Cardiac Physiology

Chapter Overview

The importance of the circulatory system, particularly the heart, in maintaining homeostasis has been known to some degree by most of us since our childhood days. This heart-homeostasis relationship is probably the best known aspect of homeostasis. From the bending and twisting of an embryonic blood vessel an organ develops that will pump the blood. Complete with muscular walls and valves, the heart responds to the autorhythmicity of the sinoatrial node. Using specialized conductive cells, action potentials are spread throughout the organ and coordinated contractions occur. After a brief period of relaxation, the cycle begins again.

The electrical and mechanical activities of the heart produce sounds, pressures, and electrical changes that can be detected on the surface of the body. Electrocardiography is an important tool in monitoring cardiac activities.

To meet the changing homeostatic needs of all the cells, the heart must be able to change its output. Cardiac output is controlled through changes in heart rate and stroke volume. While the heart is working for all the cells it must also nourish itself. This is one of the most frequent areas of complications in the circulatory system.

Even though the heart is emphasized in science and culture, in reality it is but a part of an organ system controlled by the nervous and endocrine systems. The remarkable properties of the heart are specializations of the general properties and functions of all cells. The circulatory system aids in maintaining homeostasis which is essential for the survival of cells.

Chapter Outline

INTRODUCTION
- The circulatory system consists of the heart, the blood vessels and the blood.
- The pulmonary circulation consists of a closed loop of vessels carrying blood between the heart and lungs, whereas the systemic circulation consists of a circuit of vessels carrying blood between the heart and organ systems.

ANATOMICAL CONSIDERATIONS
  The heart is located in the middle of the chest cavity.
  - The heart is situated at an angle under the sternum so that its base lies predominately to the right and the apex to the left of the sternum.
  - The fact that the heart is positioned between two bony structures, the sternum and vertebrae, make it possible to manually drive blood out of the heart.

  The heart is a dual pump.
  - Even though anatomically the heart is a single organ, the right and left sides of the heart function as two separate pumps.
  - The upper chambers, the atria, receive blood returning to the heart and transfer it to the lower chambers, the ventricles, which pump the blood from the heart.
  - The vessels that return blood from the tissues to the atria are veins, and those that carry blood away from the ventricles to the tissues are arteries.
  - The right side of the heart pumps blood into the pulmonary circulation.
  - The right ventricle pumps blood out through the pulmonary artery to the lungs.
• The left side of the heart pumps blood into the systemic circulation.
• The large artery carrying blood away from the left ventricle is the aorta.
• Both sides of the heart simultaneously pump equal amounts of blood.
• The volume of oxygen-poor blood being pumped to the lungs by the right side of the heart soon becomes the same volume of oxygen-rich blood being delivered to the tissues by the left side of the heart.
• The pulmonary circulation is a low-pressure, low-resistance system, whereas the systemic circulation is a high-pressure, high-resistance system.

*Heart valves ensure that the blood flows in the proper direction through the heart.*
• Blood flows through the heart in one fixed direction from veins to atria to ventricles to arteries.
• Two of the heart valves, the right and left atrioventricular (AV) valves, are positioned between the atrium and the ventricle on the right and left sides, respectively.
• The two remaining heart valves, the aortic and pulmonary valves, are located at the junction where the major arteries leave the ventricles.
• They are known as semilunar valves because they are composed of three cusps, each resembling a shallow half-moon shaped pocket.
• The heart forms from a single tube that bends upon itself and twists on its axis during embryonic development.

*The heart walls are composed primarily of spirally arranged cardiac muscle fibers interconnected by intercalated discs.*
• The heart wall consists of three distinct layers: (1) The endocardium is a thin inner layer of endothelium that lines the entire circulatory system. (2) The myocardium, the middle layer composed of cardiac muscle, constitutes the bulk of the heart wall. (3) The epicardium is a thin external membrane covering the heart.
• The myocardium consists of interlacing bundles of cardiac muscle fibers arranged spirally around the circumference of the heart.
• The spiral arrangement is due to the heart's complex twisting during development.
• When the ventricular muscle contracts and shortens, the diameter of the ventricular chambers is reduced while the apex is simultaneously pulled upward toward the top of the heart in a rotating manner.
• The individual cardiac muscle cells are interconnected to form branching fibers, with adjacent cells joined end to end at specialized structures known as intercalated discs.
• Within an intercalated disc, there are two types of membrane junctions: desmosomes and gap junctions.
• Cardiac muscle is capable of generating action potentials without nervous stimulation.
• There are no gap junctions between atrial and ventricular contractile cells, and furthermore, these muscle masses are separated by the electrically nonconductive fibrous skeleton that surrounds the valves.
• An important specialized conducting system is present to facilitate and coordinate the transmission of electrical excitation from the atria to the ventricles.
• Either all of the cardiac muscle fibers contract or none of them do.
• Gradation of cardiac contraction is accomplished by varying the strength of contraction of all the cardiac muscle cells.
• Cardiac muscle cells contain an abundance of mitochondria and myoglobin.
• No new cardiac-muscle cells are produced after infancy.

