Cardiovascular Physiology
Anatomy

**Location of the Heart**

- The heart lies in the center of the thorax.
- Position of AV valves
- Sternum
- Apex of heart
- Base of heart
- Position of semilunar valves

**Anatomy of the Thoracic Cavity**

- The heart is on the ventral side of the thoracic cavity, sandwiched between the lungs.
- Thyroid gland
- Lung
- Trachea
- Diaphragm
- Apex of heart
- First rib (cut)
Vessels that carry well-oxygenated blood are red; those with less well-oxygenated blood are blue.
Anatomy 3

The heart is encased within a membranous fluid-filled sac, the pericardium.

The ventricles occupy the bulk of the heart. The arteries and veins all attach to the base of the heart.
Anatomy 4

Structure of the Heart

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During ventricular contraction, the AV valves remain closed to prevent blood flow backward into the atria.

The semilunar valves prevent blood that has entered the arteries from flowing back into the ventricles during ventricular relaxation.
Cardiac Muscle

(a) The spiral arrangement of ventricular muscle allows ventricular contraction to squeeze the blood upward from the apex of the heart.

(b) Intercalated disks contain desmosomes that transfer force from cell to cell and gap junctions that allow electrical signals to pass rapidly from cell to cell.
EC Coupling

1. Action potential enters from adjacent cell.
2. Voltage-gated Ca\(^{2+}\) channels open. Ca\(^{2+}\) enters cell.
3. Ca\(^{2+}\) induces Ca\(^{2+}\) release through ryanodine receptor-channels (RyR).
4. Local release causes Ca\(^{2+}\) spark.
5. Summed Ca\(^{2+}\) sparks create a Ca\(^{2+}\) signal.
6. Ca\(^{2+}\) ions bind to troponin to initiate contraction.
7. Relaxation occurs when Ca\(^{2+}\) unbinds from troponin.
8. Ca\(^{2+}\) is pumped back into the sarcoplasmic reticulum for storage.
9. Ca\(^{2+}\) is exchanged with Na\(^{+}\).
10. Na\(^{+}\) gradient is maintained by the Na\(^{+}\)-K\(^{+}\)-ATPase.
Modulation of Contraction

Epinephrine from adrenal medulla
Norepinephrine from sympathetic neurons
bind to
$\beta_1$ receptors on myocardial contractile cell
that activate
cAMP second messenger system
resulting in phosphorylation of
Voltage-gated Ca$^{2+}$ channels
Open time increases
$\uparrow$ Ca$^{2+}$ entry from ECF
Phospholamban
$\uparrow$ Ca$^{2+}$-ATPase activity of sarcoplasmic reticulum (SR)
$\uparrow$ Ca$^{2+}$ stores in SR
$\uparrow$ Ca$^{2+}$ released through Ca$^{2+}$-induced Ca$^{2+}$ release
More forceful contraction
Ca$^{2+}$ removed from cytosol faster
Time of Ca-troponin binding shorter
Shorter duration of contraction

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Action Potentials

Membrane potential (mV)

Time (msec)

1. $P_{Na}$
2. $P_{K}$ and $P_{Ca}$
3. $P_{K}$ and $P_{Ca}$
4. $P_{Na}$

<table>
<thead>
<tr>
<th>Phase</th>
<th>Membrane channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Na$^+$ channels open</td>
</tr>
<tr>
<td>1</td>
<td>Na$^+$ channels close</td>
</tr>
<tr>
<td>2</td>
<td>Ca$^{2+}$ channels open; fast K$^+$ channels close</td>
</tr>
<tr>
<td>3</td>
<td>Ca$^{2+}$ channels close; slow K$^+$ channels open</td>
</tr>
<tr>
<td>4</td>
<td>Resting potential</td>
</tr>
</tbody>
</table>

$P_X = $ Permeability to ion $X$
Autorhythmic Cells

(a) The pacemaker potential gradually becomes less negative until it reaches threshold, triggering an action potential.

(b) Ion movements during an action and pacemaker potential

(c) State of various ion channels

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Modulation by Nervous Sys.

(a) Sympathetic stimulation and epinephrine depolarize the autorhythmic cell and speed up the depolarization rate, increasing the heart rate.

(b) Parasympathetic stimulation hyperpolarizes the membrane potential of the autorhythmic cell and slows depolarization, slowing down the heart rate.
Depolarizations of autorhythmic cells rapidly spread to adjacent contractile cells through gap junctions.
Electrical Conduction

(a) The conducting system of the heart

(b) SA node depolarizes.

(c) Electrical activity goes rapidly to AV node via internodal pathways.

(d) Depolarization spreads more slowly across atria. Conduction slows through AV node.

(e) Depolarization moves rapidly through ventricular conducting system to the apex of the heart.

(f) Depolarization wave spreads upward from the apex.

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Einthoven Triangle

Right arm

II

Left leg

III

Left arm

Electrodes are attached to the skin surface.

A lead consists of two electrodes, one positive and one negative.
Leads

• 1. Left arm (+); Right arm (-); Left leg (gr)**
• 2. Left arm (gr); Right arm (-); Left leg (+)
• 3. Left arm (-); Right arm (gr); Left leg (+)
ECG Explained

START

1. P wave: atrial depolarization
2. PQ or PR segment: conduction through AV node and A-V bundle
3. Q wave
4. R wave

Electrical events of the cardiac cycle

The end

T wave: ventricular repolarization

ST segment

Ventricles contract

S wave

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ECG v. Myocardial AP

(a) 1 mV 1 sec

The electrocardiogram represents the summed electrical activity of all cells recorded from the surface of the body.

(b) 110 mV 1 sec

The ventricular action potential is recorded from a single cell using an intracellular electrode. Notice that the voltage change is much greater when recorded intracellularly.
Mechanical Events

1. Late diastole—both sets of chambers are relaxed and ventricles fill passively.

2. Atrial systole—atrial contraction forces a small amount of additional blood into ventricles.

3. Isovolumic ventricular contraction—first phase of ventricular contraction pushes AV valves closed but does not create enough pressure to open semilunar valves.

4. Ventricular ejection—as ventricular pressure rises and exceeds pressure in the arteries, the semilunar valves open and blood is ejected.

5. Isovolumic ventricular relaxation—as ventricles relax, pressure in ventricles falls, blood flows back into cups of semilunar valves and snaps them closed.
Cardiac Output

• EDV-ESV=Stroke Volume
  (End Diastolic Volume-End Systolic Volume)
• Cardiac Output= HR x Stroke Volume
  (Heart Rate)
Blood Pressure Cuff

When the cuff is inflated so that it stops arterial blood flow, no sound can be heard through a stethoscope placed over the brachial artery distal to the cuff.

Korotkoff sounds are created by pulsatile blood flow through the compressed artery.

Blood flow is silent when the artery is no longer compressed.
MAP

• Mean Arterial Pressure
• MAP=Diastolic P + [ Systolic Pressure-Diastolic Pressure](1/3)