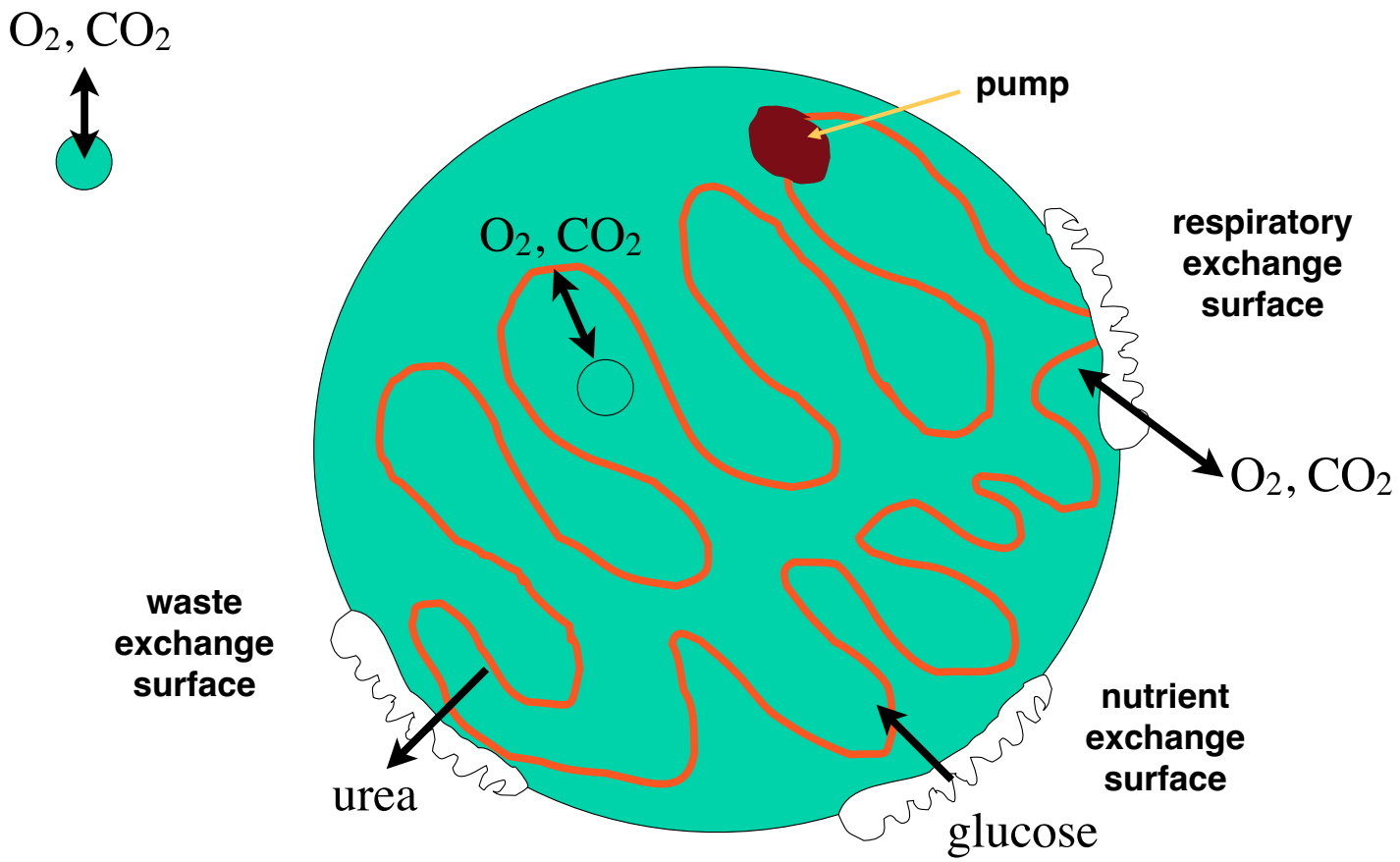
Human Phys PCB4701

Heart 1
Fox Chapter 13 part 1
(Chapter 12.6 Cardiac Muscle)

Anatomy of The Heart
Cardiac Cycle
Cardiac Action Potential and ECG

Circulatory System: Active Pumping

to transport gases from respiratory surface to tissues



Atrium

receives incoming blood, passes it to ventricle

Ventricle

more muscular pump sending blood to a separate circulation (either pulmonary circulation (lungs) or systemic circulation).

Arteries (arterial blood)

vessels carrying blood from heart towards the capillaries.
Thick muscular walls to keep pressure up.
High in oxygen (except for pulmonary arteries).

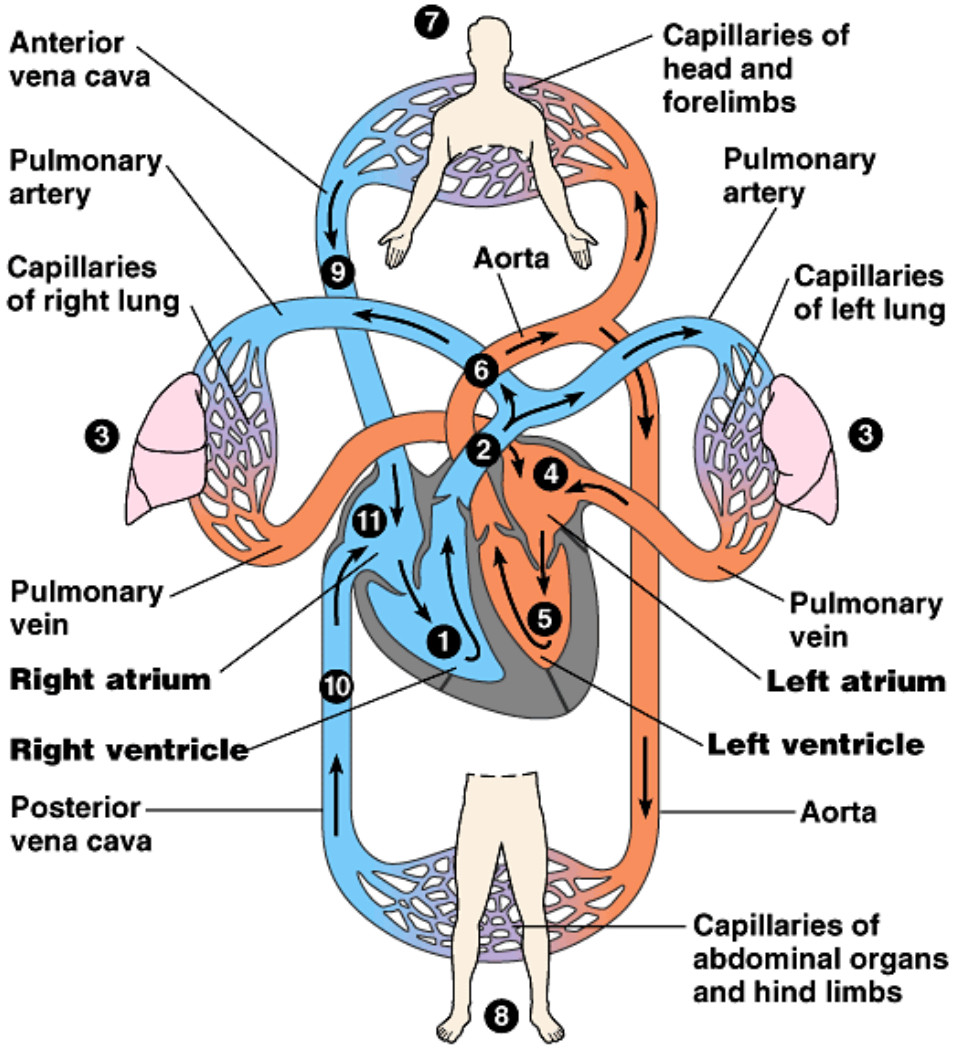
Veins (venous blood)