*The heart is enclosed by the pericardial sac.*
• The heart is enclosed in the double-walled, membranous pericardial sac.
• The sac is lined by a membrane that secretes a thin pericardial fluid, which provides lubrication to prevent friction between the pericardial layers as they glide over each other.

**Electrical Activity of the Heart**
*The sinoatrial node is the normal pacemaker of the heart.*
The heart contracts, or beats, rhythmically as a result of action potentials that it generates by itself, a property known as autorhythmicity.

There are two types of cardiac muscle cells: (2) Ninety-nine percent of the cardiac muscle cells are contractile cells. (2) The autorhythmic cells do not contract, but instead are specialized for initiating and conducting the action potentials responsible for contraction.

The cardiac autorhythmic cells display pacemaker activity.

The membrane potential's slow drift to threshold is caused by a cyclical decrease in passive outward flux of potassium superimposed on a slow, unchanging inward leak of sodium.

The cardiac cells capable of autorhythmicity are found in the following specific locations: (1) the sinoatrial node, (2) the atrioventricular node, (3) the bundle of His, and (4) the Purkinje fibers.

Various autorhythmic cells differ in the rates at which they are normally capable of generating action potentials.

The SA node, which normally exhibits the fastest rate of autorhythmicity, is known as the pacemaker of the heart.

The non-SA nodal autorhythmic tissues are latent pacemakers.

*The spread of cardiac excitation is coordinated to ensure efficient pumping.*

- For efficient cardiac function, the spread of excitation should satisfy three criteria: (1) Atrial excitation and contraction should be complete before the onset of ventricular contraction. (2) Excitation of cardiac muscle fibers should be coordinated to ensure that each heart chamber contracts as a unit to accomplish efficient pumping. (3) The pair of atria and pair of ventricles should be functionally coordinated so that both members of the pair contract simultaneously.
- Simultaneous contraction permits synchronized pumping of blood into the pulmonary and systemic circulation.
- The normal spread of cardiac excitation is carefully orchestrated to ensure that these criteria are met and the heart functions efficiently.
- An action potential originating in the SA node first spreads throughout both atria, primarily from cell to cell via gap junctions.
- The interatrial pathway extends from the SA node within the right atrium to the left atrium.
- This pathway ensures that both atria become depolarized to contract more or less simultaneously.
- The internodal pathway extends from the SA node to the AV node.
- The internodal conduction pathway directs the spread of an action potential originating at the SA node to the AV node to ensure sequential contraction of the ventricles following atrial contraction.
- The action potential is conducted relatively slowly through the AV node.
- The slowness is advantageous because it allows time for complete ventricular filling to occur.
- The impulse rapidly travels down the bundle of His and throughout the ventricular myocardium via the Purkinje fibers.
- The ventricular conduction system is more highly organized and more important than the interatrial and internodal conduction pathways.
- The rapid conduction of the action potential down the bundle of His and its swift, diffuse distribution throughout the Purkinje network lead to almost simultaneous activation of the ventricular myocardial cells in both ventricular chambers, which ensures a single, smooth, coordinated contraction that can efficiently eject blood into both the systemic and pulmonary circulations at the same time.

*The action potential of contractile cardiac muscle cells shows a characteristic plateau.*

- Unlike autorhythmic cells, the membrane of contractile cells remains essentially at rest at about -90mV until excited by electrical activity propagated from the pacemaker.
- Once the membrane is excited, an action potential is generated by a complicated interplay of permeability changes and membrane potential changes.
• During the rising phase of the action potential, the membrane potential rapidly becomes reversed to a positive value of +30mV as a result of an explosive sodium influx.

• The membrane potential is maintained at this positive level for several hundred milliseconds, producing a plateau phase of the action potential.

• Two voltage-dependent permeability changes are responsible for maintaining this plateau: activation of "slow" calcium channels and a marked decrease in potassium permeability.

• The rapid falling phase of the action potential results from inactivation of the calcium channels and activation of potassium channels.

• The mechanism by which an action potential in a cardiac muscle fiber brings about contraction of that fiber is quite similar to the excitation--contraction coupling process of skeletal muscle and smooth muscle.

• Cardiac muscle's T tubular dihydropyridine receptors serve as calcium channels that are opened in response to local membrane depolarization.

• Calcium diffuses into the cytosol across the T tubule membrane during cardiac action potential.

• Entering calcium triggers release of calcium from the sarcoplasmic reticulum.

• Calcium also diffuses into the cytosol across the plasma membrane from the ECF during a cardiac action potential.

• This extra supply of calcium is not only the major factor responsible for the prolongation of the cardiac action potential but is also responsible for the subsequent lengthening of the period of cardiac contraction.

• In cardiac muscle the extent of cross-bridge activity varies with the amount of cytosolic calcium.

Tetanus of cardiac muscle is prevented by a long refractory period.

