml blood
  - Increase due to higher amount of O_2 taken up
    - Used for oxidative ATP production
- **Fick equation**
  - Relationship between cardiac output (Q), a-vO_2 difference, and VO_2

$$VO_2 = Q \times \text{a-v}O_2 \text{ difference}$$

Changes in Cardiovascular Variables During Exercise

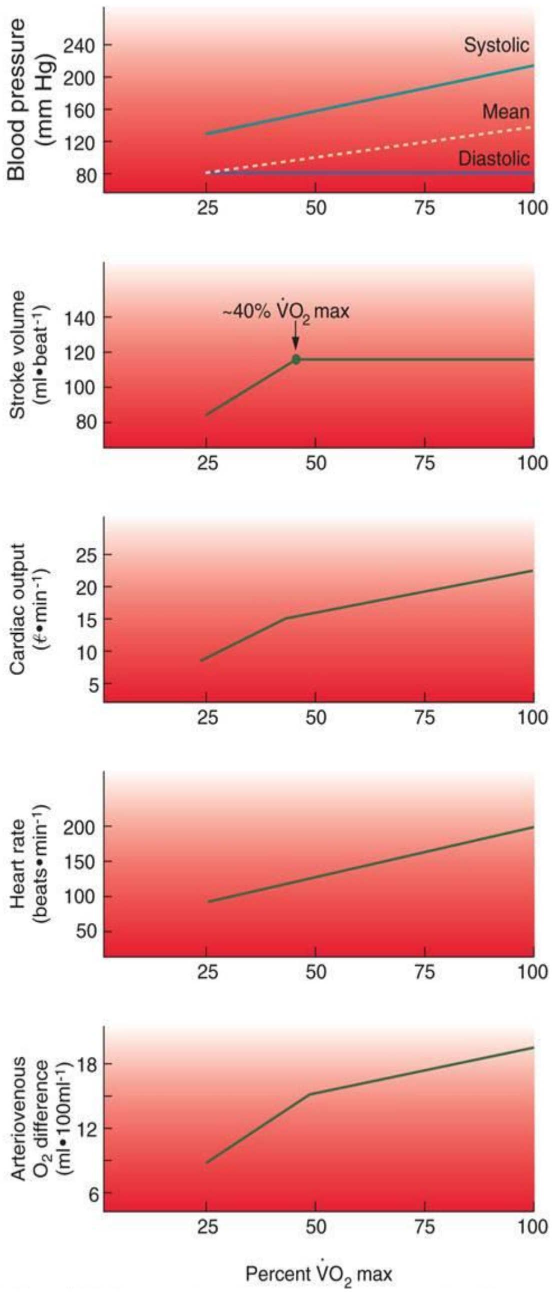


Figure 9.22

Redistribution of Blood Flow During Exercise

- **Increased blood flow to working skeletal muscle**
  - At rest, 15–20% of cardiac output to muscle
  - Increases to 80–85% during maximal exercise
- **Decreased blood flow to less active organs**
  - Liver, kidneys, GI tract
- **Redistribution depends on metabolic rate**
  - Exercise intensity