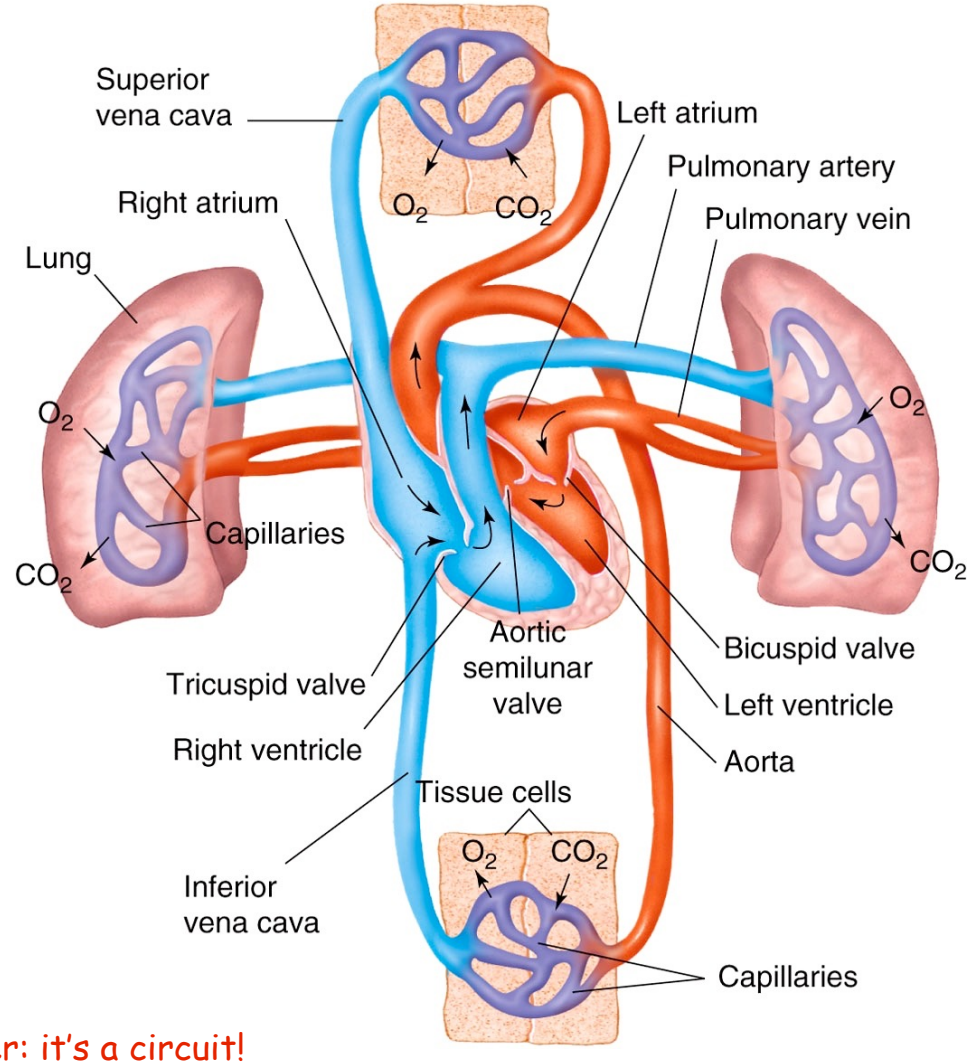
vessels carrying blood from capillaries back to heart. Very thin flabby walls with low pressure, but have one-way valves to prevent blood from backing up. Low in oxygen (except for pulmonary veins).

Capillaries

very small vessels (one blood cell wide) that perfuse all the tissues.

Figure 42.4 The mammalian cardiovascular system: an overview





remember: it's a circuit!

Figure 13.10

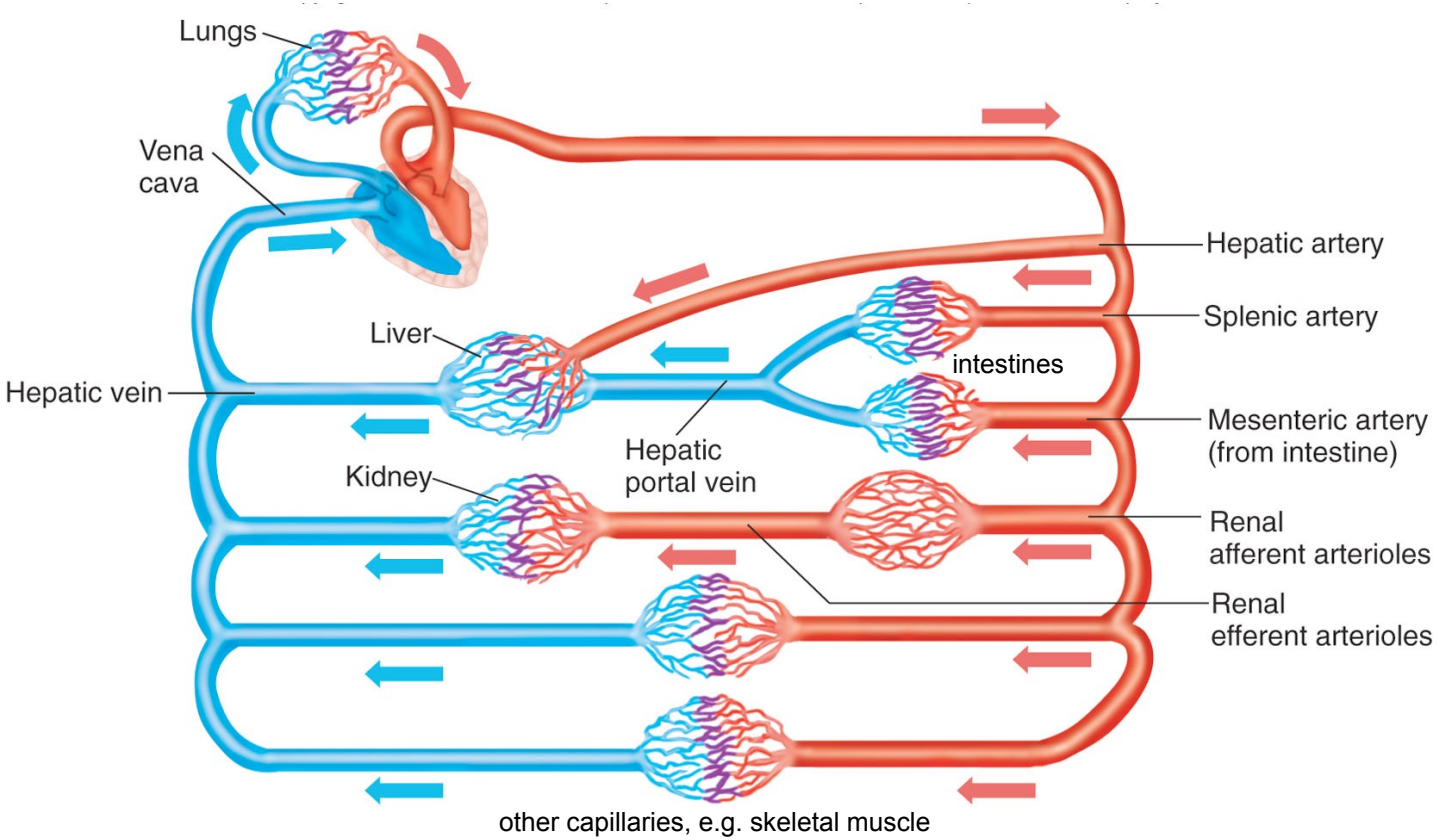

Lungs
Vena cava
Hepatic artery
Splenic artery
Liver
intestines
Hepatic vein
Mesenteric artery (from intestine)
Hepatic portal vein
Kidney
Renal afferent arterioles
Renal efferent arterioles
other capillaries, e.g. skeletal muscle