• During the refractory period, which occurs immediately after the initiation of an action potential, an excitable membrane's responsiveness is totally abolished.

• Cardiac muscle has a long refractory period.

• Consequently, cardiac muscle cannot be restimulated until contraction is almost over, making summation of contractions and tetanus of cardiac muscle impossible.

The ECG is a record of the overall spread of electrical activity through the heart.

• An ECG is a recording of that portion of the electrical activity induced in the body fluids by the cardiac impulse that reaches the surface of the body, not a direct recording of the actual electrical activity of the heart.

• The ECG is a complex recording representing the overall spread of activity throughout the heart during depolarization and repolarization.

• The ECG is not a recording of a single action potential in a single cell.

• The recording represents comparisons in voltage detected by electrodes at two different points on the body surface, not the actual potential.

• To provide standard comparisons, ECG records routinely consist of twelve conventional electrode systems or leads.

Various components of the ECG record can be correlated to specific cardiac events.

• A normal ECG exhibits three distinct waveforms: the P wave, the QRS complex, and the T wave.

• The P wave represents atrial depolarization.

• The QRS complex: represents ventricular depolarization.

• The T wave represents ventricular repolarization.

• The electrical activity associated with atrial repolarization normally occurs simultaneously with ventricular depolarization and is marked by the QRS complex.

• The P wave is much smaller than the QRS complex because the atria have a much smaller muscle mass than the ventricles.

• There are three times when no current is flowing in the heart musculature and the ECG remains at baseline: (1) During the AV nodal delay, (2) the ST segment, and (3) the TP interval.
The ECG can be useful in diagnosing abnormal heart rates, arrhythmias, and damage of heart muscle.

- Because electrical activity triggers mechanical activity, abnormal electrical patterns are usually accompanied by abnormal contractile activity of the heart.
- The principle deviations from normal that can be ascertained through electrocardiography are as follows: tachycardia, bradycardia, arrhythmia, atrial flutter, atrial fibrillation, ventricular fibrillation, and heart block.
- Abnormal ECG waves are also important in the recognition and assessment of cardiac myopathies, such as myocardial ischemia, necrosis, coma, and acute myocardial infarction.

MECHANICAL EVENTS OF THE CARDIAC CYCLE
The heart alternately contracts to empty and relaxes to fill.

- The cardiac cycle consists of alternate periods of systole and diastole.
- The atria and ventricles go through separate cycles of systole and diastole.
- Because of the continuous inflow of blood from the venous system into the atrium, atrial pressure slightly exceeds ventricular pressure even though both chambers are relaxed.
- The AV valve opens and blood flows directly from the atrium into the ventricle throughout ventricular diastole.
- Ventricular volume slowly continues to rise even before atrial contraction takes place.
- Late in ventricular diastole, the SA node fires.
- The impulse spreads throughout the atria (P wave).
- Atrial depolarization brings about atrial contraction.
- Throughout atrial contraction, atrial pressure still slightly exceeds ventricular pressure, so the AV valve remains open.
- Ventricular diastole ends at the onset of ventricular contraction.
- The volume of blood in the ventricle at the end of diastole is known as the end-diastolic volume (EDV).

- Following atrial excitation, the impulse passes through the AV node and specialized conducting system to excite the ventricle.
- Simultaneously, atrial contraction is occurring.
- By the time ventricular activation is complete, atrial contraction is already accomplished.
- The QRS complex represents this ventricular excitation, which induces ventricular contraction.
- As ventricular contraction begins, ventricular pressure immediately exceeds atrial pressure.
- The backward pressure differential forces the AV valve closed.
- There is a brief period of time between closure of the AV valve and opening of the aortic valve when the ventricle remains a closed chamber.
- This interval is termed the period of isovolumetric ventricular contraction.
- When ventricular pressure exceeds aortic pressure, the aortic valve is forced open and ejection of blood begins.
- Ventricular systole includes both the period or isovolumetric contraction and the ventricular ejection phase.
- About half of the blood contained within the ventricle at the end of diastole is pumped out during the subsequent systole.
- The amount of blood remaining in the ventricle at the end of ventricular systole is known as end-systolic volume (ESV).
- The amount of blood pumped out of each ventricle with each contraction is known as the stroke volume, the difference between the volume of blood in the ventricle before contraction and the volume after contraction (EDV-ESV).
- The T wave signifies ventricular repolarization occurring at the end of ventricular systole.
- As the ventricle starts to relax, the aortic valve closes.
- Closure of the aortic valve produces a disturbance or notch on the aortic pressure curve known as the dicrotic notch.
- All valves are once again closed for a brief period of time known as isovolumetric ventricular relaxation.
• When the ventricular pressure falls below the atrial pressure, the AV valve opens and ventricular filling occurs once again.

Two heart sounds associated with valve closures can be heard during the cardiac cycle.
• Two major heart sounds normally can be heard during the cardiac cycle when listening with a stethoscope.
• The first sound is associated with the closure of the semilunar valves.
• Closure of the AV node occurs at the onset of ventricular contraction.
• Closure of the semilunar valves occurs at the onset of ventricular relaxation.