Changes in Muscle and Splanchnic Blood Flow During Exercise

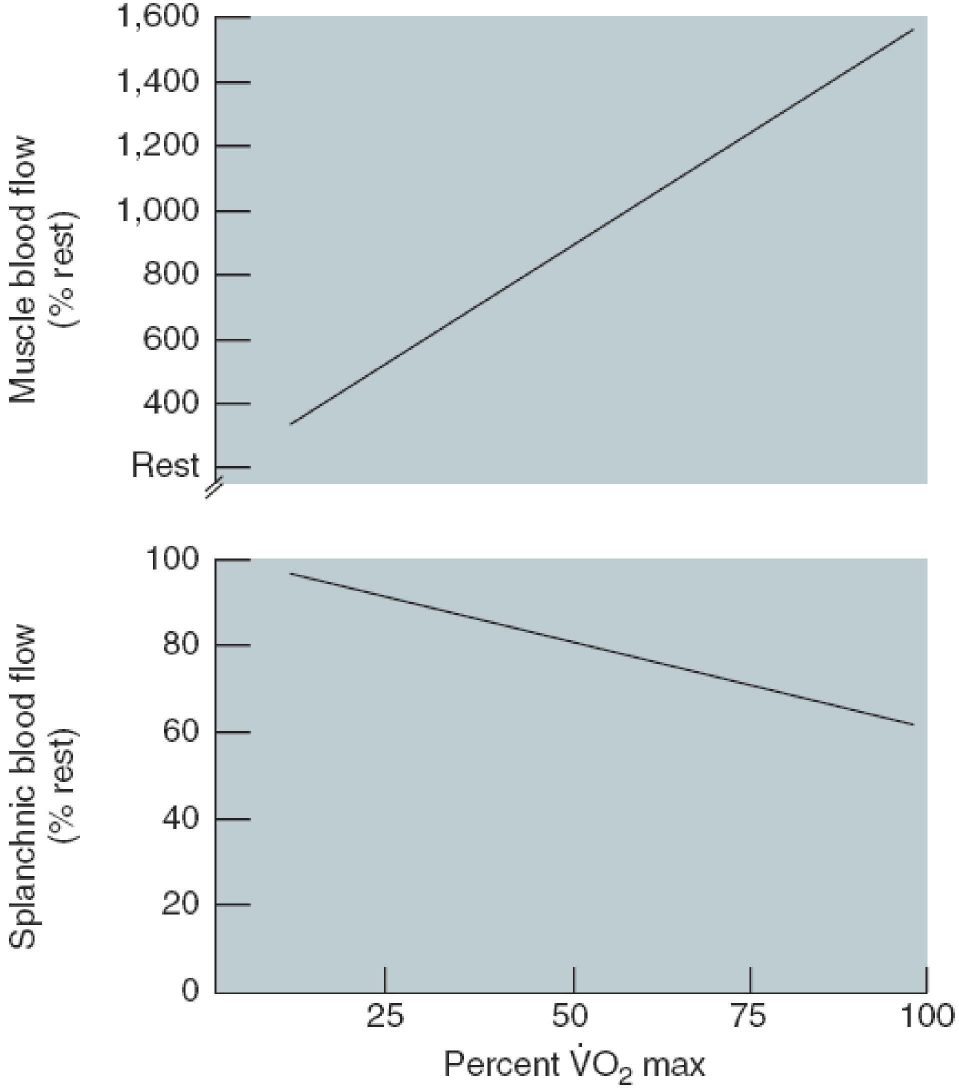
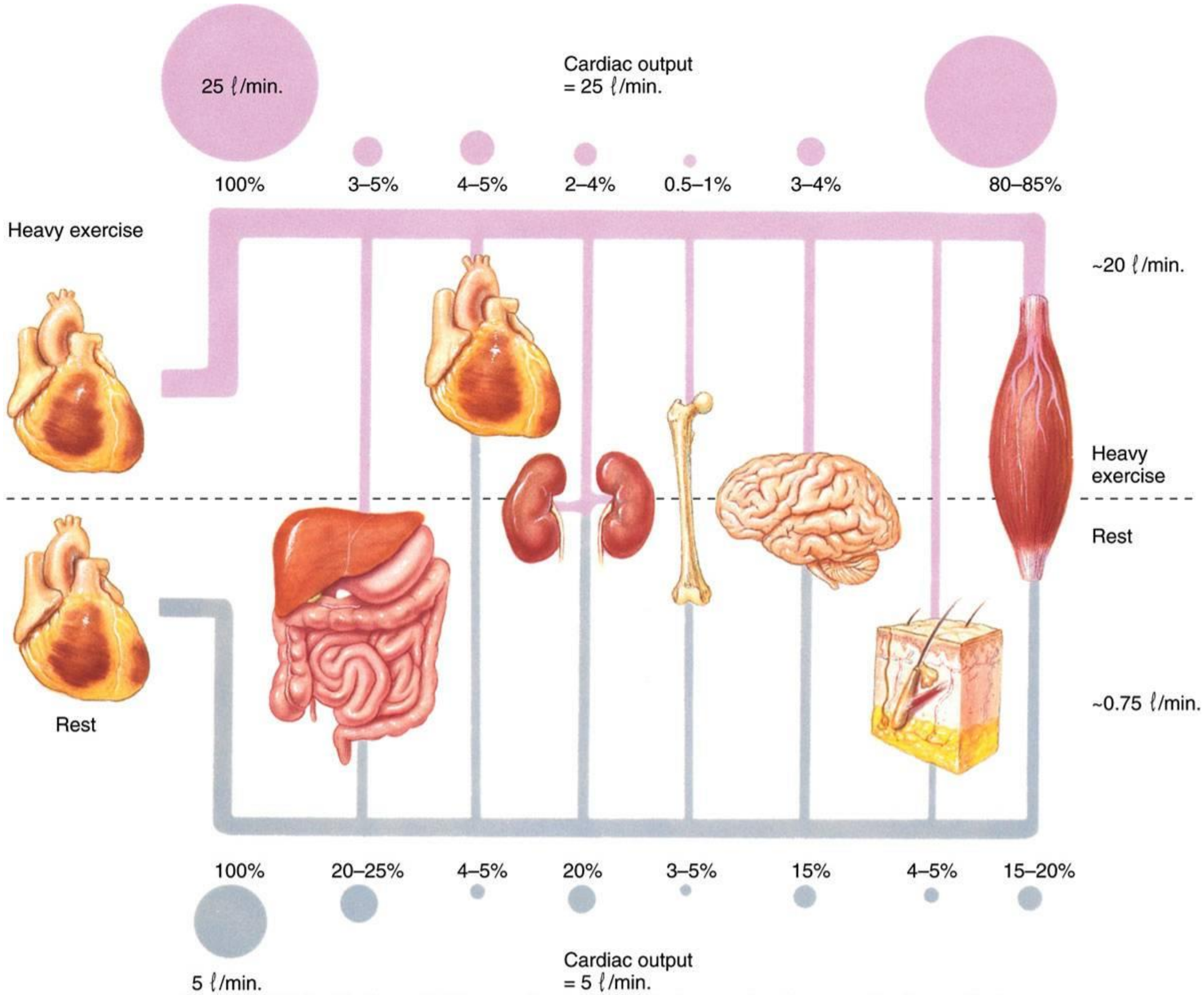