Figure 14.17

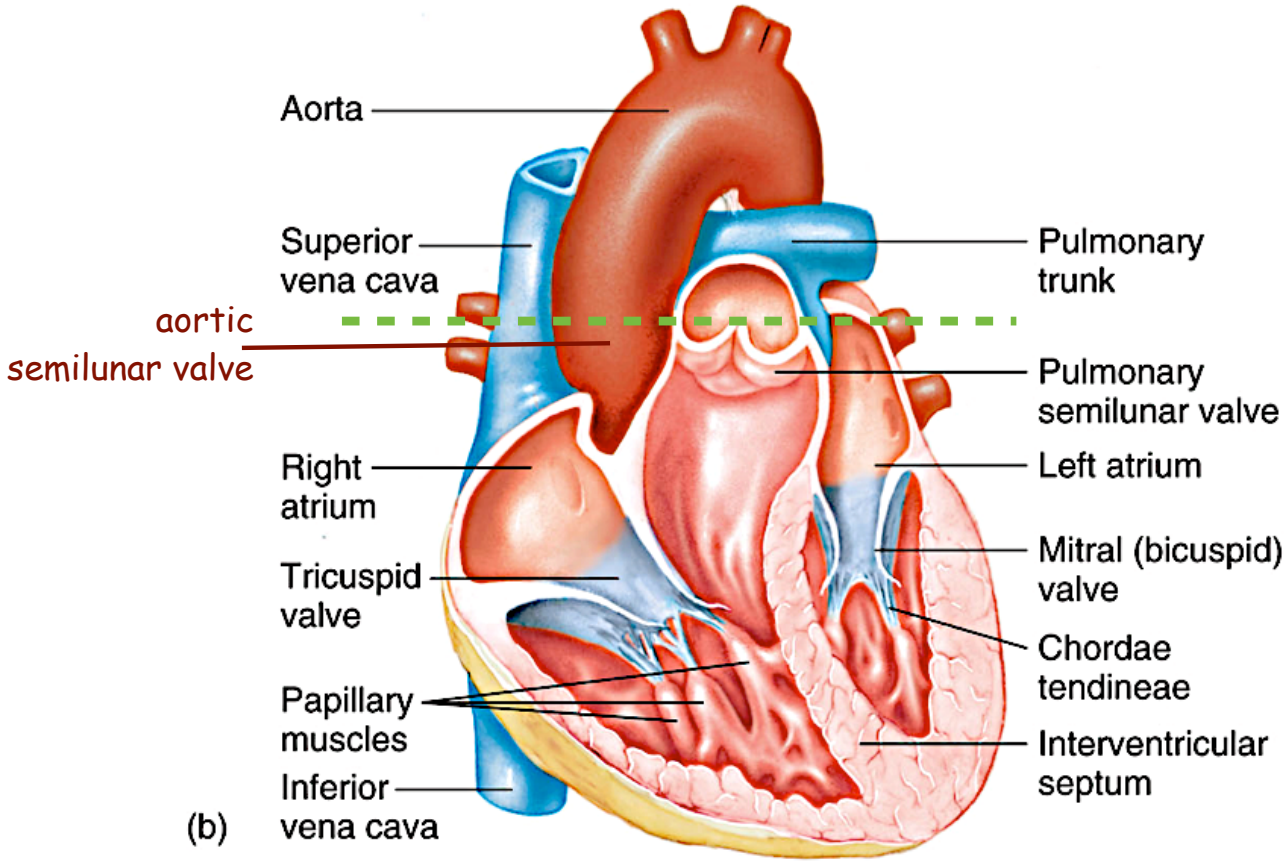
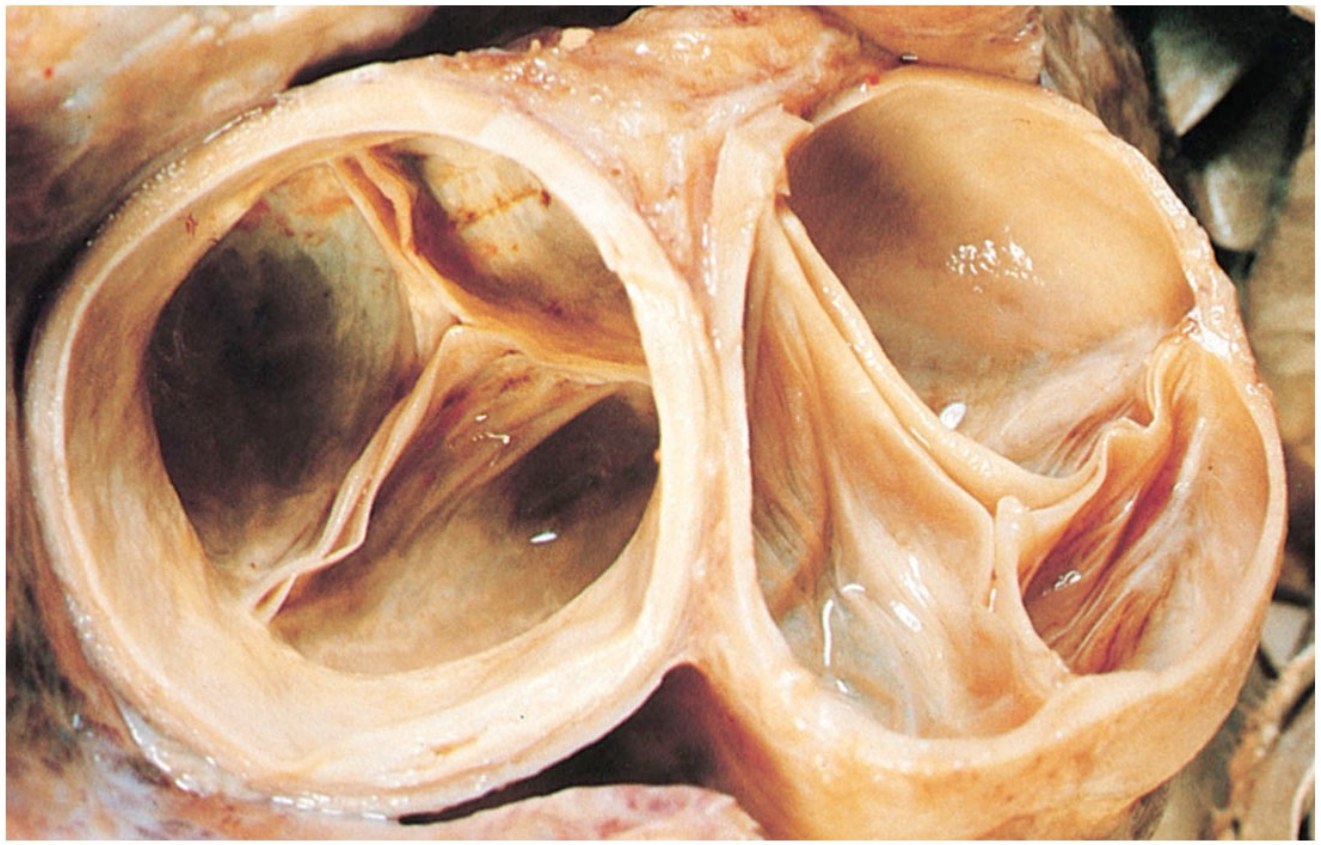

Aorta
Superior vena cava
aortic semilunar valve
Right atrium
Tricuspid valve
Papillary muscles
Inferior vena cava
(b)
Pulmonary trunk
Pulmonary semilunar valve
Left atrium
Mitral (bicuspid) valve
Chordae tendineae
Interventricular septum

Figure 13.11

aortic semilunar valves

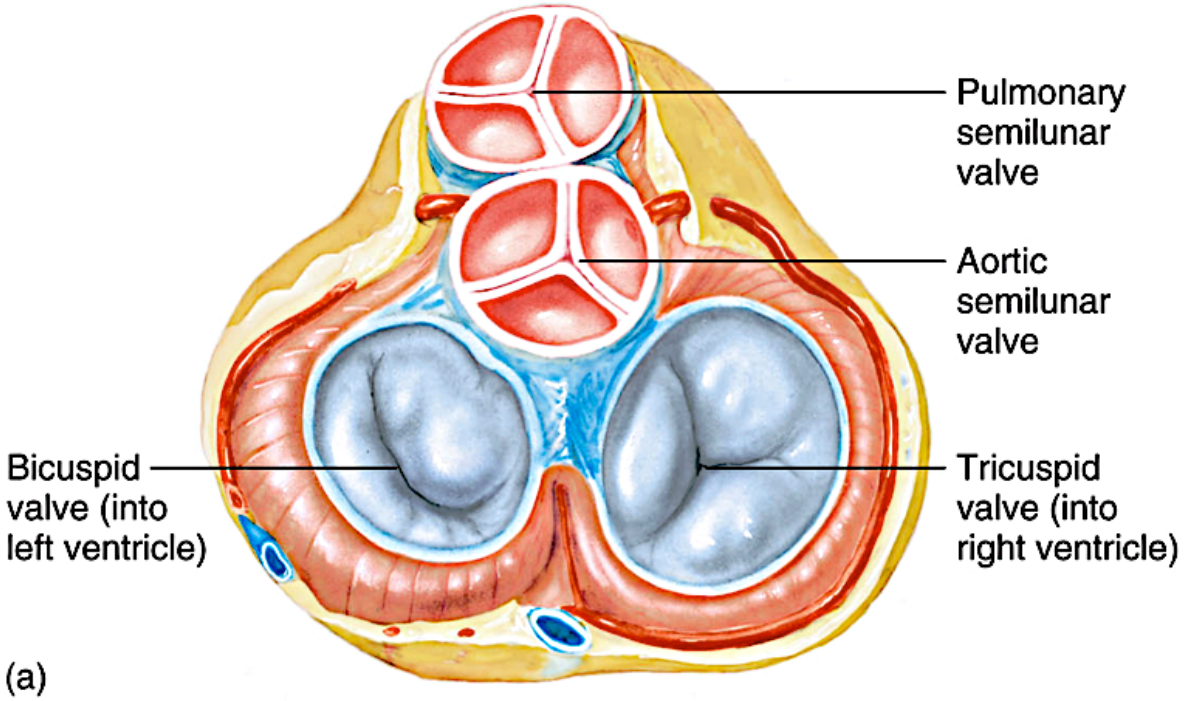
pulmonary semilunar valves



Igaku-Shoin, Ltd., Tokyo, Japan

Figure 13.12

“dub” = closing of semilunar valves = S2



“lub” = closing of AV valves = S1

Figure 13.11

The Cardiac Cycle

Diastole
chambers are relaxed, blood can flow in

Atrial Systole
atria contract, pushing blood into ventricles

Ventricular Systole
ventricles contract with high pressure, pushing blood into the lungs and systemic circulation

Diastolic pressure (bottom number)
arterial pressure when ventricle is relaxed

Systolic pressure (top number)
arterial pressure when ventricle contracts and pumps

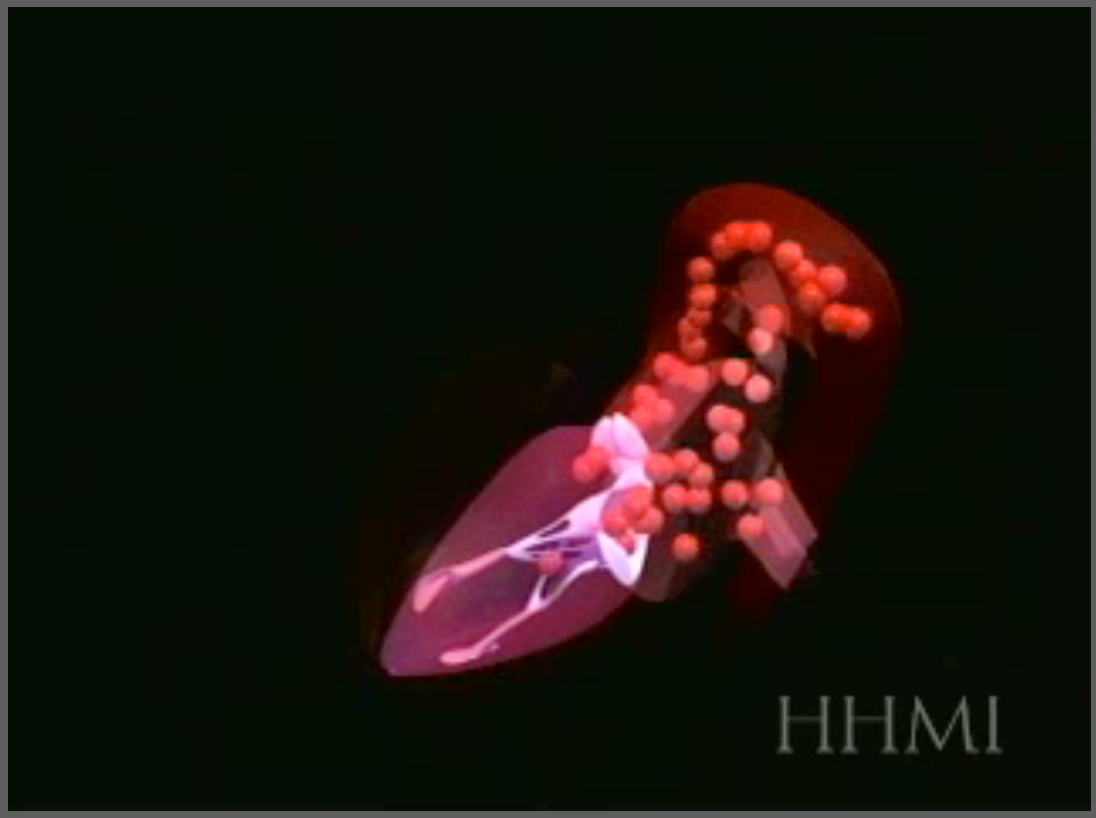
http://www.hhmi.org/biointeractive/cardiovascular/animations.html

