Chapter 20

The Heart

heart anatomy
located in the mediastinum, the medial cavity, of the thorax
lungs flank the heart and partially obscure
lies slightly to the left of the midline

apex points down towards the left

base is the broader upper aspect where the great vessels emerge

layers of the heart wall
1. epicardium or visceral pericardium
   outer thin layer of mesothelium
   is simple squamous epithelium
   some areolar tissue
   has adipocytes

2. myocardium
   1. mainly cardiac muscle
   2. thickest layer
   3. contains tissue to conduct electrical current
   4. contains a connective tissue fiber skeleton: the fibrous skeleton of the heart
      1. anchors cardiac muscle
      2. reinforces cardiac muscle
      3. provides support for great vessels
      4. limits spread of action potentials to specific pathways

3. endocardium
   1. single layer of endothelium attached to a thin layer of connective tissue
   2. lines the heart chambers
   3. is continuous with the endothelial linings of the blood vessels
   provides a none clotting surface
chamber and great vessels of the heart
heart has four chambers
right and left atria
right and left ventricles

atria
are the receiving chambers and receive blood returning to the heart
only need to contract enough to push blood into the ventricles
thus are thin walled
don’t contribute to the pumping of blood throughout the body

ventricles
1. right and left are separated by interventricular septum
2. make up most of the heart mass
3. are the discharging chambers thus are more massive
   right ventricle pumps out the pulmonary trunk to the lungs (low oxygen blood) so generate little pressure
   left pumps out the rest of the body (the systemic circulation)
and must generate greater pressure so is larger than right

Blood flow through the chambers of the heart (pp. 723)
1. blood enters right atria via three vessels
   1. inferior vena cava
   2. superior vena cava
   3. coronary sinus
2. blood passes by right AV valve (tricuspid valve)
3. blood enters right ventricle
4. blood is forces out the right ventricle passed the pulmonary semilunar valve
5. blood enters pulmonary trunk with splits into right and left pulmonary arteries
6. blood is sent to lungs
7. blood returns form lungs via one of four pulmonary veins (two rights and two lefts
8. blood enters left atria
9. blood passes left AV valve (bicuspid valve)
10 blood enters left ventricle
11. blood is forced passed aortic semilunar valve
12. blood enters aorta and is sent to body minus the lungs via
    brachiocephalic a,
    left carotid a,
    left subclavian a
    descending aorta

1. out the aorta return to right atria = **systemic circulation**
2. out the pulmonary trunk return to left atria = **pulmonary circulation**

   equal volume of blood passes through both circuits but
   work load is different

**pulmonary circuit** is short and low pressure circuit so
right ventricle has to pump less

**systemic circuit** is long and requires high pressure
thus the left ventricle is much larger (3X)

The heartbeat

Cardiac Physiology
The primary function of the heart is to propel blood though out the pulmonary and
systemic circulatory loops.

This is accomplished by the contraction of the cardiocytes that make up the heart

contraction of the heart’s contractile cells is triggered by **action potentials** that originate at the heart

There are types of cardiocytes
1. Specialized **conduction cells**
   that make up the conduction system and are designed to
   rapidly conduct electrical current

2. **Contractile cells**
   These are the cells that shorten which pushes the blood from the heart
   Are 99% of all cardiocytes

   Contractile cells are more common
All cardiocytes have the ability to depolarize spontaneously producing action potentials

For example:
- isolated atrial cells depolarize thus contract (beat) 60 times per min
- isolated ventricular cells depolarize thus contract 20-40 times per min

The cells that depolarize fastest will set the rate or pace of heart contractions

Under normally conditions the cells that pace the heart are located at the top of the right atrium.
- This piece of tissue is called the Sinoatrial node (SA node) or the pacemaker

from these pacemaker cells the action potentials spread across the heart along a conduction pathway

**Conduction system for the spread of electrical activity across the heart**

**Sinoatrial node**
- located in rear wall of right atrium near opening of superior vena cava

  - has fastest rhythm (80-100 a.p./min) & normally overrides all others
  - this is were the pacemaker cells are found and is also called the cardiac pacemaker

  action potential travels through walls of atria causing wave of atrial depolarization followed by a wave of atrial contraction
  - its rate of depolarization sets the heart rate (sinus rhythm)

**Internodal pathways**
- Connects SA node to atrioventricular (AV) node,

  - Consists of three major bands of conduction cells that branch through out the atria
    - Takes about 50 msec for the action potential to travel the internodal pathway
    - Along the way the contractile cells of the atria are stimulated to depolarize and produce action potentials
Action potentials spread from cell-to-cell via gap junctions (electrical synapses). Following depolarization the contractile cells of the atria contract and push blood into the ventricles.

The electrical events occurring in the atria do not pass to the ventricles due to a band of tissue called the fibrous skeleton that breaks the gap junction connections between atrial cells and ventricular cells. Due to a slow conduction speed down the internodal pathway, the atria will completely depolarize before the action potential reaches the next part of the conduction pathway, the AV node.