Figure 9.23

Redistribution of Blood Flow During Exercise



Regulation of Local Blood Flow During Exercise

- **Skeletal muscle vasodilation**
  - Autoregulation
    - Blood flow increased to meet metabolic demands of tissue
    - Due to changes in O_2 tension, CO_2 tension, nitric oxide, potassium, adenosine, and pH
- **Vasoconstriction to visceral organs and inactive tissues**
  - SNS vasoconstriction

In Summary

- Oxygen delivery to exercising skeletal muscle increases due to: (1) an increased cardiac output and (2) a redistribution of blood flow from inactive organs to the contracting skeletal muscle.
- Cardiac output increases as a linear function of oxygen uptake during exercise. During exercise in the upright position, stroke volume reaches a plateau at approximately 40% of VO_2 max; therefore, at work rates above 40% VO_2 max, the rise in cardiac output is due to increases in heart rate alone.

In Summary

- During exercise, blood flow to contracting muscle is increased, and blood flow to less active tissues is reduced.
- Regulation of muscle blood flow during exercise is primarily regulated by local factors (called *autoregulation*). Autoregulation refers to intrinsic control of blood flow by changes in local metabolites (e.g., oxygen tension, pH, potassium, adenosine, and nitric oxide) around arterioles.

Circulatory Responses to Exercise

- **Changes in heart rate and blood pressure**
- **Depend on:**
  - Type, intensity, and duration of exercise
  - Environmental condition
  - Emotional influence
    - Can raise pre-exercise heart rate and blood pressure

Transition From Rest to Exercise and Exercise to Recovery

- **At the onset of exercise:**
  - Rapid increase in HR, SV, cardiac output
  - Plateau in submaximal (below lactate threshold) exercise
- **During recovery**
  - Decrease in HR, SV, and cardiac output toward resting
  - Depends on:
    - Duration and intensity of exercise
    - Training state of subject