lower lights

RIGHT atrium & ventricle

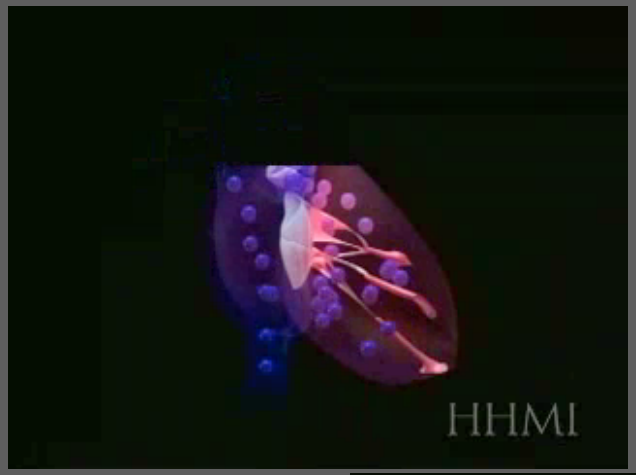
systemic veins -> vena cava -> right atrium ->
right ventricle -> pulmonary artery -> lungs

LEFT atrium & ventricle

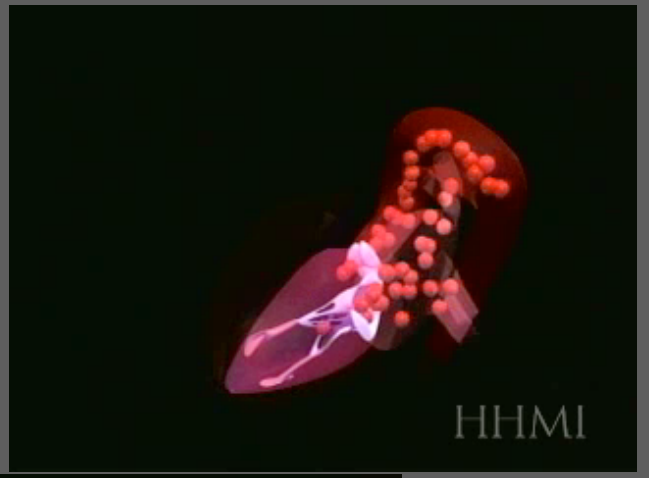


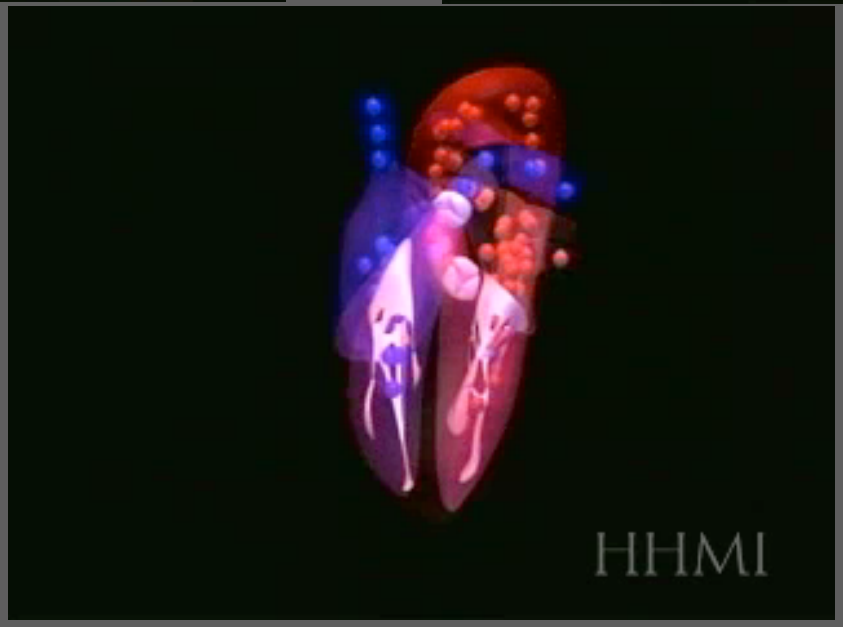
lungs -> pulmonary vein -> left atrium -> left ventricle -> aorta -> systemic arteries

RIGHT atrium & ventricle



LEFT atrium & ventricle





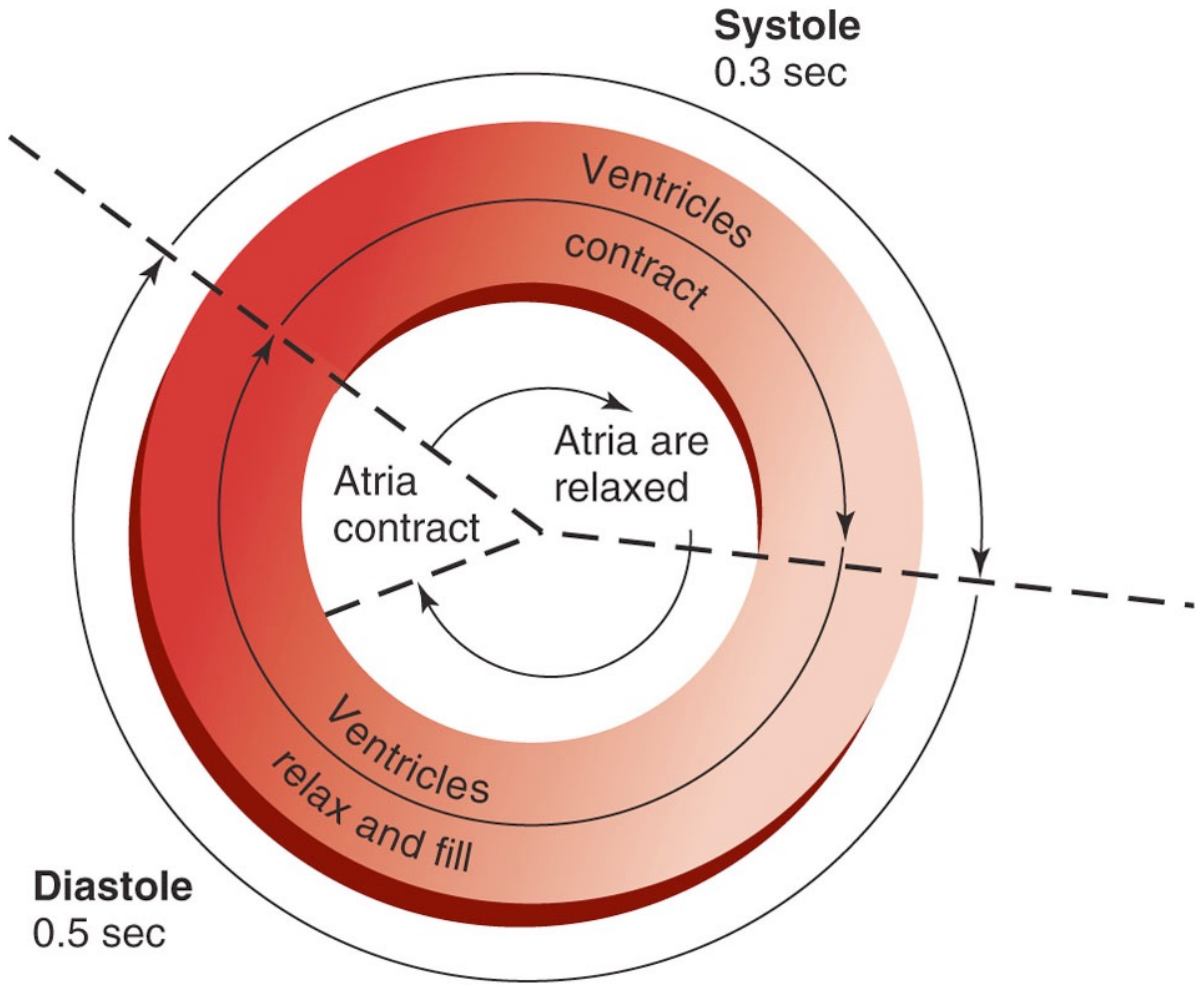
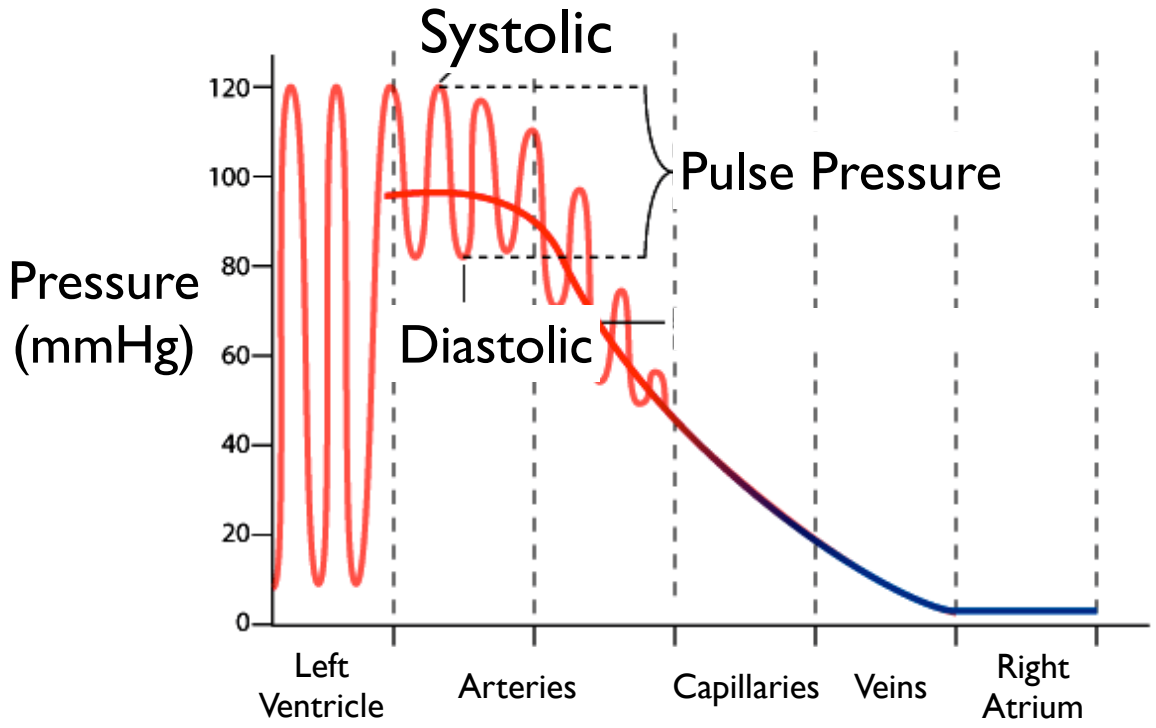

