

**Chapter 9**  
**Circulatory Responses to Exercise**

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**Objectives**

1. Give an overview of the design and function of the circulatory system.
2. Describe the cardiac cycle and the associated electrical activity recorded via the electrocardiogram.
3. Discuss the pattern of redistribution of blood flow during exercise.
4. Outline the circulatory responses to various types of exercise.

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**Objectives**

5. Identify the factors that regulate local blood flow during exercise.
6. List and discuss those factors responsible for regulation of stroke volume during exercise.
7. Discuss the regulation of cardiac output during exercise.

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## The Circulatory System

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## The Circulatory System

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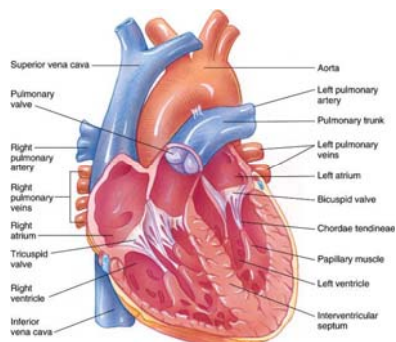
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## Structure of the Heart



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Figure 9.1

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## Pulmonary & Systemic Circuits

- Pulmonary circuit
  
- Systemic circuit

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## Pulmonary & Systemic Circulations

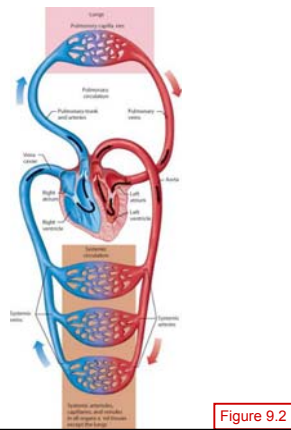


Figure 9.2

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## Cardiac Muscle

- The heart wall
  - Epicardium
  - Myocardium
  - Endocardium

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## The Heart Wall

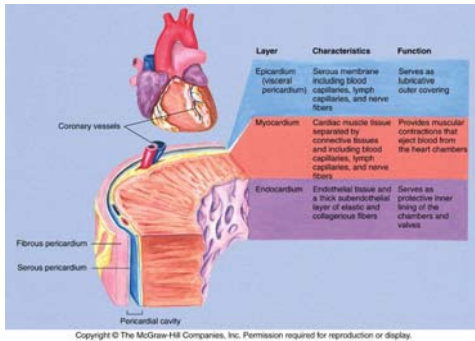


Figure 9.3

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## Endurance Exercise Protects Against Cardiac Injury during Heart Attack

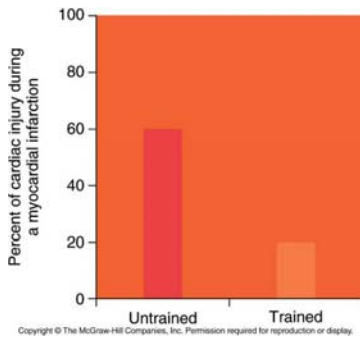


Figure 9.4

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## Comparison of Cardiac & Skeletal Muscle

TABLE 9.1 A Comparison of the Structural and Functional Differences/Similarities Between Heart Muscle and Skeletal Muscle		
Structural Comparison	Heart Muscle	Skeletal Muscle
Contractile proteins: actin and myosin	Present	Present
Shape of muscle fibers	Shorter than skeletal muscle fibers and branching	Elongated—no branching
Nuclei	Single	Multiple
Z discs	Present	Present
Striated	Yes	Yes
Cellular junctions	Yes—intercalated discs	No junctional complexes
Connective tissue	Endomyosium	Epimysium, perimysium, and endomysium
Functional Comparison		
Energy production	Aerobic (primarily)	Aerobic and anaerobic
Calcium source (for contraction)	Sarcoplasmic reticulum and extracellular calcium	Sarcoplasmic reticulum
Neural control	Involuntary	Voluntary
Regeneration potential	None—no satellite cells present	Some possibilities via satellite cells

Table 9.1

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## The Cardiac Cycle

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## Cardiac Cycle at Rest & During Exercise

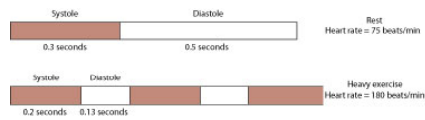


Figure 9.5

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## Pressure $\Delta$ s during the Cardiac Cycle

- Diastole
- Systole
- Heart sounds

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### Pressure, Volume, & Heart Sounds during the Cardiac Cycle