Transition From Rest to Exercise to Recovery

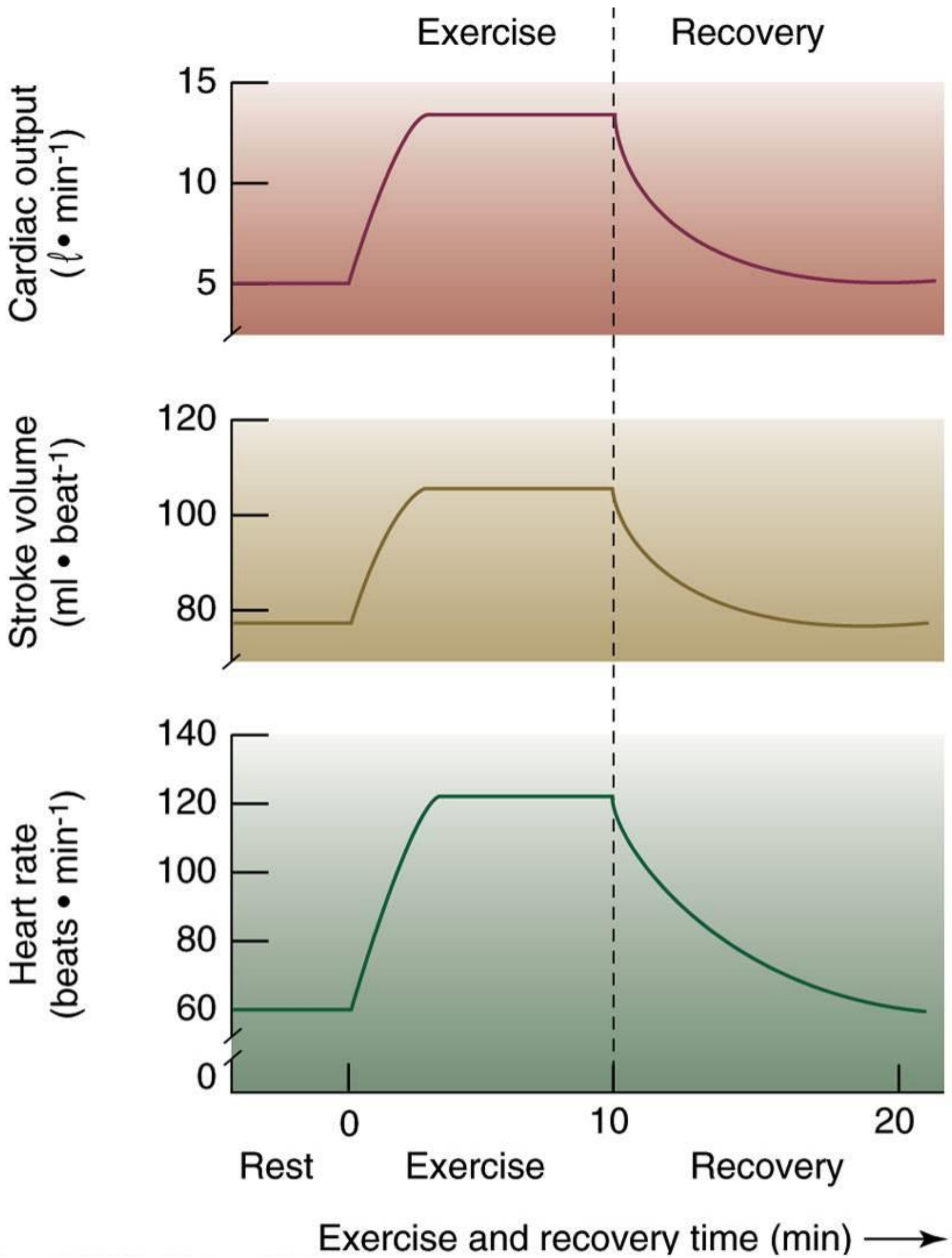


Figure 9.25

Incremental Exercise

- **Heart rate and cardiac output**
  - Increases linearly with increasing work rate
  - Reaches plateau at 100% VO_2 max
- **Blood pressure**
  - Mean arterial pressure increases linearly
    - Systolic BP increases
    - Diastolic BP remains fairly constant
- **Double product**
  - Increases linearly with exercise intensity
  - Indicates the work of the heart
  - Double product = HR x systolic BP

Changes in Double Product During Exercise

TABLE 9.3 Changes in the Double Product (i.e., Heart Rate × Systolic Blood Pressure) During an Incremental Exercise Test in a Healthy 21-Year-Old Female Subject

Note that the double product is a dimensionless term that reflects the relative changes in the workload placed on the heart during exercise and other forms of stress.

