Chapter 20: The Cardiovascular System: The Heart

Chapter Objectives

ANATOMY OF THE HEART
1. Describe the location and orientation of the heart within the thorax and mediastinal cavity.
2. Describe the layers of the pericardium and state each layer’s function.
3. Examine the three layers of the heart wall and know what type of tissue is found in each layer.
4. Know the names of the valves of the heart. Know what type of valve each is and the exact location of each valve within the heart.
5. Explain the basic function of the heart valves.
6. Describe how the two atrioventricular valves work during a cycle of the heart.
7. Describe the difference in structure of the semilunar valves compared with the atrioventricular valves and show how they work.

CARDIAC MUSCLE AND THE CARDIAC CONDUCTION SYSTEM
8. Explain why the conduction system of the heart is different in terms of electrical signaling.
9. Describe the sequence in which the cardiac action potential spreads through the conduction system.
10. Describe an action potential in cardiac contractile fibers in terms of depolarization, plateau, and repolarization.

THE CARDIAC CYCLE
11. Define systole and diastole.
12. Explain how the passage of depolarization and repolarization through different areas of the heart is related to specific components of the wave pattern of an electrocardiogram (ECG).
13. Demonstrate how the various components of the ECG correlate to the events occurring within the chambers of the heart.
14. State which heart sound is the result of the atrioventricular valves closing and which is the result of the semilunar valves closing.
15. Define End diastolic volume, End systolic volume and Stroke volume.
16. Describe what occurs to ventricular pressure during the following phases of the Cardiac cycle: isovolumetric relaxation, ventricular filling, and ventricular systole.
**CARDIAC OUTPUT**

17. Define cardiac output (CO), describe the factors that affect it, and note changes with exercise in relation to cardiac reserve.

18. Define Preload, Contractility, and Afterload.

19. Explain that change in heart rate is controlled by the CNS and hormones so as to influence cardiac output and blood pressure.

**Chapter Lecture Notes**

**Introduction**

The heart is the pump that circulates the blood through an estimated 60,000 miles of blood vessels.

Heart pumps over 1 million gallons per year.

The heart is situated between the lungs in the mediastinum with about two-thirds of its mass to the left of the midline (Fig 20.1).

The study of the normal heart and diseases associated with it is known as **cardiology**.

**Pericardium**

The heart is enclosed and held in place by the pericardium. (Fig 20.2)

The pericardium consists of an outer fibrous pericardium and an inner serous pericardium (epicardium).

Fibrous pericardium

- dense irregular CT
- protects and anchors the heart, prevents overstretching

The serous pericardium is a thin delicate membrane composed of a outer, parietal layer and an inner, visceral layer (epicardium).

Between the parietal and visceral layers is the pericardial cavity which is filled with pericardial fluid that reduces friction between the two membranes.

Pericarditis - inflammation of the pericardium
Cardiac tamponade - bleeding into the pericardial cavity which compresses the heart and is potentially lethal

Layers of the Heart Wall

The wall of the heart has three layers: epicardium, myocardium, and endocardium (Fig 20.2)

The epicardium (visceral pericardium) consists of simple squamous epithelium and connective tissue

The myocardium is composed of cardiac muscle and is the bulk of the heart

Cardiac muscle fibers swirl diagonally around the heart in interlacing bundles

Myocarditis - inflammation of the myocardium

The endocardium consists of simple squamous epithelium and connective tissue

chamber lining & valves

Endocarditis - inflammation of the endocardium. It usually involves the heart valves.

