1. Circulation
2. Heart Muscle
3. Heart Function
4. Diving Response

Reading of Text:
Start with Chapters 23 & 24
(skip the invert material if you like)
Next week we will discuss 21 & 22
(read Chapter 20 quickly)
EXAM THURSDAY, Paper Drafts today
1. Draw a graph that represents the length-tension curve.  
   3 points

2. Explain, mechanistically, why the curve above has the shape it does.  
   2 points

3. Describe two characteristics that differ between muscle fiber types.  
   2 points

4. Explain what ryanodine and dihydropyridine receptors are and what they do.  
   3 points

Include Name and Lab time
**Cardiac Muscle** (the other striated muscle)
- Small muscle fiber cells with only one nucleus
- Individual fibers are connected to neighbors electronically via gap junctions

- Two types of fibers:
  1. **Contractile** (similar to skeletal muscle)
  2. **Conducting** (including pacemaker cells)
    - Do not contract, but transmit electrical signal

- Cardiac contraction **myogenic** (arises within heart)
  - Can be influenced by autonomic nervous system (alpha, beta adrenoreceptors increase [Ca2+])

- Long-lasting AP with long plateau phase, and long refractory period - why?
Cardiac Muscle (the other striated muscle)

- Intracellular calcium from SR and across plasma membrane (unlike in skeletal)

- Dihydropyridine receptors in T-tubules are voltage-activated calcium channels

- Ryanodine receptors then release more calcium from SR into the cytoplasm (calcium-induced calcium release)

- During relaxation, Calcium pumped actively back into SR and out across plasma membrane

Vertebrate Circulation (too big for diffusion!)

Heart is main propulsive organ

Arterial system
  - distributes blood
  - regulates pressure

Capillaries
  - transfer between blood and tissues

Venous system
  - return blood to heart
  - storage reservoir

Divided into Central and Peripheral
Focus on Mammalian Circulation with some exceptions
Gravity and BP

FIGURE 3.15 Arterial and venous pressures in a man as he assumes different postures. The figures indicate the pressures at various points in relation to the pressure in the right atrium of the heart. (1 mm Hg = 0.13 kPa).

[Modified from Burton 1972]

Knut Schmidt_Nielsen 1997

Circulatory Roles and Components

Valves control direction of blood flow

Smooth muscle controls diameter of peripheral vessels, thereby altering resistance and flow to different tissues.
Circulatory Roles and Components

- Gases (CO₂, O₂)
- Nutrients
- Waste
- Hormones
- Antibodies
- Salts
- etc.

-Temperature Regulation

-Blood volume 5-10% of body volume

Development of Terrestrial Circulatory System:

gills simple (and linear):
1. Blood goes to gills
2. O₂-rich blood goes to tissues
3. O₂-poor blood goes to heart
4. Blood gets pumped back to gills

lungs more complex because get 2 circuits in parallel:
1. Pulmonary circuit (lower pressure)
2. Systemic circuit (higher pressure)
Spongy vs. Compact Myocardium

Fish Circulation through gills
Addition of lungs more complicated

Water vs. air

Mammalian Circulation

Two parallel closed circuits:

1. Pulmonary (lower press.)
2. Systemic

Note venous reservoir

(Eckert, 12-3)
Tissue Beds in Parallel, not Series

All cells within 2-3 cells of a capillary
Can control amount of flow to each tissue independently

In addition to Heart,

Blood also moved via
1. Elastic recoil of arteries
2. Squeezing of vessels during body movement
3. Peristaltic contractions of smooth muscle in vessels
Non-Mammalian Heart Examples:

Amphibians and Reptiles (except crocodilians) with 3 chambers (= one ventricle, two atria)

- incomplete ventricular septum
- BUT separate rich and poor blood
- AND alter pressure in systemic and pulmonary
- able to alter flow to systemic or pulmonary circuit

Cardiovascular System

Amphibians:

only vertebrates where $O_2$ poor blood to skin
(as well as to lungs)

adults with paired pulmocutaneous arteries divide into two branches
1. Pulmonary
2. Cutaneous (to flanks and dorsum)

skin provides 20-90% $O_2$ uptake
30-100% $CO_2$ release
**Cardiovascular System**

**FROG Heart**

- conus arteriosus w/ spiral valve
- trabeculae (create channels)
- role of Tb and HR

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**Cardiovascular System**

**Reptilian Heart (not crocs)**

(no conus arteriosus, no spiral valve)

- 2 systemic arches and one pulmonary artery from single ventricle
- BUT, single ventricle functions as THREE
- 3-chambered heart anatomically
- 5-chambered heart functionally

- RAA = right aortic arch
- LAA = left aortic arch
- PA = pulmonary artery

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**Muscular Ridge**

- RA = right atrium
- LA = left atrium
Reptilian and Amphibian Circulation

Cardiac Shunts (in 3-chambered heart)

1. temperature regulation
2. breath holding (diving, turtle in shell, inflated lizards)
3. stabilize $O_2$ content of blood when breathe intermittently

**R to L**

$O_2$ poor to systemic via aortic arches  
(short delay between valves opening)

**L to R**

$O_2$ rich to pulmonary artery  
(longer delay between valves opening)
Mammalian fetus:

**Ductus arteriosus** (R -> L shunt, lung bypass)
- pulmonary artery to systemic arch
- when lung inflate resistance down (pulm)
- when lose placental circ. resistance up (syst)
- closes at birth

**Foramen ovale** (interatrial shunt R -> L)
- hole in wall between atria
- closes at birth

Bird chick:

**Chorioallantois**
= network of vessels under shell surface

**Interatrial septum**
- R -> L shunt, lung bypass
- closes after hatching
Electrical Activity in the Mammalian Heart

Influenced by autonomic NS

Cardiac Cells electronically linked by Gap Junctions

(except from atrial to ventricular cells...)