Condition	Heart Rate (beats · min^{-1})	Systolic Blood Pressure (mm Hg)	Double Product
Rest	75	110	8,250
Exercise			
25% $\dot{V}O_2$ max	100	130	13,000
50% $\dot{V}O_2$ max	140	160	22,400
75% $\dot{V}O_2$ max	170	180	30,600
100% $\dot{V}O_2$ max	200	210	42,000

Arm Versus Leg Exercise

- **At the same oxygen uptake, arm work results in higher:**
  - Heart rate
    - Due to higher sympathetic stimulation
  - Blood pressure
    - Due to vasoconstriction of large inactive muscle mass

Heart Rate and Blood Pressure During Arm and Leg Exercise

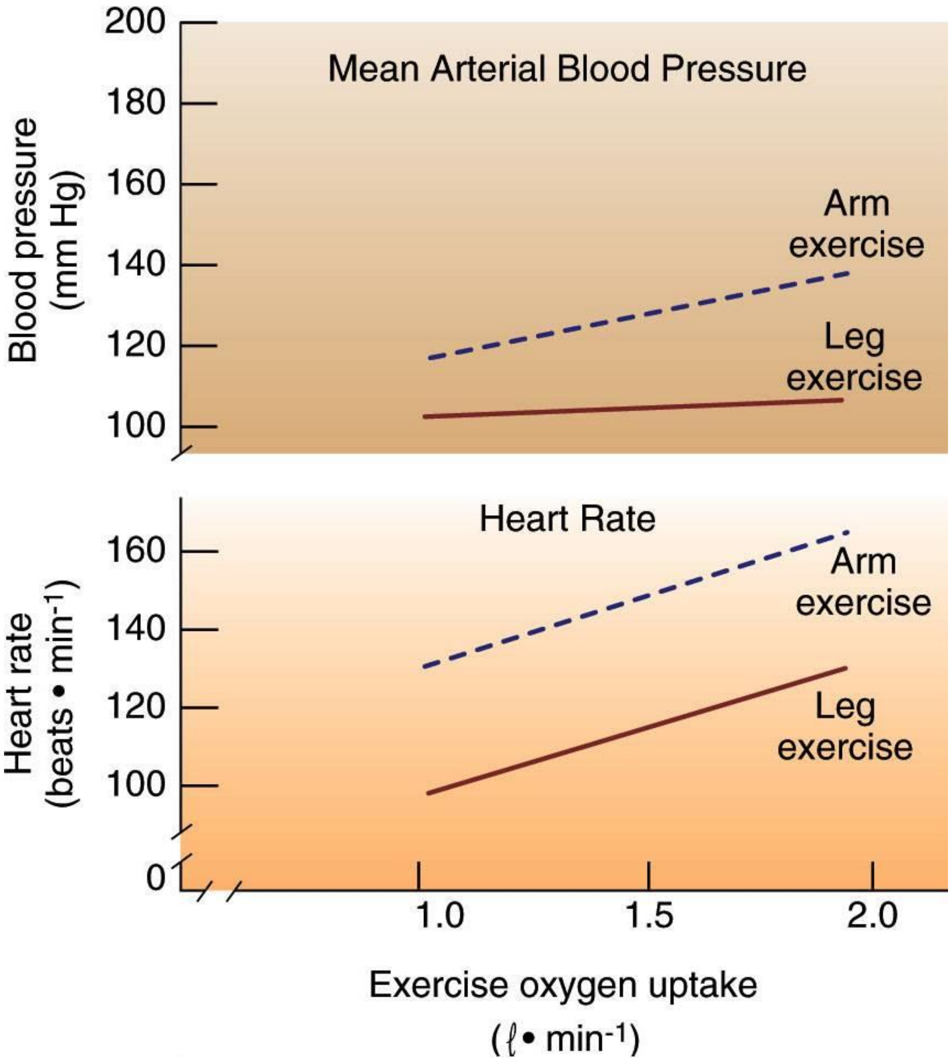


Figure 9.26

Intermittent Exercise

- **Recovery of heart rate and blood pressure between bouts depend on:**
  - Fitness level
  - Temperature and humidity
  - Duration and intensity of exercise

Prolonged Exercise

- **Cardiac output is maintained**
- **Gradual decrease in stroke volume**
  - Due to dehydration and reduced plasma volume
- **Gradual increase in heart rate**
  - Cardiovascular drift