Systole
0.3 sec
Ventricles
contract
Atria are
relaxed
Atria
contract
Ventricles
relax and fill
Diastole
0.5 sec

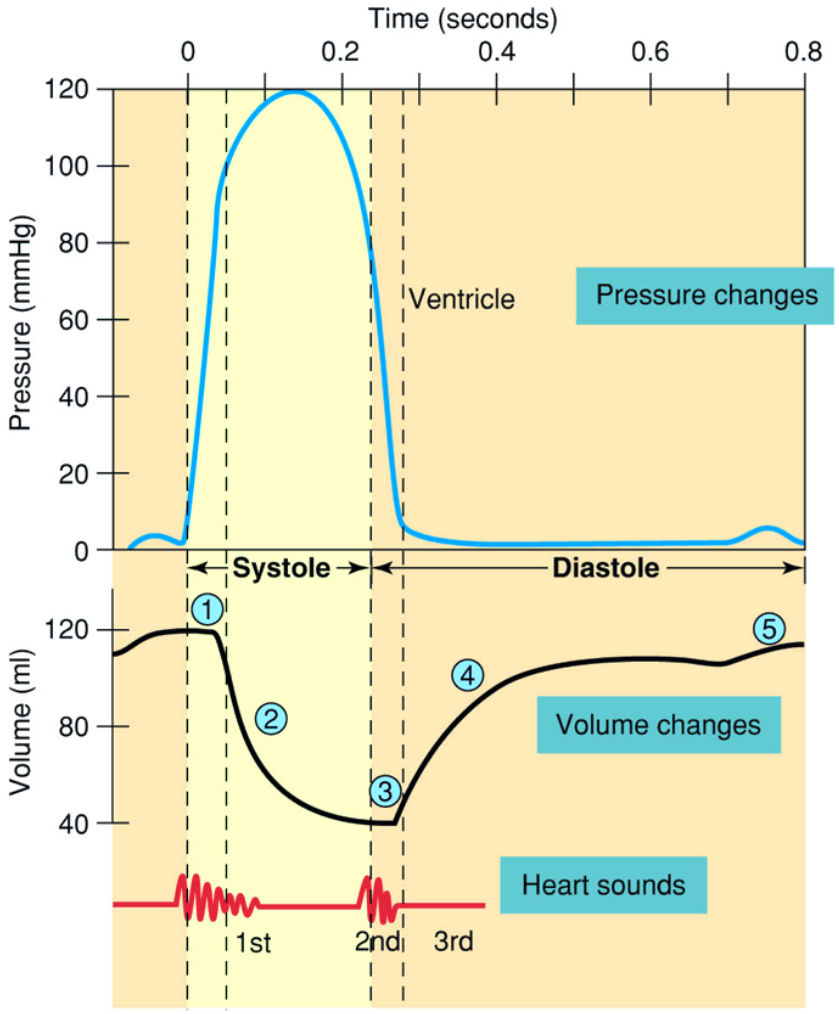
Figure 13.16

Blood Pressure:

Arterial Pressure > Venous Pressure



http://www.adinstruments.com


Time (seconds)
0
0.2
0.4
0.6
0.8
Pressure (mmHg)
120
100
80
60
40
20
0
Ventricle
Pressure changes
Systole
Diastole
Volume (ml)
120
80
40
1
2
3
4
5
Volume changes
Heart sounds
1st
2nd
3rd

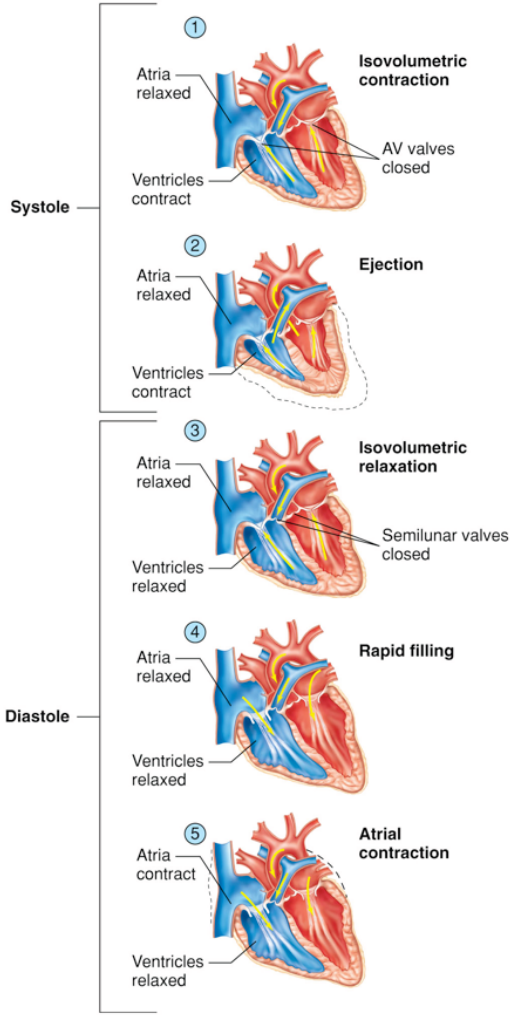
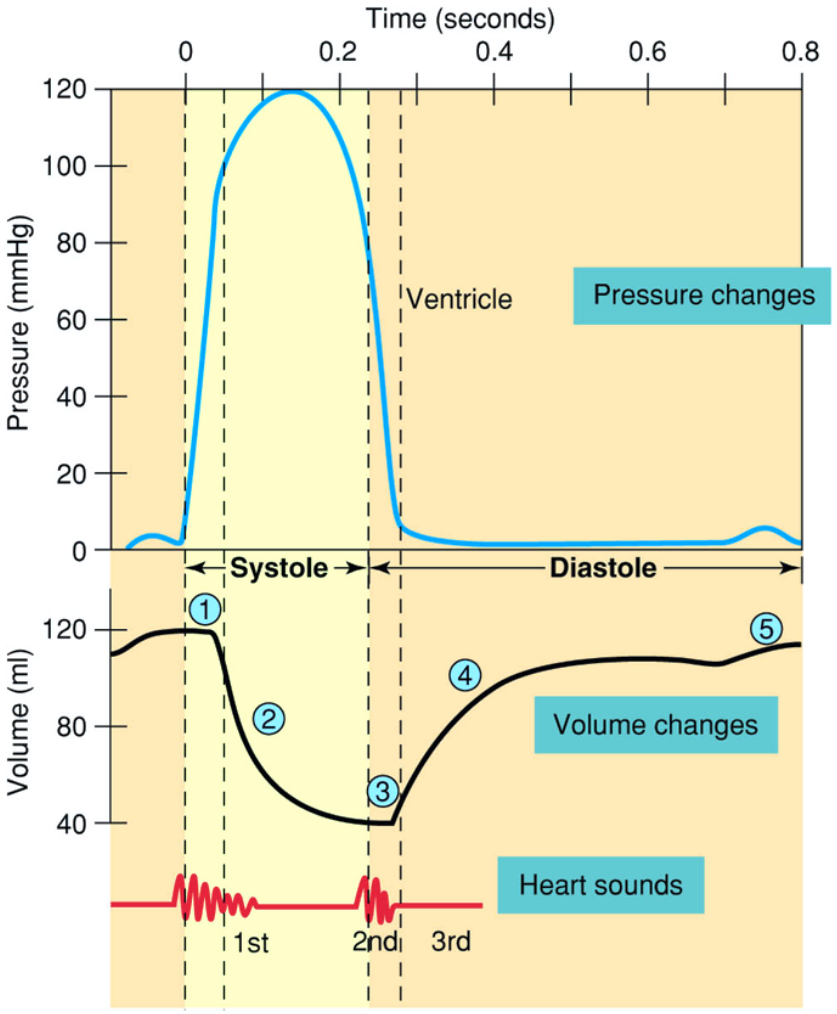