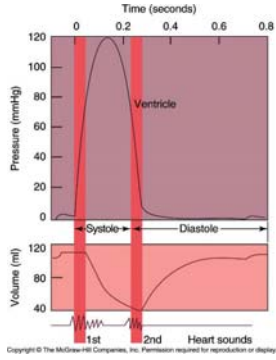


Figure 9.6

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### Arterial BP

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### Hypertension

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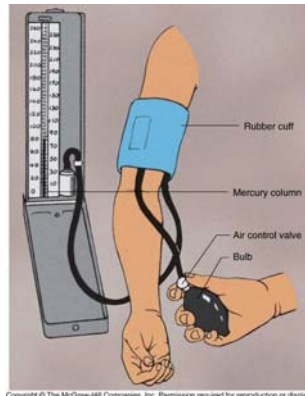
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## Measurement of BP



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Figure 9.7

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## Factors that Influence Arterial BP

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

$$\text{MAP} = \text{cardiac output} \times \text{total vascular resistance}$$

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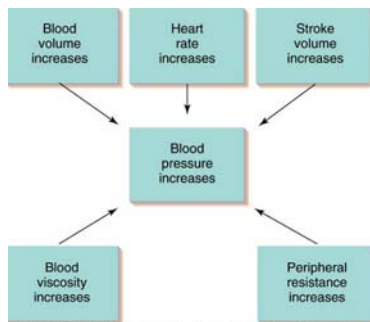
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## Factors that Influence Arterial BP



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Figure 9.8

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## Electrical Activity of the Heart

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## Conduction System of the Heart

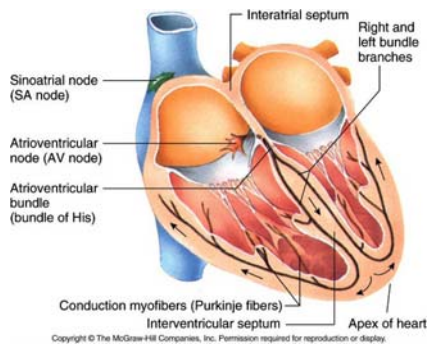


Figure 9.9

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## Electrocardiogram (ECG)

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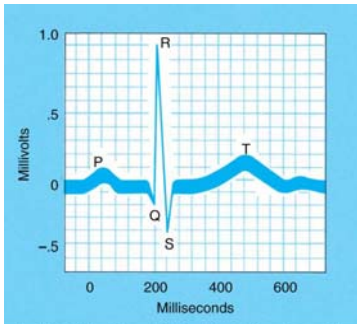
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### Normal Electrocardiogram



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Figure 9.11

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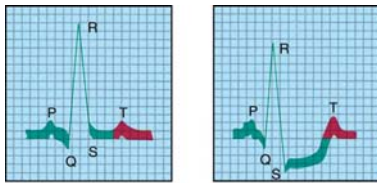
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### S-T Segment Depression on the Electrocardiogram



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Figure 9.10

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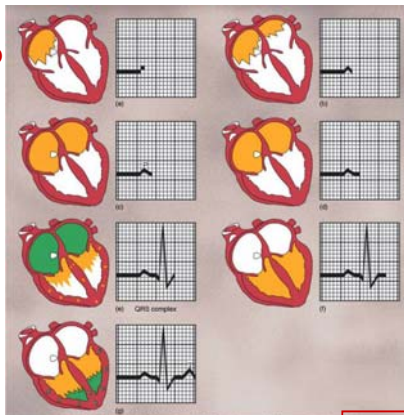
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### Relationship Between Electrical Events and the ECG



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Figure 9.12

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## Cardiac Output

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## Regulation of Heart Rate

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## Nervous System Regulation of Heart Rate

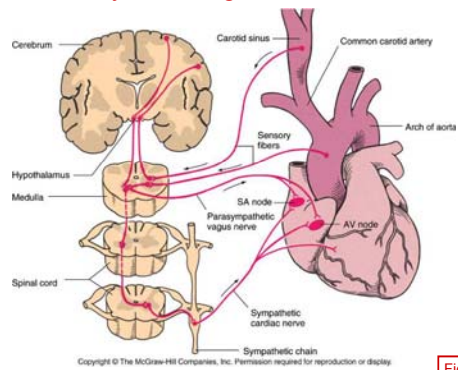


Figure 9.14

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## Regulation of Stroke Volume

- End-diastolic volume (EDV)
  - Volume of bld in the ventricles at the end of diastole (“preload”)
- Average aortic BP
  - Pressure the heart must pump against to eject bld (“afterload”)
    - Mean arterial pressure
- Strength of the ventricular contraction (contractility)
  - Enhanced by:
    - Circulating Epi & NE
    - Direct sympathetic stimulation of heart