Cardiovascular Changes During Prolonged Exercise

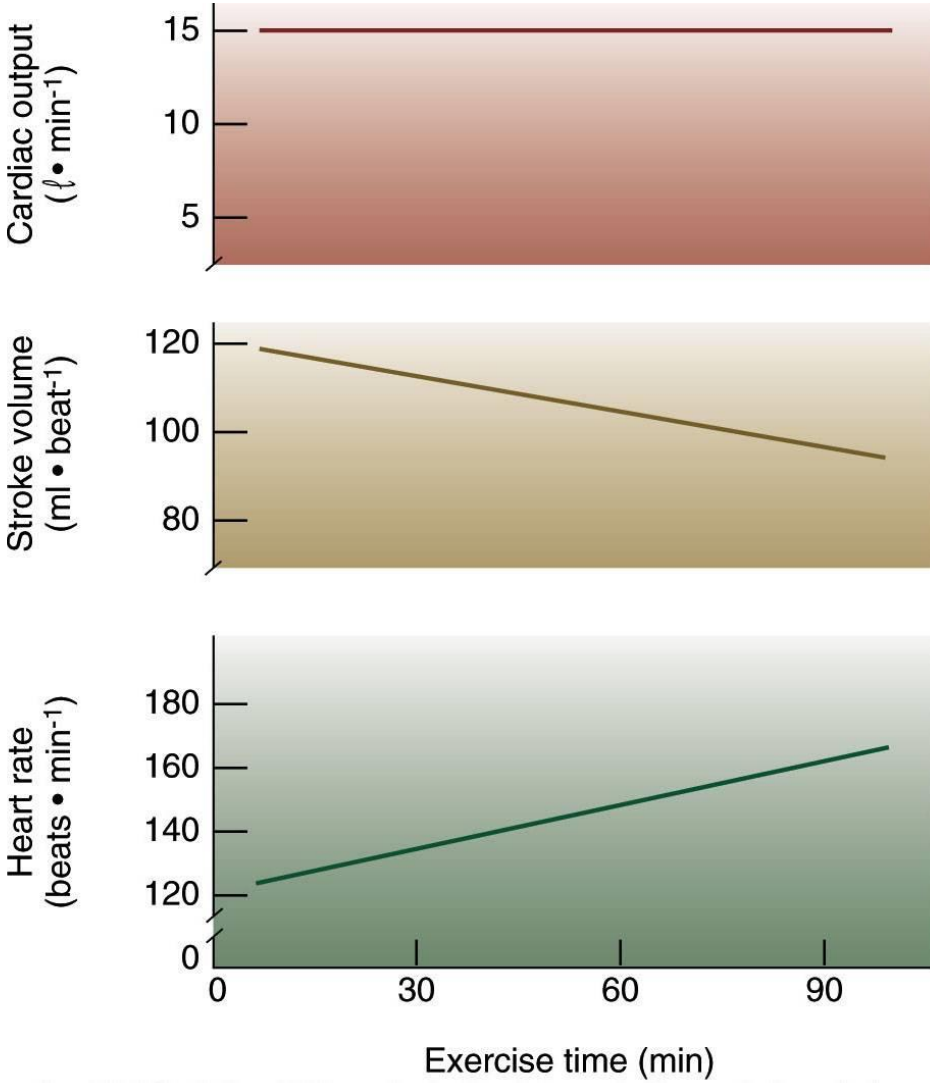


Figure 9.27

In Summary

- The changes in heart rate and blood pressure that occur during exercise are a function of the type and intensity of exercise performed, the duration of exercise, and the environmental conditions.
- The increased metabolic demand placed on the heart during exercise can be estimated by examining the double product.
- At the same level of oxygen consumption, heart rate and blood pressure are greater during arm exercise than during leg exercise.
- The increase in heart rate that occurs during prolonged exercise is called cardiovascular drift.