Systole
Diastole
1
Atria relaxed
Isovolumetric contraction
AV valves closed
Ventricles contract
2
Atria relaxed
Ejection
Ventricles contract
3
Atria relaxed
Isovolumetric relaxation
Semilunar valves closed
Ventricles relaxed
4
Atria relaxed
Rapid filling
Ventricles relaxed
5
Atria contract
Atrial contraction
Ventricles relaxed

Figure 13.17



Ventricular **Systole**

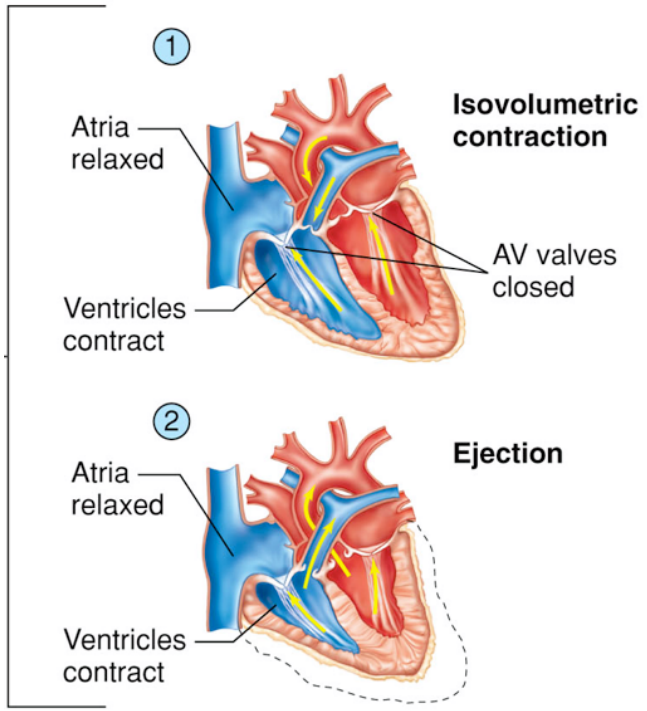


Figure 13.17

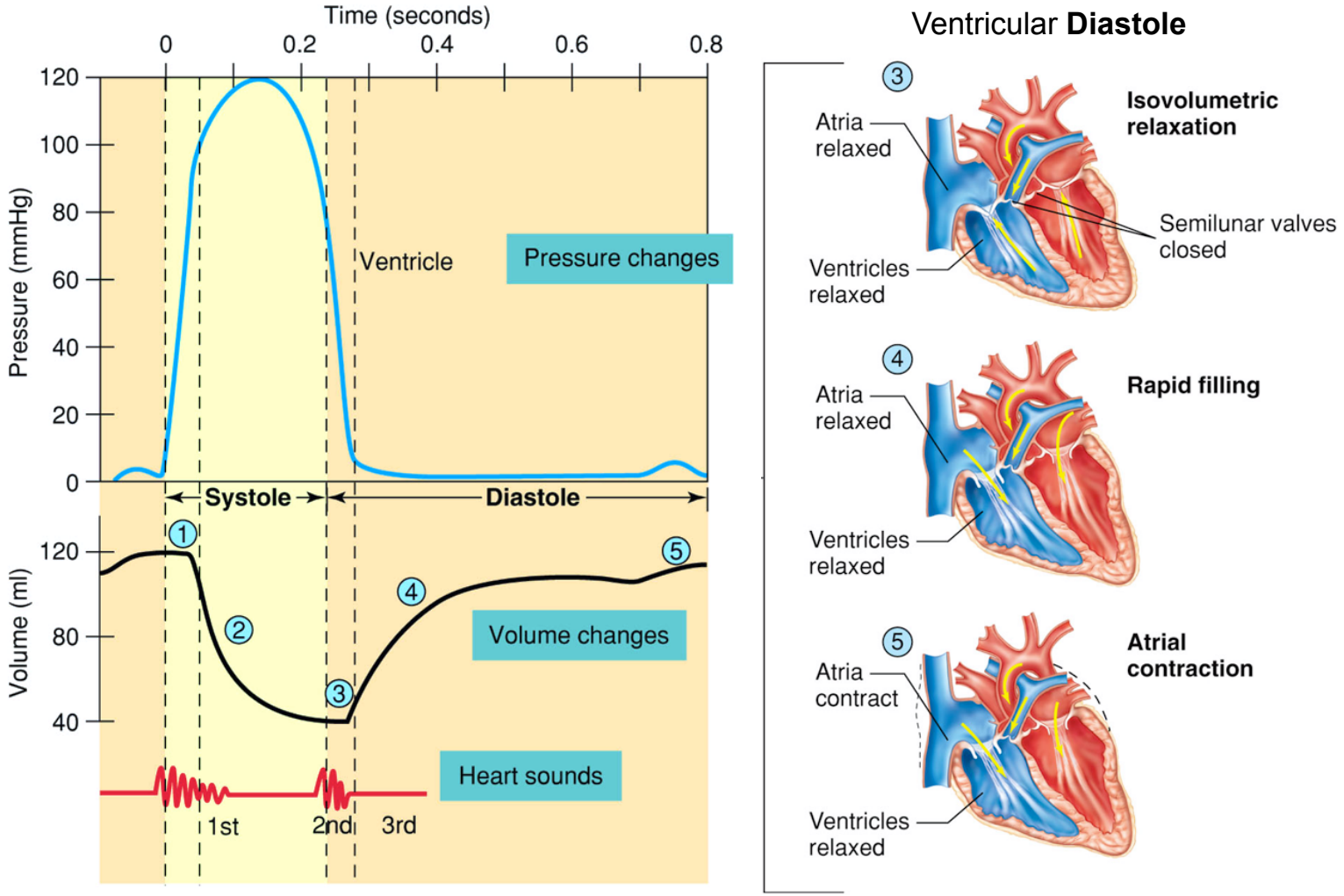

Time (seconds)
0
0.2
0.4
0.6
0.8
Pressure (mmHg)
120
100
80
60
40
20
0
Ventricle
Pressure changes
Systole
Diastole
Volume (ml)
120
80
40
1
2
3
4
5
Volume changes
Heart sounds
1st
2nd
3rd
Ventricular Diastole
3
Isovolumetric relaxation
Atria relaxed
Semilunar valves closed
Ventricles relaxed
4
Rapid filling
Atria relaxed
Ventricles relaxed
5
Atrial contraction
Atria contract
Ventricles relaxed

Figure 13.17

Events of the Cardiac Cycle

Atria	AV Valves	Ventricles	Semi-Lunar Valves	Blood Flow
diastole	open	**diastrole**	closed	into atria (from vena cava, lungs)
systole	open	**diastole**	closed	into ventricles
	"lub" ↓			
diastole	closed	**systole**	open	into lungs, aorta
			"dub" ↓	
diastole	open	**diastrole**	closed	into atria (from vena cava, lungs)

diastole = relaxed, systole = contracting

Heart Beat

1. Generate rhythmic stimulation to start cardiac action potential

2. Action potential will cause contraction of cardiac muscle

3. Allow action potential to spread across the heart; introduce delay between atria and ventricles so they don’t contract at the same time

Contraction of Cardiac Muscle (Myocardium)

Action Potential starts from pacemaker cells in **sinoatrial node** (SA node)
HCN channels open when hyperpolarized (**H**yperpolarization-activated **C**yclic **N**ucleotide-gated channels)
-> spontaneous depolarization of pacemaker cells to -40 mV
-> opening of voltage-gated Ca++ channels
-> + 20 mV -> action potential across myocardium

Myocardial Action Potential is longer than neural action potential:
fast Na+ channels -> fast depolarization
slow Ca++ channels -> plateau phase
voltage-gated K+ channels cause repolarization

Myocardium forms a functional **syncitium**, via **gap junctions**

Myocardial Contraction
Voltage-gated Na+ channels open, causing depolarization
Voltage-gated Ca++ channels open in transverse tubules
Influx of Ca++ causes release of Ca++ from sarcoplasmic reticulum
Ca++ binds to troponin to allow contraction
Ca++ ATPase pump returns Ca++ into sarcoplasmic reticulum
Na+/Ca++ exchanger pumps Ca++ from cytoplasm into extracellular fluid