Turbulent blood flows produces heart murmurs.
• Abnormal heart sounds, or murmurs, are usually associated with cardiac disease.
• Blood normally flows in a laminar fashion and does not produce any sound.
• When blood flow becomes turbulent, however, a sound can be heard and is due to vibrations created in the surrounding structures by the turbulent flow.
• The most common cause of turbulence is valve malfunction, either a stenotic (a stiff, narrowed valve) or an insufficient valve (one that cannot close completely).
• Most often, both valvular stenosis and insufficiency are caused by rheumatic fever.
• The valve involved and the type of defect can usually be detected by the location and timing of the murmur.
• A murmur occurring between the first and second heart sounds signifies a systolic murmur.
• A diastolic murmur occurs between the second and first heart sounds.
• The sound of the murmur characterizes it as either a stenotic (whistling) murmur or an insufficient (swishy) murmur.

Heart rate is determined primarily by autonomic influences on the SA node.
• The heart is innervated by both divisions of the autonomic nervous system, which can modify the rate of contraction, even though nervous stimulation is not required to initiate contraction.
• The parasympathetic nerve to the heart; the vagus nerve, primarily supplies the atrium, especially the SA and AV nodes.
• There is no significant parasympathetic innervation to the ventricles.
• The cardiac sympathetic nerves also supply the atria, including the SA and AV nodes, and richly innervate the ventricles as well.
• The parasympathetic nervous system's influence on the SA node is to decrease the heart rate.
• Parasympathetic influence on the AV node decreases the node's excitability, prolonging the AV nodal delay.
• Parasympathetic stimulation of the atrial contractile cells shortens the action potential, that is, the plateau phase is reduced and atrial contraction is weakened.
• The sympathetic nervous system speeds up the heart rate through its effect on the pacemaker tissue.
• Sympathetic stimulation of the AV node reduces the AV nodal delay
• Similarly, sympathetic stimulation speeds up the spread of the action potential throughout the specialized conducting pathway.
• Sympathetic stimulation increases contractile strength so that the heart beats more forcefully and squeezes out more blood.

Stroke volume is determined by the extent of venous return and by sympathetic activity.
• Two types of controls influence stroke volume: (1) intrinsic control related to the extent of venous return and (2) extrinsic control related to the extent of sympathetic stimulation of the heart.

Increased end-diastolic volume results in increased stroke volume.
• The direct correlation between end-diastolic volume and stroke volume constitutes the intrinsic control of stroke volume, which
refers to the heart's inherent ability to vary the stroke volume.

- For cardiac muscle, the resting cardiac muscle fiber length is less than optimal length.
- An increase in cardiac muscle fiber length, by moving closer to the optimal length, increases the contractile tension of the heart on the following systole.
- The main determinant of cardiac muscle fiber length is the degree of diastolic filling.
- This intrinsic relationship between end-diastolic volume and stroke volume is known as the Frank-Starling law of the heart.
- Stated simply, the law says that the heart normally pumps all the blood returned to it

The contractility of the heart is increased by sympathetic stimulation.

- Stroke volume is also subject to extrinsic control.
- Sympathetic stimulation and epinephrine enhance the heart's contractility.
- Sympathetic stimulation increase stroke volume by enhancing venous return.
- Sympathetic stimulation constricts the veins, which squeezes more blood forward from the veins to the heart, increasing the end-diastolic volume.
- The strength of cardiac contraction and the stroke volume can thus be graded by (1) varying the initial length of the muscle fibers; and (2) varying the extent of sympathetic stimulation.

High blood pressure increases the workload of the heart.

- When the ventricles contract, they must generate sufficient pressure to exceed the blood pressure in the major arteries in order to force open the semilunar valves.
- The arterial blood pressure is referred to as the afterload because it is the workload imposed on the heart.
- If the arterial blood pressure is chronically elevated, the ventricle has to generate more pressure to eject blood.
- A chronically elevated afterload is one of the two major factors that cause heart failure.

The contractility of the heart is decreased in heart failure.

- Heart failure refers to the inability of the cardiac output to keep pace with the body's demands for supplies and removal of wastes.
- Heart failure may occur for a variety of reasons, but the two most common are (1) damage to the heart muscle and (2) prolonged pumping against a chronically increased afterload.
- The prime defect in heart failure is a decrease in cardiac contractility.
- A failing heart will pump out a smaller stroke volume than a normal healthy heart.
- Two major compensatory measures help restore the stroke volume to normal; sympathetic activity to the heart is reflexly increased and when cardiac output is reduced, the kidneys, in a compensatory attempt to improve their reduced blood flow, retain extra salt and water in the body during urine formation to expand the blood volume.

NOURISHING THE HEART MUSCLE

The heart receives most of its own blood supply through the coronary circulation during diastole.