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## End-Diastolic Volume

- Frank-Starling mechanism
  - Greater EDV results in a more forceful contraction
    - Due to stretch of ventricles
- Dependent on venous return

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## Relationship b/n End-Diastolic Volume & Stroke Volume

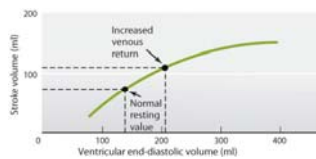


Figure 9.15

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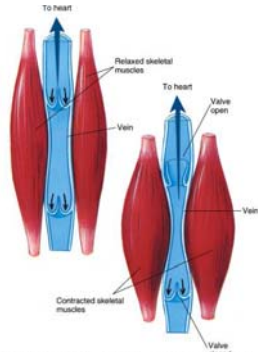
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## Skeletal Muscle Pump



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Figure 9.16

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## Effects of Sympathetic Stimulation on Stroke Volume

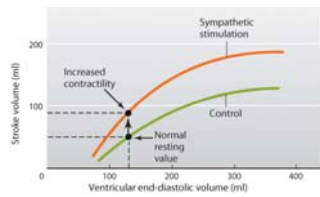


Figure 9.17

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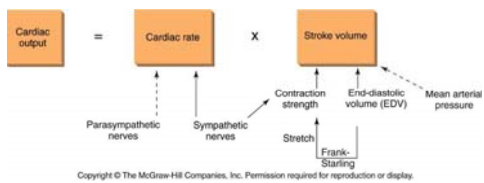
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## Factors that Regulate Cardiac Output



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Figure 9.18

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## Physical Characteristics of Bld

- Physical characteristics of bld
  - Plasma
  - Cells
  
- Hematocrit
  - %age of bld composed of cells

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## Hematocrit

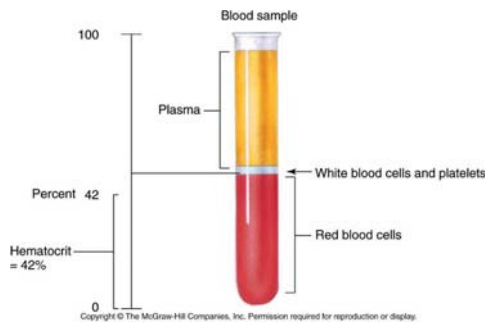


Figure 9.19

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## Hemodynamics

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## Hemodynamics

- Resistance
    - Depends upon:
      - Length of the vessel
      - Viscosity of the bld
      - Radius of the vessel
- $$\text{Resistance} = \frac{\text{Length} \times \text{viscosity}}{\text{Radius}^4}$$
- Sources of vascular resistance
    - MAP decreases throughout the systemic circulation
    - Largest drop occurs across the arterioles
      - Arterioles are called "resistance vessels"

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## Bld Flow Through the Systemic Circuit

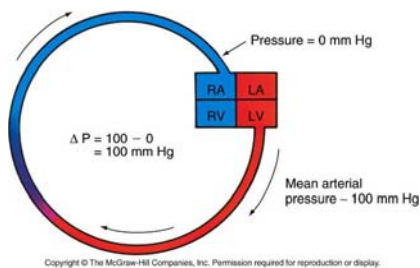


Figure 9.20

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## Pressure Δs across the Systemic Circulation

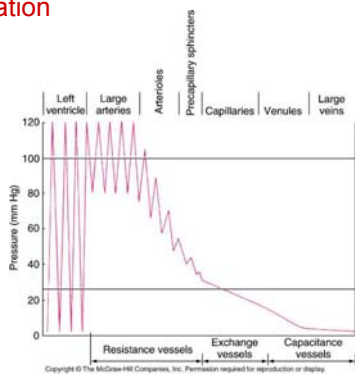


Figure 9.21

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## O<sub>2</sub> Delivery during Exercise

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## Δs in Cardiac Output during Exercise

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## Δs in Cardiovascular Variables during Exercise

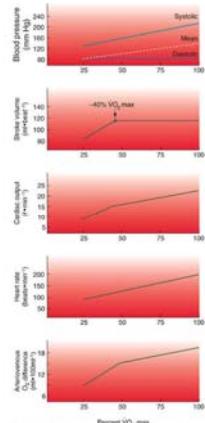


Figure 9.22

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$\Delta$ s in Arterial-Mixed Venous  $O_2$  content during Exercise

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Redistribution of Bld Flow during Exercise

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$\Delta$ s in Muscle & Splanchnic Bld Flow during Exercise