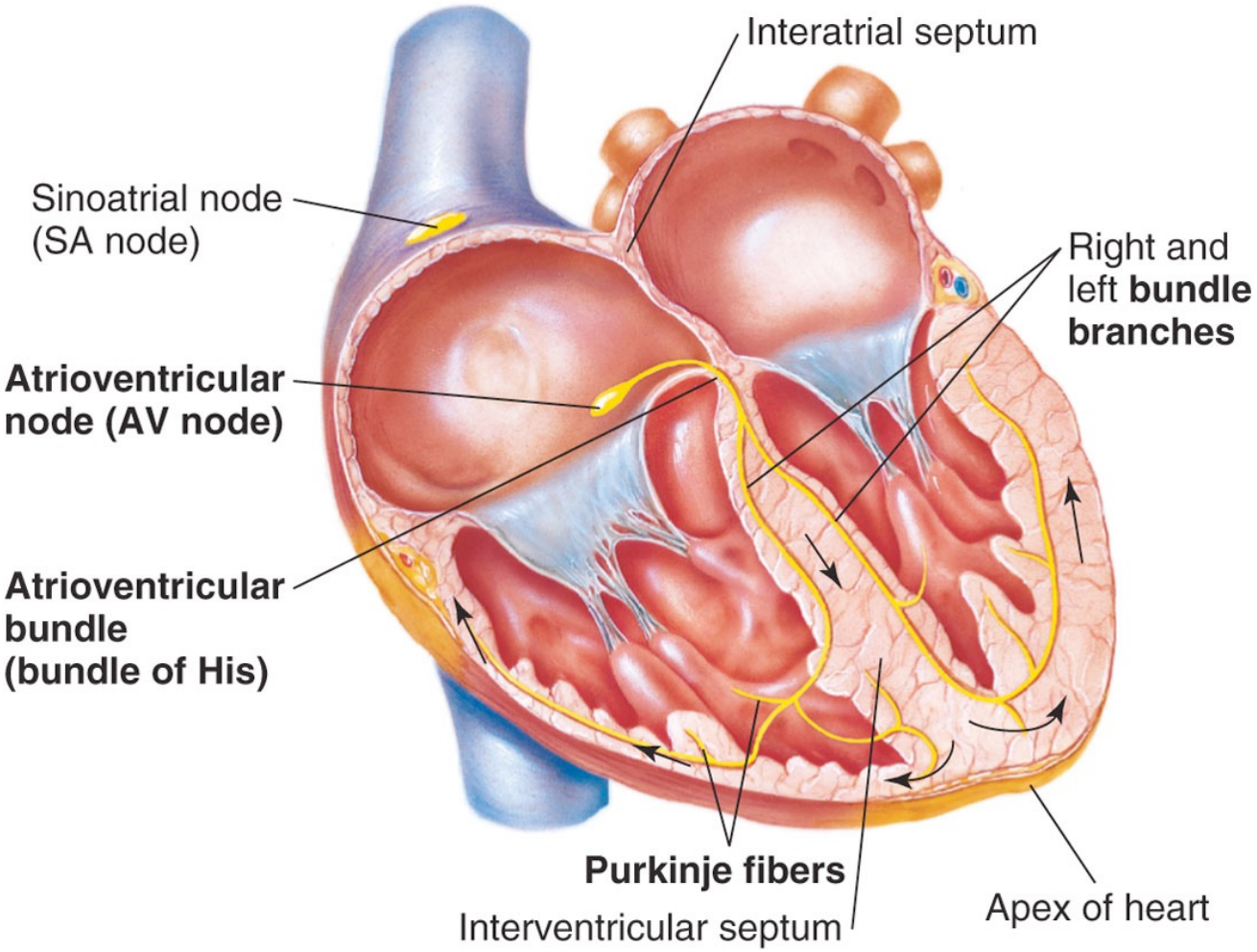
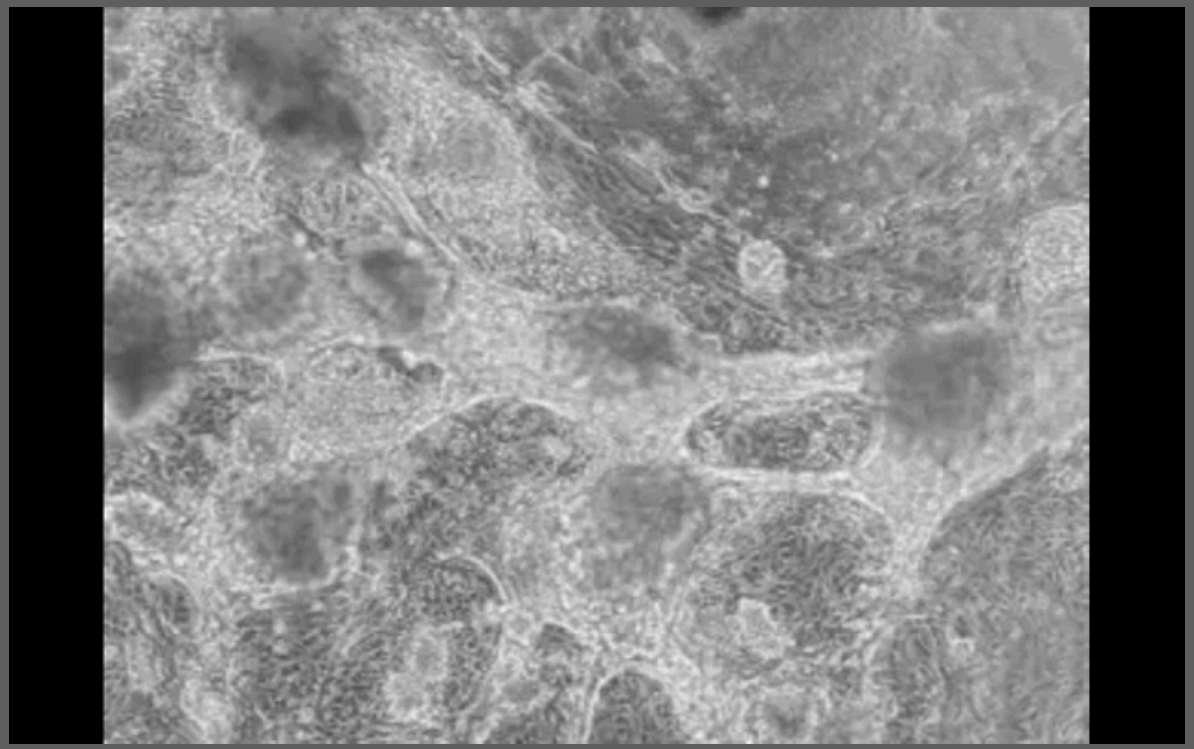

Interatrial septum
Sinoatrial node
(SA node)
Right and
left **bundle**
branches
Atrioventricular
node (AV node)
Atrioventricular
bundle
(bundle of His)
Purkinje fibers
Interventricular septum
Apex of heart

Figure 13.20

Stem cells differentiate into cardiac pacemaker cells *in vitro* (in a petri dish)