Heart Valves

The heart has two types of valves (Fig 20.4 & 20.5)

Atrioventricular valves (AV)

Tricuspid valve – between right atrium and right ventricle

has three cusps composed of dense CT covered by endocardium

Bicuspid valve - between left atrium and left ventricle

has two cusps

Pneumonic - LAMB (Left Atrioventricular, Mitral, or Bicuspid valve)

Semilunar valves (SL)

Pulmonary semilunar valve - blood flows from right ventricle into pulmonary trunk

Aortic semilunar valve - blood flows from left ventricle into the ascending aorta

Heart Valve Function

Valves open and close in response to pressure changes as the heart contracts and relaxes

AV valves open and allow blood to flow from atria into ventricles when ventricular pressure is lower than atrial pressure (Fig 20.6)
ventricles are relaxed
chordae tendineae are slack
papillary muscles are relaxed

AV valves close preventing backflow of blood into atria

ventricles are contracted
increased blood pressure in ventricles push valve cusps closed
chordae tendineae are pulled taut
papillary muscles contract to pull cords and prevent cusps from everting

Semilunar valves open with ventricular contraction
allow blood to flow into pulmonary trunk and aorta

Semilunar valves close with ventricular relaxation
prevents blood from returning to ventricles
blood fills valve cusps and tightly closes the SL valves

Conduction System of Heart

Cardiac muscle cells are autorhythmic cells because they are self-excitable. They repeatedly
generate spontaneous action potentials that then trigger heart contractions. *(Fig 20.10)*
The autonomic nervous system and hormones, such as epinephrine, do modify the heartbeat (in
terms of rate and strength of contraction), but they do not establish the fundamental
rhythm
caffeine & nicotine increase activity

Sinoatrial (SA) node

Autorhythmic cluster of cells in wall of right atrium
SA node generates an Action potential spontaneously 90-100 times per minute
begins heart activity that spreads through the intercalated discs to all cardiac muscle cells in
both atria
excitation spreads to AV node
Atrioventricular (AV) node

in atrial septum

AV node fires at 40-50 times per minute

transmits signal to bundle of His

Atrioventricular (AV) bundle - bundle of His

the connection between atria and ventricles

divides into bundle branches

Right and left bundle branches - large diameter fibers that conduct signals quickly

in the interventricular septum

Purkinje fibers

in trabeculae carneae, papillary muscles and the myocardium

SA node sets pace since it is the fastest

In 50 msec excitation spreads through both atria and down to AV node

100 msec delay at AV node due to smaller diameter fibers - allows atria to fully contract filling

ventricles before ventricles contract

In 50 msec excitation spreads through both ventricles simultaneously

Action Potential and Contraction of Contractile Fibers

An Action potential in a ventricular contractile fiber is characterized by rapid depolarization,

plateau, and repolarization (Fig 20.11)

Depolarization

Cardiac cell resting membrane potential is -90mv

excitation spreads through gap junctions in the intercalated discs

fast Na⁺ channels open for rapid depolarization

Plateau phase

250 msec (only 1msec in neuron)
slow Ca\(^{2+}\) channels open, let Ca\(^{2+}\) enter from outside cell and from storage in sarcoplasmic reticulum, while most K\(^{+}\) channels remain closed

Ca\(^{2+}\) binds to troponin to allow for actin-myosin cross-bridge formation & tension development

Repolarization

Ca\(^{2+}\) channels close and K\(^{+}\) channels open & -90mv is restored as potassium leaves the cell

Refractory period - the time interval when a second contraction cannot be triggered

very long so heart can fill

longer in a cardiac muscle fiber than the contraction itself; therefore tetanus cannot occur in myocardial cells

Cardiac Cycle

At 75 beats/min, one cycle requires 0.8 sec

A cardiac cycle can be described using (Fig 20.14)

Contraction and relaxation cycles

Electrical signals – Electrocardiogram (ECG or EKG)

Heart sounds

Ventricular volumes

Pressure changes in the heart

Cardiac Cycle – Systole/Diastole

A cardiac cycle consists of

atrial systole (contraction)

simultaneous atrial diastole (relaxation) and ventricular systole

ventricular diastole – both chambers are relaxed until the next atrial systole

Cardiac Cycle - ECG

ECG (Fig 20.12 & 20.13)

action potentials of all active cells can be detected and recorded
P wave
atrial depolarization
after the P wave begins, the atria contract (atrial systole)