Vander 2001

Sherwood 1997
Electrical Activity in the Mammalian Heart

Recall AP and refractory period differences...

(Eckert, 12-7)
Types of Cardiac Cells:

A. **Contractile**

B. **Conducting**
   - autorhythmic
     - SA node
     - AV node
   - fast-conducting
     - Internodal
     - Interatrial
     - Bundle of His
     - Purkinje
     - Etc.
**Types of Cardiac Cells:**

A. Contractile

B. Conducting
   - 1° autorhythmic
     SA node
     AV node
   - 1° fast-conducting
     Internodal
     Interatrial
     Bundle of His
     Purkinje
     Etc.

**Pacemakers:**

- Normally HR driven by SA node
- Others are Latent pacemakers
- Called Ectopic pacemaker when node other than SA driving HR

Sherwood 1997

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**Figure 9.12** Different Autorhythmic Rates

(a) Recording from autorhythmic cell A. (b) Recording from autorhythmic cell B. Because cell A has a faster rate of depolarization, it reaches threshold more quickly than cell B and therefore generates action potentials more rapidly.

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Action Potentials Per Minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA node (normal pacemaker)</td>
<td>70–80</td>
</tr>
<tr>
<td>AV node</td>
<td>60–70</td>
</tr>
<tr>
<td>Bundle of His and Purkinje fibers</td>
<td>20–60</td>
</tr>
</tbody>
</table>

*In the presence of parasympathetic tone (see p. 206).

Sherwood 1997
The Heart Rate Train

**Autorhythmic Cardiac Muscle (e.g. SA node)**

- Transient Ca\(^{2+}\) channels
- K\(^+\), Na\(^+\)

Which way would you alter channel permeabilities to speed or slow HR??

9-11, Sherwood 1997
Contractile Cardiac Muscle

Ca$^{2+}$ current maintains plateau

(a) Electrocardiogram

(Eckert, 12-8)

P = Atrial depolarization

Q,R,S = Ventricular depolarization

T = Ventricular repolarization

(Q,R,S masks atrial repolarization)
Wiggers Diagram

Valves open/close where pressure curves cross

760 mmHg = 1 atm = 9.8 m blood

1:2

14-25, Vander 2001
**Figure 9.22** Ventricular Filling Profiles during Normal and Rapid Heart Rates: Because much of ventricular filling occurs early in diastole during the rapid-filling phase, filling is not seriously impaired when diastolic time is reduced as a result of an increase in heart rate.

**Figure 9.26** Frank-Starling Curve: The cardiac muscle fiber's length, which is determined by the extent of venous filling, is normally less than the optimal length for developing maximal tension. Therefore, an increase in end-diastolic volume (i.e., an increase in venous return) by moving the cardiac muscle fiber length closer to optimal length, increases the contractile tension of the fibers on the next systole. A stronger contraction expels more blood. Thus, as more blood is returned to the heart and the end-diastolic volume increases, the heart automatically pumps out a correspondingly larger stroke volume.

**Figure 14-30** Effects on stroke volume of stimulating the sympathetic nerves to the heart. Stroke volume is increased at any given end-diastolic volume; that is, the sympathetic stimulation has increased ventricular contractility.

_Atrial Kick_

_Highlighted text_

_Sherwood 1997_

_Sherwood 1997_

_Frank-Starling Curve_

_Sysotle = Ventricular Emptying_

_Diastole = Ventricular Filling (rest)
Cardiac Output:

\[ CO = \text{cardiac output} \ (\text{ml/min from 1 ventricle}) \]

\[ SV = \text{stroke volume} \ (\text{ml/beat from 1 ventricle}) \]

\[ = \text{EDV} - \text{ESV} \ (\text{end-diastolic - end-systolic volume}) \]

\[ HR = \text{heart rate} \ (\text{beats/min}) \]

\[ \text{MABP} = CO \times TPR \]

\[ \text{MABP} = DP + \frac{1}{3}(SP-DP) \]

- Heart can utilize different types of energy sources (unlike brain)
HR control

Parasympathetic vs. Sympathetic

Gravity and BP

FIGURE 3.15 Arterial and venous pressures in a man as he assumes different postures. The figures indicate the pressures at various points in relation to the pressure in the right atrium of the heart. (1 mm Hg = 0.13 kPa).
[Modified from Burton 1972]

Knut Schmidt_Nielsen 1997
Peripheral Circulation

- Endothelium lining vessels
- Middle layer with smooth muscle (esp. arteries)
- Outer fibrous layer

Capillaries with ~ only Endothelium
Peripheral Circulation

**Compliance vs. Elasticity**

~ Veins vs. Arteries

**Volume Reservoir vs. Pressure Reservoir**
**Volume Reservoir vs. Pressure Reservoir**

(Eckert, 12-27)

~Constant P and Q at Capillaries!

**Venous System**

- **low pressure** (11 mm Hg or less)
- thin walled veins with **less muscle**
- more **compliant** and less elastic
- **valves**
- blood moved by **skeletal muscle** (and smooth)
- **breathing** creates vacuum (low pressure) in chest to aid blood flow to heart