- The heart muscle must receive blood through blood vessels, specifically by means of the coronary circulation.
- The coronary arteries branch from the aorta just beyond the aortic valve, and the coronary veins empty into the right atrium.
- Most coronary arterial flow occurs during diastole.
- Coronary blood flow is adjusted primarily in response to changes in the heart's oxygen requirements.
- The link that coordinates coronary blood flow with myocardial oxygen needs is adenosine.
- Increased formation and release of adenosine from the cardiac cells occur (1) when there is cardiac oxygen deficit, or (2) when cardiac activity is increased and the heart accordingly requires more oxygen and is using more ATP as an energy source.
Atherosclerotic coronary artery disease can deprive the heart of essential oxygen.

- Coronary artery disease can cause myocardial ischemia by the three following mechanisms: (1) profound vascular spasm of the coronary arteries, (2) the formation of atherosclerotic plaques, and (3) thromboembolism.
- Vascular spasm is an abnormal spastic constriction that transiently narrows the coronary vessels.
- Atherosclerosis is a progressive, degenerative arterial disease that leads to occlusion of affected vessels.
- Potential complications of coronary atherosclerosis are angina pectoris and thromboembolism.

The amount of "good" cholesterol versus "bad" cholesterol in the blood is linked to atherosclerosis.

- There are two sources of cholesterol for the body: (1) dietary intake of cholesterol, and (2) manufacture of cholesterol by many organs within the body.
- There are three major lipoproteins, named for their density of protein as compared to lipid: (1) high-density lipoproteins (HDL), (2) low-density lipoproteins (LDL), and (3) very-low-density lipoproteins (VLDL).
- Cholesterol carried in LDL complexes has been termed "bad" cholesterol, because cholesterol is transported to the cells, including those lining the blood-vessel walls, by means of LDL.

- In contrast, cholesterol carried in HDL complexes has been dubbed "good" cholesterol, because HDL removes cholesterol from the cells and transports it to the liver for partial elimination from the body.
- It is difficult to significantly reduce cholesterol levels in the blood by decreasing cholesterol intake.
- The liver has a primary role in determining total blood cholesterol levels, and the interplay between LDL and HDL determines the traffic flow of cholesterol between the liver and the individual cells of the body.
- Evidence suggests that the propensity toward developing atherosclerosis substantially increases with elevated levels of LDL.
- Elevated levels of HDL are associated with a low incidence of atherosclerotic heart disease.
- The higher the HDL-cholesterol concentration in relationship to the total blood cholesterol level the lower the risk of atherosclerosis.
- Some other factors known to influence atherosclerotic risk are: (1) cigarettes smoking which lowers HDL, (2) higher HDL level in individuals who exercise regularly, (3) estrogen in premenopausal women causes higher HDL levels, and (4) vitamins E and C have been shown to slow plaque deposition.
- The ingestion of polyunsaturated fatty acids, the predominant fatty acids of most plants tends to reduce blood cholesterol levels by enhancing the elimination of both cholesterol and cholesterol-derived bile salts in the feces.

**Key Terms**

Acute myocardial infarction  
After load  
Angina pectoris  
Apolipoprotein A-I, A-II  
Arrhythmia  
Atherosclerosis  
Atrial flutter  
Atrial fibrillation  
Atrioventricular (AV) node  
Atrioventricular (AV) valves  
Atrium  

Autorhythmicity  
AV nodal delay  
Blood  
Bicuspid valve  
Bradycardia  
Bundle of His (atrioventricular bundle)  
C-reactive protein  
Cardiac myopathies  
Cardiac output (CO)  
Cardiopulmonary resuscitation (CPR)  
Chordae tendineae
Complete heart block
Coronary artery disease (CAD)
Congestive heart failure
Contractility
Diastole
Diastolic murmur
Electrocardiogram
Electrical defribulation
End-diastolic volume
End-systolic volume
Endocardium
Epicardium
Extrasystole (premature beat)
Fibrillation
First heart sound
Gingivitis
Heart
Heart attack
Heart block
High density lipoproteins
Homocysteine
Intercalated discs
Lipoprotein(a)
Low density lipoproteins
Mitral valve
Myocardial infarction
Myocardial ischemia
Myocardium
Necrosis
Nitric oxide
Pacemaker
Pacemaker activity
Pacemaker potential
Papillary muscle
Pericarditis
Pericardial fluid
Plaque
Preload
Pulmonary circulation
Purkinje fibers
P wave
QRS complex
Regurgitation
Second heart sound
Semilunar valves
Septum
Sinoatrial (SA) node
Stenotic valve
Sternum
Systemic circulation
Systolic murmur
Stroke volume
Systole
Tachycardia
Thoracic cavity
Tricuspid valve
Thromboembolism
Thrombus
T wave
Ventricular fibrillation
Review Exercises
Answers are in the appendix

True/False

1. Ninety-nine percent of the cardiac muscle cells are autorhythmic cells.

2. The AV node, which normally exhibits the fastest rate of autorhythmicity is known as the pacemaker of the heart.

3. An action potential originating in the SA node first spreads throughout both atria primarily from cell to cell via gap junctions.