P to Q interval
conduction time from atrial to ventricular excitation

QRS complex
ventricular depolarization
the action potential moves rapidly through the bundle branches, Purkinje fibers, and the ventricular myocardium
ventricular contraction continues through the ST segment

T wave
ventricular repolarization

Cardiac Cycle – Heart Sounds
First sound (Lubb) – closing of the AV valves (Fig 20.14)
Occurs during ventricular systole and follows the QRS complex

Second sound (Dubb) – closing of the SL valves
Occurs during ventricular diastole and follows a T wave

Cardiac Cycle – Ventricular Volumes
Ventricular volume changes during the cardiac cycle (Fig 20.14)
End diastolic volume (EDV)
volume in ventricle at end of diastole, about 130ml
End systolic volume (ESV)
volume in ventricle at end of systole, about 60ml
Stroke volume (SV)
the volume ejected per beat from each ventricle, about 70ml

SV = EDV - ESV
Cardiac Cycle – Pressure Changes

During a cardiac cycle atria and ventricles alternately contract and relax forcing blood from areas of high pressure to areas of lower pressure. (Fig 20.14)

Changes in ventricular pressures during a cardiac cycle

Isovolumetric relaxation

occur at beginning of ventricular diastole

semilunar and AV valves are closed

brief period when volume in ventricles does not change

as ventricles relax, pressure drops and AV valves open

Ventricular filling - occurs in 3 phases while the ventricle is relaxed

rapid ventricular filling as blood flows from full atria

Diastasis - blood flows from atria in smaller volume

atrial systole pushes final 20-25 ml blood into ventricle

Ventricular systole

ventricular systole

ventricles contract and increasing pressure forces the AV valves to close

isovolumetric contraction

brief period, AV valves close before SL valves open

pressure continues to rise opening the SL valves leading to ventricular ejection

ventricular ejection - SL valves open and blood is ejected

Cardiac Output

Cardiac output (CO) is the volume of blood ejected from the left ventricle (or the right ventricle) into the aorta (or pulmonary trunk) each minute.

Cardiac output equals the stroke volume multiplied by the heart rate - CO = SV X HR

at 70ml stroke volume & 75 beat/min = 5 1/4 liters/min

entire blood supply passes through circulatory system every minute
Cardiac reserve - the maximum cardiac output a person can achieve/the cardiac output at rest.

average is 4-5x while athlete’s is 7-8x

Influences on Stroke Volume (Fig 20.17)

Preload (affect of stretching)

According to the Frank-Starling law of the heart, a greater preload (stretch) on cardiac

   muscle fibers just before they contract increases their force of contraction during

   systole.

Preload is proportional to EDV.

EDV is determined by length of ventricular diastole and venous return.

The Frank-Starling law of the heart equalizes the output of the right and left ventricles

   and keeps the same volume of blood flowing to both the systemic and pulmonary

   circulations.

Contractility

   Strength of contraction at any given preload

   Positive - autonomic nerves, epinephrine, increased interstitial Ca+2

   Negative – increased interstitial K+ levels

Afterload

   the pressure that must be overcome before a semilunar valve can open

   amount of pressure created by the blood in the way

   high blood pressure creates high afterload

Regulation of Heart Rate

   Changing heart rate is the body’s principal mechanism of short-term control over cardiac

   output and blood pressure.

   Nervous control from the cardiovascular center in the medulla (Fig 20.16)

      baroreceptors (pressure receptors) located in the arch of the aorta and carotid arteries

      detect change in blood pressure and send info to the cardiovascular center
sympathetic impulses increase heart rate and force of contraction

parasympathetic impulses decrease heart rate

Hormones

epinephrine, norepinephrine, thyroid hormones

Ions (Na\(^+\), K\(^+\), Ca\(^{+2}\))

Age, gender, physical fitness, and temperature