Summary of Cardiovascular Responses to Exercise

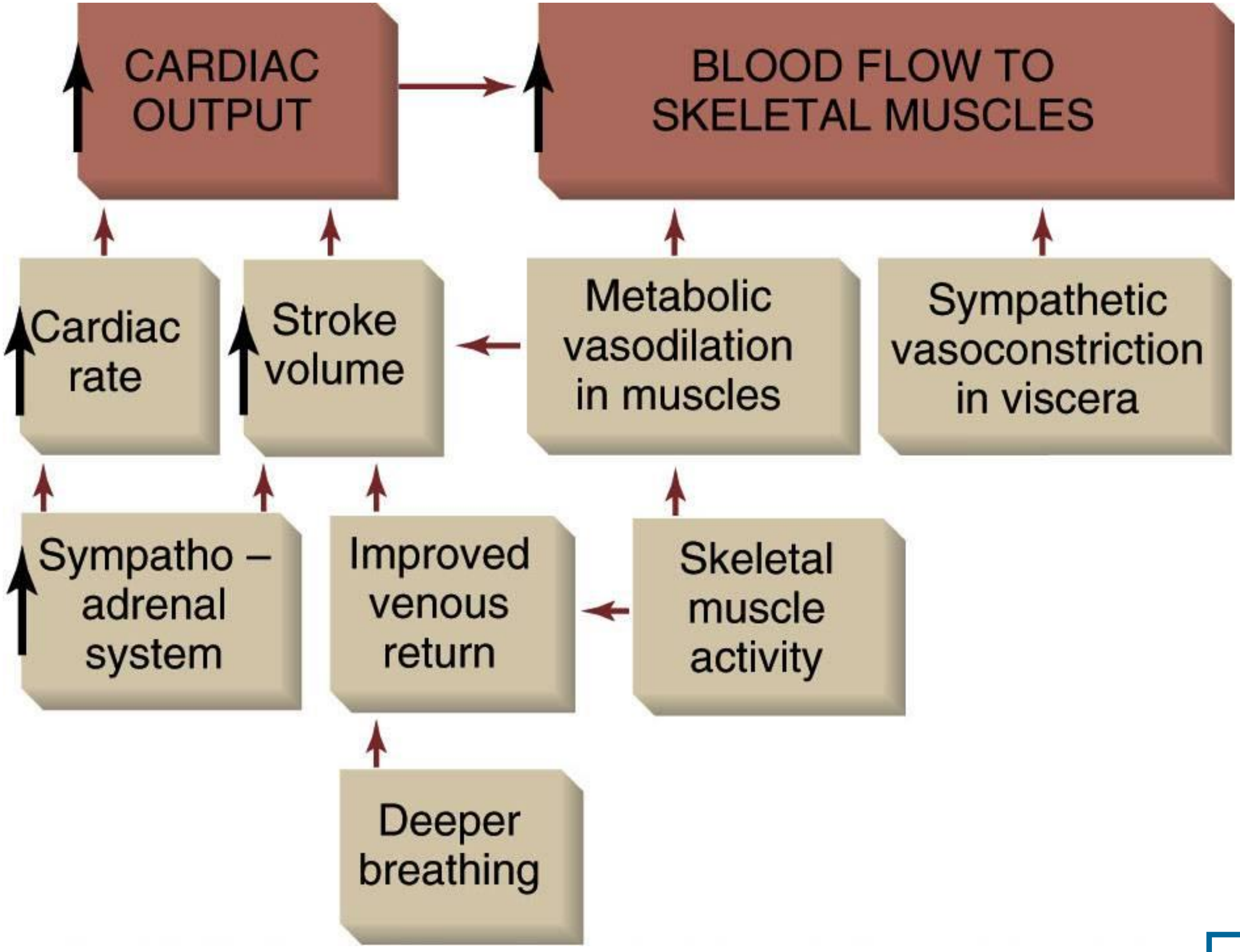


Figure 9.28

Study Questions

1. What are the major purposes of the cardiovascular system?
2. Briefly, outline the design of the heart. Why is the heart often called “two pumps in one”?
3. Outline the cardiac cycle and the associated electrical activity recorded via the electrocardiogram.
4. Graph the heart rate, stroke volume, and cardiac output response to incremental exercise.
5. What factors regulate heart rate during exercise? Stroke volume?
6. How does exercise influence venous return?

Study Questions

7. What factors determine local blood flow during exercise?
8. Graph the changes that occur in heart rate, stroke volume, and cardiac output during prolonged exercise. What happens to these variables if the exercise is performed in a hot/humid environment?
9. Compare heart rate and blood pressure responses to arm and leg work at the same oxygen uptake. What factors might explain the observed differences?
10. Explain the central command theory of cardiovascular regulation during exercise.