4. The internodal conduction pathway directs the spread of an action potential originating at the SA node to the AV node to assure sequential contraction of the ventricles following atrial contraction.

5. The ventricular conduction system is more highly organized and more important than the interatrial and internodal conduction pathways.
6. Cardiac muscle has a short refractory period.

7. A normal ECG exhibits three distinct wave forms: the P wave, the QRS complex, and the T wave.

8. The QRS complex represents atrial depolarization

9. The two determinants of cardiac output are heart rate and stroke volume.

10. The parasympathetic nervous system's influence on the SA node is to increase the heart rate.

11. The parasympathetic nervous system stimulation of the AV node reduces the AV nodal delay.

12. Sympathetic stimulation increases stroke volume by enhancing venous return.

13. The prime defect in heart failure is a decrease in cardiac contractility.

14. Cholesterol carried in HDL complexes has been termed "bad" cholesterol.

15. It is difficult to significantly reduce cholesterol levels in the body by decreasing cholesterol intake.

16. The liver has a primary role in determining total blood cholesterol levels.

17. Elevated levels of HDL are associated with a low incidence of atherosclerotic heart disease.

18. The cardiac cycle consists of alternate periods of systole and diastole.

19. Early in ventricular diastole, the SA node reaches threshold and fires.

20. Atrial depolarization brings about atrial contraction.

21. Ventricular systole includes both the period of isovolumetric contraction and the ventricular ejection phase.

22. The first heart sound is associated with closure of the AV valve.

23. Laminar flow produces a faint sound.

24. The sound of the murmur characterizes it as either a stenotic murmur or an insufficient murmur.

25. There are no gap junctions between the atrial and ventricular contractile cells.

26. Either all the cardiac muscle fibers contract or none of them do.

27. Cardiac muscle cells contain no mitochondria and no myoglobin.

28. Few new cardiac muscle cells are produced after infancy.
29. Blood serves as the transport medium.

30. Pulmonary circulation consists of a circuit of vessels carrying blood between the heart and organ systems.

31. Anatomically the heart is a single organ, though it has a right and left side, they still function as a single pump.

32. The left side of the heart pumps blood into the pulmonary circulation.

33. Both sides of the heart simultaneously pump equal amounts of blood.

34. The systemic circulation is a low-pressure, low-resistance system.

35. Blood flows through the heart in one fixed direction from veins to atria to ventricles to arteries.

36. Cardiac muscle is capable of generating action potentials without any nervous stimulation.

Fill in the Blank

37. _________________ is an abnormal spastic constriction that transiently narrows the coronary vessels.

38. _________________ is a progressive, degenerative arterial disease that leads to occlusion of affected vessels.

39. An abnormal clot attached to a vessel wall is known as a(n) _________________.

A freely floating clot is known as _________________.

40. ________________ exists when small terminal branches form adjacent blood vessels nourish the same area.

41. There are three major lipoproteins: (1) ________________, which contain the most protein and least cholesterol, (2) ________________, which contain less protein and more cholesterol, and (3) ________________, which contain the least protein and most lipid, but the lipid carried is neutral fat, not cholesterol.

42. Random, uncoordinated excitation and contraction of the cardiac cells is known as ____________.
43. The _______________ pathway extends from the SA node within the right atrium to the left atrium.

44. The _______________ represents ventricular repolarization.

45. A rapid heart rate of more than 100 beats per minute is known as _______________.

46. A slow heart rate of fewer than 60 beats per minute is known as _______________.

47. _______________ fibrillation is characterized by rapid, irregular, uncoordinated depolarization of the atria with no definite P waves.

48. The heart has a broad base at the top and tapers to a pointed tip known as the _______________ at the bottom.

49. CPR is short for _______________.

50. _______________ pump blood from the heart.

51. The vessels that return blood from the tissues to the atria are _______________.

52. The large artery carrying blood away from the left ventricle is the _______________.

53. The right AV valve is also called the _______________.

54. The _______________ is a thin external membrane covering the heart.

55. The non-SA nodal autorhythmic tissues are _______________.

56. _______________ is the volume of blood pumped by each ventricle per minute.

57. The difference between the cardiac output at rest and the maximum volume of blood the heart is capable of pumping per minute is known as the _______________.

58. The direct correlation between end-diastolic volume and stroke volume constitutes the _______________ of stroke volume, which refers to the heart's inherent ability to vary the stroke volume.

59. The intrinsic relationship between end-diastolic volume and stroke volume is known as the _______________.

60. _______________ refers to the inability of the cardiac output to keep pace with the body's demands for supplies and removal of wastes.
61. The volume of blood in the ventricle at the end of diastole is known as the _____________________.

62. When all the valves are closed and no blood can enter or leave the ventricle during this time, this interval is termed the period of _____________________.

63. The amount of blood remaining in the ventricle at the end of systole when ejection is complete is known as the _____________________.