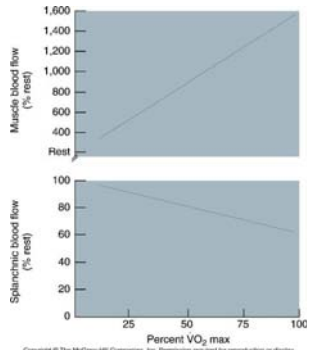


Figure 9.23

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## Redistribution of Bld Flow during Exercise

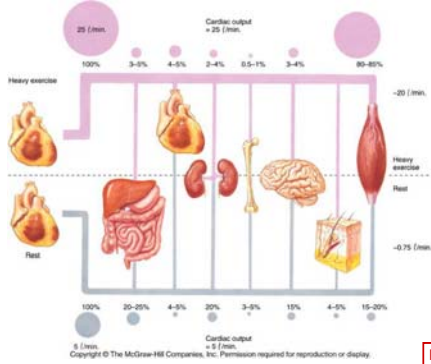


Figure 9.24

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## Regulation of Local Bld Flow during Exercise

- Skeletal muscle vasodilation
  - Autoregulation
    - Bld flow ↑d to meet metabolic demands of tissue
    - Due to Δs in O<sub>2</sub> tension, CO<sub>2</sub> tension, nitric oxide, potassium, adenosine, & pH
- Vasoconstriction to visceral organs & inactive tissues
  - SNS vasoconstriction

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## Circulatory Responses to Exercise

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Transition from Rest to Exercise & Exercise to Recovery

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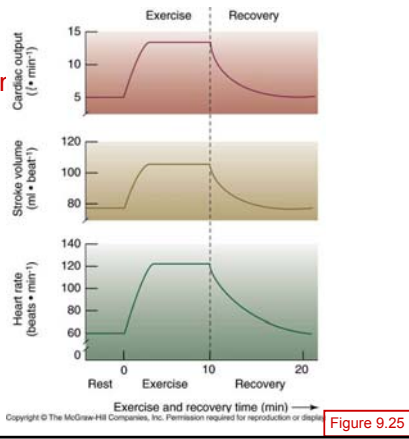
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Transition from Rest to Exercise to Recovery



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Incremental Exercise

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## Δs 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 <sup>-1</sup> )	Systolic Blood Pressure (mm Hg)	Double Product
Rest	75	110	8,250
Exercise			
25% V <sub>O<sub>2</sub></sub> max	100	130	13,000
50% V <sub>O<sub>2</sub></sub> max	140	160	22,400
75% V <sub>O<sub>2</sub></sub> max	170	180	30,600
100% V <sub>O<sub>2</sub></sub> max	200	210	42,000

Table 9.3

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## Arm vs. Leg Exercise

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## HR & BP during Arm & Leg Exercise

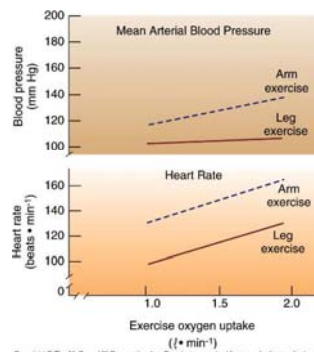


Figure 9.26

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### Intermittent Exercise

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### Prolonged Exercise

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### Cardiovascular $\Delta$ s during Prolonged Exercise

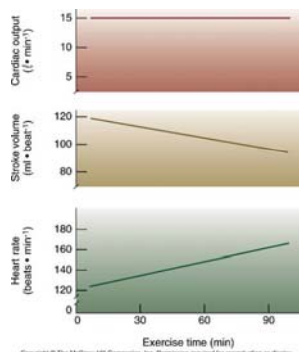


Figure 9.27

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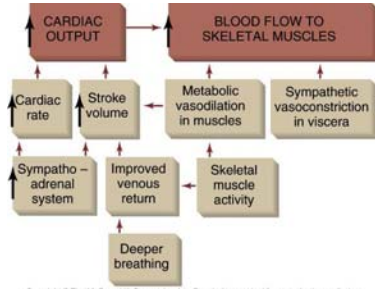
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### Regulation of Cardiovascular Adjustments to Exercise



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Figure 9.28

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### Summary of Cardiovascular Control During Exercise

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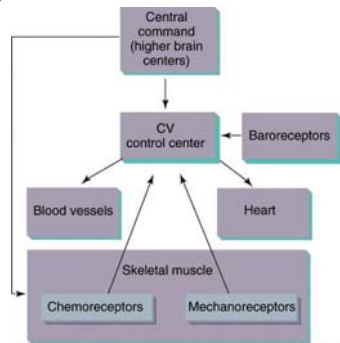
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### Summary of Cardiovascular Control during Exercise



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Figure 9.29

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