**Atrioventricular node**

Large node located at the junction between the atria and the ventricles in the right posterior portion of the interatrial septum.

AV nodal cells are smaller in diameter and have few gap junctions thus have a much slower rate of action potential propagation. Takes about 100 msec for action potential to through AV node.

Slower conduction speed in nodal fibers, allows complete atrial depolarization before action potential spreads to ventricles.

Thus allow the atria to contract and finish filling the ventricles with blood before the ventricles contract.

Under normal conditions the AV node can generate action potentials at a max rate of 230/min. This sets the maximum ventricular contraction rate (heart rate) at 230 beats/min.

If the SA node and thus atria contract faster it cannot result in a faster rate of ventricular contraction (the AV is the bottle neck).

After the AV node depolarizes the action potential next spreads to the AV bundle of His.

**AV Bundle of His**

*Only* electrical connection between atria & ventricles.

Fiber skeleton insulates the rest of the atria from ventricles.
Divides into right & left bundle branches as it passes through the ventricular septum
  Left is larger and supplies the larger left ventricle
  Both branches travel down towards the apex of the heart where they fan out into smaller Purkinje fibers

**Purkinje fibers**
Pass through ventricular myocardium

Fast rate of action potential generation and serve to synchronize ventricular contraction
  the contraction of the **ventricles** starts at the apex so that all blood is forced up and out

action potentials spread from cell to cell via **gap junctions** all along the conduction pathway and from cardiocyte to cardiocyte

By the time the action potential has reached the ventricular muscle at the apex the atria have completed their contraction maximizing the blood in the ventricles and the ventricles can now start to contract to expel the blood from the heart

**Generation of the electrical activity of the heart**
The heart generates its own electrical activity and this electrical activity triggers the heart (cardiocytes) to contract which pumps the blood

What is responsible for this electrical activity (action potentials)?

**Generation of the action potential at the pacemaker cells**
The SA node (pacemaker cells) spontaneously depolarizes (fires) 70-80 times per minute
  This occurs because the SA nodal cells have an unstable resting membrane potential

  1. negative charges accumulate inside the cells as it repolarizes from the last action potential
  2. the negative charges repel negative charges that are part of a special type of sodium channel
  3. this repulsion opens the sodium channel and now a lot of sodium enters the cell (sodium permeability goes up)
    This sodium channel is called the **slow spontaneously opening sodium channel**
4. now the membrane potential drops from -60mv until it reaches a **threshold** value (around -40mv)
   this opens **fast voltage-sensitive calcium channels**

5. now calcium rapidly enter to further depolarize the cell (not sodium like in nerve and skeletal muscle)

6. the entry of calcium neutralizes negative charges further, opening adjacent voltage sensitive calcium channels
   thus the action potential is propagated by calcium channels

5. the fast calcium channels and the slow spontaneously opening sodium channel close while voltage- sensitive potassium channels open this causes repolarization

As the cell repolarizes negative charges are accumulating inside the pacemaker cell
   This will now start to repel the negative charges on the spontaneously opening sodium channel starting the cycle over

   Thus the pacemaker cells have an unstable resting membrane potential

**Spread of electrical activity**

Once a pacemaker cell has depolarized (generated an action potential) this electrical charge spreads by the passing of positive charges from one cell to the next via gap junctions
   Thus the first cell to generate an action potential will force the adjacent cells to depolarize due to the attachment through gap junctions

   Therefore the action potential will spread quickly across and down the conduction pathway until it reaches the atria and ventricles where the contractile cells are

**electrical events at the contractile cells**

1. through gap junctions positive charges enters the cells and depolarizes a small area of membrane opening **fast voltage-sensitive sodium channels**
2. this allows more sodium to enter thus opening adjacent fast voltage-sensitive sodium channels
   thus the action potential is propagated by sodium channels
3. as the fast voltage-sensitive sodium channels start to close a second type of channel opens called the **slow voltage-sensitive calcium channel**

4. this channel lets positively charged calcium enter the cell and holds the cell depolarized for about 150 msec
   
   (this results in a **plateau** on the action potential)

5. repolarization begins when the voltage sensitive calcium channel will slowly close and voltage-sensitive potassium channels will slowly open to repolarize the cell

**Reason for a plateau:**

results in a long depolarization (200msec) thus have strong muscle contraction

   (not a twitch)

a long absolute refractory period so no tetanus

   absolute refractory period lasts until relaxation phase of contraction begins

**Role of the action potential**

- Results in opening calcium channels that let in 20% of the total calcium
- Makes the heart very sensitive to changes in blood calcium levels
- Makes these channels important targets for drug therapies

Stimulates the smaller sarcoplasmic reticulum to release the other 80% of calcium

**Role of calcium**

**excitation-contraction-coupling**

1. the action potential will be propagated down the T tubules

causing the sarcoplasmic reticulum to release calcium

2. the calcium from the ER and the calcium that entered from ion channels will bind to troponin

   This moves tropomyosin exposing a myosin binding site on actin

Now have cross bridge formation and power stroke resulting in filaments sliding = contraction

   contraction = pumping

**Innervation of the heart**