64. Abnormal heart sounds are called _____________________.

65. An abnormal heart sound occurring between the first and second heart sounds signifies a(n) _____________________.

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Matching

*Match the division of the autonomic nervous system to the effect it exerts on the heart or structures that influence the heart.*

a. sympathetic
   b. parasympathetic

   ___ 66. Has no effect on the adrenal medulla
   ___ 67. Increases contractility of the atrial muscle and strengthens contraction
   ___ 68. Decreases excitability; increases AV nodal delay
   ___ 69. Has no effect on the ventricular conduction pathway
   ___ 70. Increases rate of depolarization to threshold of SA node; increases heart rate
   ___ 71. Promotes adrenomedullary secretion of epinephrine
   ___ 72. Increases contractility of the ventricular muscle; strengthens contraction
   ___ 73. Increases venous return
   ___ 74. Decreases contractility of atrial muscle
   ___ 75. Increases excitability; decreases AV nodal delay

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Multiple Choice

76. This cardiac disorder is most often caused by a streptococcus bacterial infection.
   a. myocardial infarction
   b. myocardial ischemia
   c. atherosclerosis
   d. congestive heart failure
   e. valvular stenosis
77. This cardiac complication can be caused by prolonged pumping against a chronically increased afterload.
   a. myocardial infarction
   b. myocardial ischemia
   c. atherosclerosis
   d. congestive heart failure
   e. valvular stenosis

78. This chest pain is associated with myocardial ischemia.
   a. myocardial nociceptosis
   b. angina pectoris
   c. atheroma
   d. valvular stenosis
   e. heartburn

79. This is a noncancerous tumor of smooth-muscle cells within the blood-vessel walls.
   a. myocardial infarction
   b. myocardial ischemia
   c. atheroma
   d. fibroblastoma
   e. glioma

80. This cardiac disorder can be caused by profound vascular spasm of the coronary arteries.
   a. myocardial infarction
   b. myocardial ischemia
   c. atherosclerosis
   d. congestive heart failure
   e. valvular stenosis

81. This is a progressive, degenerative arterial disease that leads to occlusion of affected vessels.
   a. myocardial infarction
   b. myocardial ischemia
   c. atherosclerosis
   d. congestive heart failure
   e. valvular stenosis

82. This heart disorder can be caused by thromboembolism.
   a. myocardial infarction
   b. myocardial ischemia
   c. atherosclerosis
   d. congestive heart failure
   e. valvular stenosis

83. This disease has a close relationship with cholesterol.
   a. myocardial infarction
   b. myocardial ischemia
   c. atherosclerosis
   d. congestive heart failure
   e. valvular stenosis
84. This disease is characterized by abnormally large amounts of blood being dammed up in the venous system.
   a. myocardial infarction
   b. myocardial ischemia
   c. atherosclerosis
   d. congestive heart failure
   e. valvular stenosis

85. This condition is commonly known as a heart attack.
   a. myocardial infarction
   b. myocardial ischemia
   c. atherosclerosis
   d. congestive heart failure
   e. valvular stenosis

86. Which of the following compounds reduces the force of cardiac contraction by blocking calcium influx during an action potential?
   a. digitalis
   b. nicotine
   c. verapamil
   d. caffeine
   e. all of the above

Modified Multiple Choice

*Indicate the proper order of the events during the cardiac cycle by placing the numbers in the blank preceding the events in sequence. The first and last events are already so indicated as a guide.*

87. _1_ AV valve open; aortic valve closed; ventricular filling occurring
88. _2_ blood ejected from the ventricle
89. _3_ isovolumetric ventricular relaxation
90. _4_ atrial contraction
91. _5_ AV valves open; ventricular filling occurs again; one cardiac cycle is complete
92. _6_ aortic valve opens
93. _7_ SA node discharges
94. _8_ ventricular filling complete
95. _9_ ventricular relaxation begins
96. _10_ aortic valve closes
97. _11_ isovolumetric ventricular contraction
98. _12_ ventricular contraction begins: AV valves close

*Indicate which valve abnormality is being described using the answer code below.*

A = valvular stenosis
B = valvular insufficiency

99. _13_ produces a “gurgling” murmur
100. _14_ produces a “whistling murmur
101. _15_ valve does not close completely
102. _____ valve does not open completely

*Indicate which ion is involved in each event being described by using the following answer code:*

\[
\begin{align*}
A &= \text{K}^+ \\
B &= \text{Na}^+ \\
C &= \text{Ca}^{2+}
\end{align*}
\]

103. Inactivity of _____ channels brings about the slow drift of membrane potential to threshold in the cardiac autorhythmic cells.

104. Explosive increase in membrane permeability to _____ brings about the rapidly rising phase of the action potential in contractile cardiac cells.

105. Slow inward diffusion of _____ is largely responsible for the plateau portion of the cardiac action potential.

106. The rapid falling phase of the cardiac action potential is brought about primarily by the outward diffusion of _____.

107. Changes in cytosolic _____ concentration bring about changes in the strength of cardiac contraction.

108. Parasympathetic stimulation increases the permeability of the SA node to _____, whereas sympathetic stimulation decreases the permeability to this same ion.

*Complete the following discussion by circling the correct phrase within the parentheses.*

If the venous return increases, at the end of diastole the ventricular volume will be (109. increased, decreased the same as before). Therefore, the length of the cardiac muscle cells will be (110. increased, decreased, the same as before). Consequently, during the next contraction the tension developed by the heart will be (111. greater than before, less than before, the same as before). The amount of blood pumped out as a result of this contraction will be (112. more than, less than, the same as) the amount pumped out by the contraction prior to the increase in venous return. Therefore, as venous return to the heart increases, the stroke volume ejected by the heart (113. increases, decreases, remains unchanged).

*Use the following answer code to indicate which factor involved in the initiation and spread of cardiac excitation is being identified.*

\[
\begin{align*}
A &= \text{SA node} \\
B &= \text{AV node} \\
C &= \text{is and Purkinje system} \\
D &= \text{gap junctions}
\end{align*}
\]

114. _____ has the fastest rate of pacemaker activity

115. _____ allows the impulse to spread from cell to cell

116. _____ delays conduction of the impulse

117. _____ only point of electrical contact between the atria and ventricles

118. _____ normal pacemaker of the heart

119. _____ rapidly conducts the impulse down the ventricular septum and throughout much of the ventricular musculature
Points to Ponder

1. Congenital heart defects are routinely corrected through the miracles of modern surgery. What happens to the number of people having such disorders as a result of these surgical techniques? What is the solution to this problem?

2. After carefully studying the sections of this chapter involving cholesterol and lipids, why do you suppose a good physician checks the triglycerides in the blood?

3. Speculate as to how much more work the heart of a physically inactive person has to perform than that of a physically active person.

4. Do adults of babies have the same heart rate? Blood pressure? Explain your answers.

5. How do the AV valves ensure a one-way flow of blood?

6. How does aerobic exercise help the heart?

7. How would you differentiate between heart flutter and fibrillation?

8. How does a defibrillator work physiologically?

9. What risk factors for heart disease can be modified? Which can’t be modified?

Clinical Perspectives

1. With respect to the heart, why do people generally sleep in a prone position?

2. What happens to the heart in these two situations?
   A. You sense you are about to sneeze so you close your mouth and hold your nose to muffle the sneeze. Then you sneeze.
   B. You are extremely constipated. In an effort to have a bowel movement you strain very hard.

3. Why do you suppose the sympathetic nervous system has an effect on the adrenal medulla while the parasympathetic has no effect at all?

4. Why is the nitroglycerin tablet placed under the tongue in cardiac patients?

5. Why does a physician or nurse practitioner tap a patient’s chest wall during a physical examination?

6. Why is it that individuals who have atrial fibrillation do not appear to have a higher mortality rate than those who have normal functioning atria?

7. What is meant by the phrase “splitting the heart sounds.”

8. How would you explain to a patient the relationship between plasma lipids and heart disease?

9. If a patient has premature ventricular contractions, how would this affect stroke volume?
Chapter 9: Cardiac Physiology

True/False

1. False—Contractile cells.
2. False—SA node.
3. True
4. True
5. True
7. True
9. True
10. False—Decrease.
11. False—Sympathetic.
12. True
13. True
14. False—LDL.
15. True
16. True
17. True
18. True
19. False—Late.
20. True
21. True
22. True
23. False—Produces no sound.
24. True
25. True
26. True
27. False—Contain an abundance of myoglobin.
28. False—None are produced.
29. True
30. False—Systemic circulation.
31. False—Function as two separate pumps.
32. False—Right side.
33. True
34. False—Pulmonary circulation.
35. True
36. True
37. Aorta
38. Tricuspid valve
39. Epicardium
40. Latent pacemakers
41. Cardiac output
42. Cardiac reserve
43. Intrinsic control
44. Frank-Starling Law of the Heart
45. Heart failure
46. End-diastolic volume
47. Isovolumetric ventricular contraction
48. End-systolic volume (ESV)
49. Murmurs
50. Systolic murmur

Matching

66. b
67. a
68. b
69. b
70. a
71. a
72. a
73. a
74. b
75. a

Multiple Choice

76. e
77. d
78. b
79. c
80. b
81. c
82. b
83. c
84. d
85. a
86. c
87. 1
88. 8
89. 11
90. 3
91. 12
92. 7
93. 2
94. 4
95. 9

Fill in the Blank

37. Vascular spasm
38. Atherosclerosis
39. Thrombus, embolus
40. Collateral circulation
41. HDL, LDL, VLDL
42. Fibrillation
43. Interatrial
44. T
45. Tachycardia
46. Bradycardia
47. Atrial
48. Apex
49. Cardiopulmonary resuscitation
50. Ventricles
51. Veins