Drexel University

http://io9.com/5882963/whoa-a-petri-dish-that-has-a-pulse

https://www.youtube.com/watch?v=BqzW9Jq-OVA

Spontaneous Depolarization of Pacemaker Cells

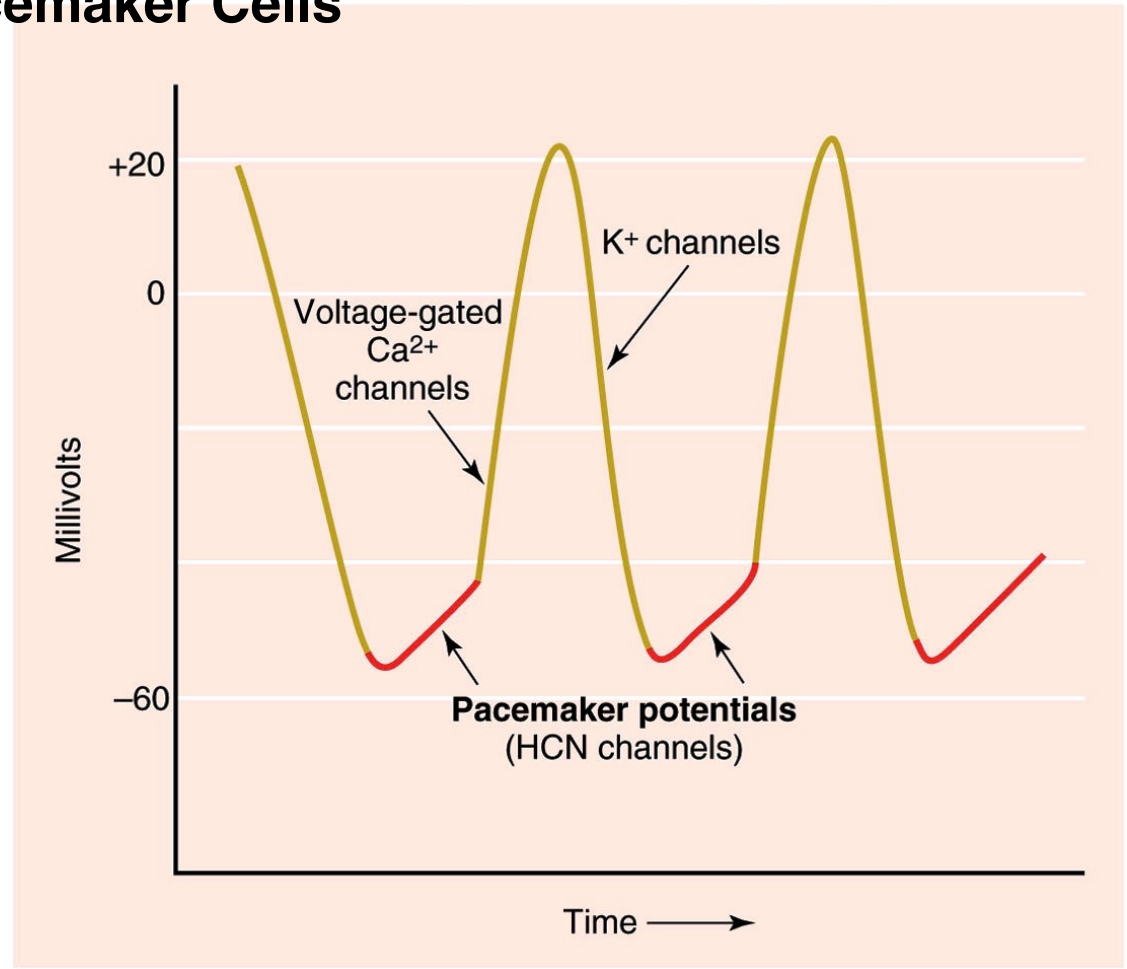
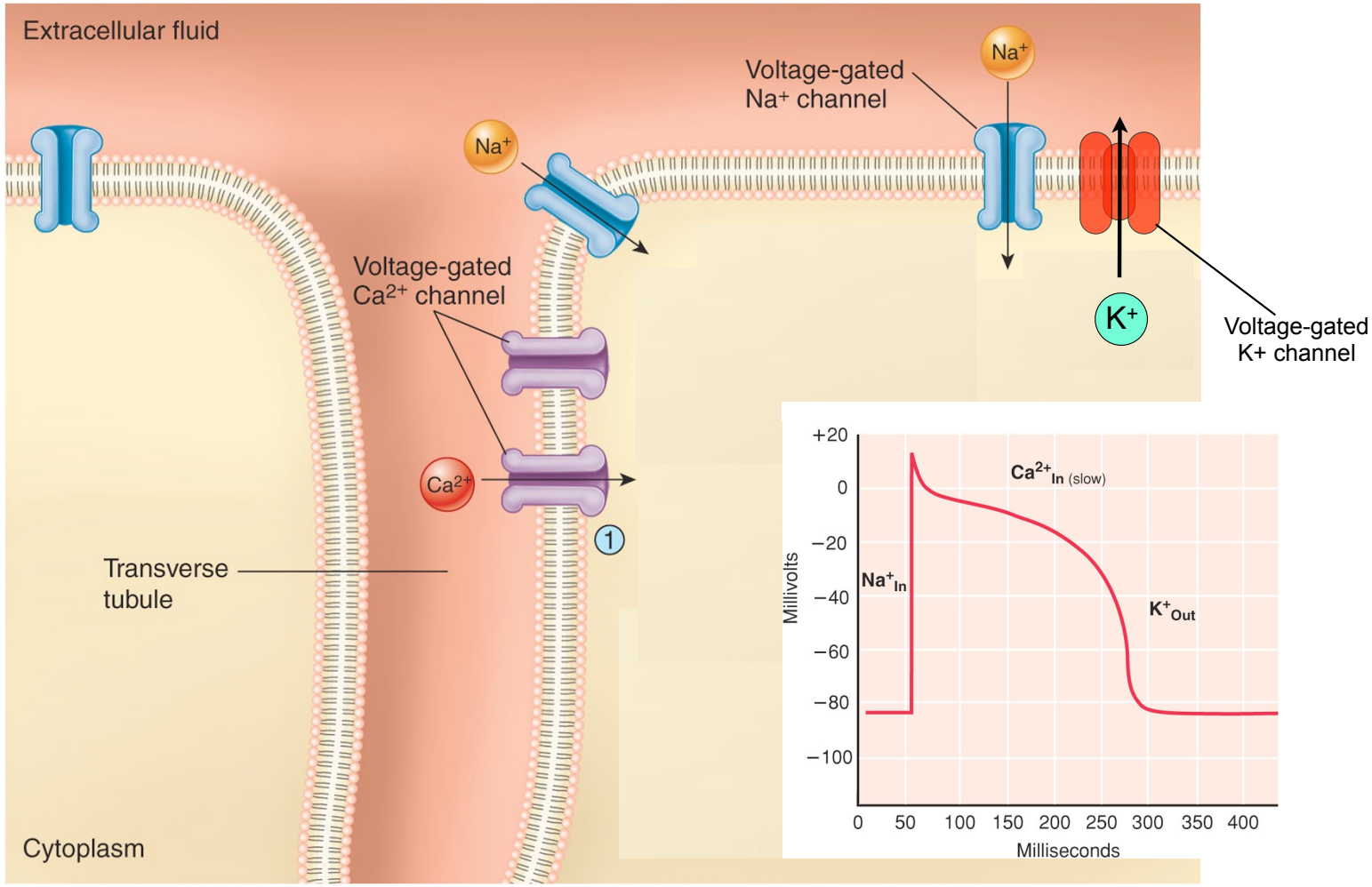


Figure 13.18



frog heart does not beat in Ca++ free buffer

Comparison of Skeletal Muscle and Cardiac Muscle

Skeletal Muscle	Cardiac Muscle
Striated; actin and myosin arranged in sarcomeres	Striated; actin and myosin arranged in sarcomeres
Well-developed sarcoplasmic reticulum and transverse tubules	Moderately developed sarcoplasmic reticulum and transverse tubules
Contains troponin in the thin filaments	Contains troponin in the thin filaments
Ca^{2+} released into cytoplasm from sarcoplasmic reticulum	Ca^{2+} enters cytoplasm from sarcoplasmic reticulum and extracellular fluid
Cannot contract without nerve stimulation; denervation results in muscle atrophy	Can contract without nerve stimulation; action potentials originate in pacemaker cells of heart
Muscle fibers stimulated independently; no gap junctions	Gap junctions present as intercalated discs

myocardial infarction (tissue damage due to lack of oxygen)
-> cardiac troponin in the blood

Table 12.8

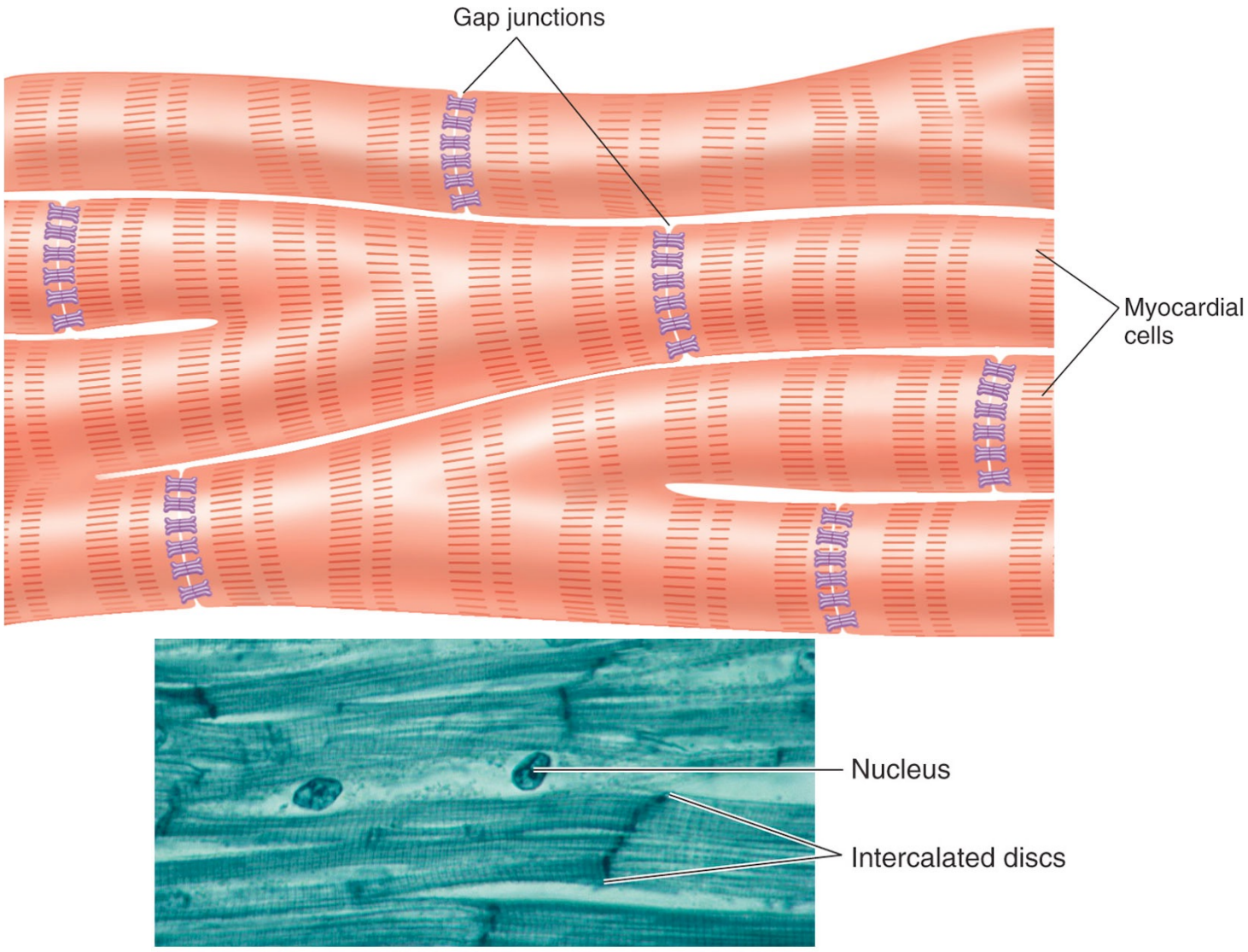

Gap junctions
Myocardial cells
Nucleus
Intercalated discs
© Ed Reschke

Figure 12.32

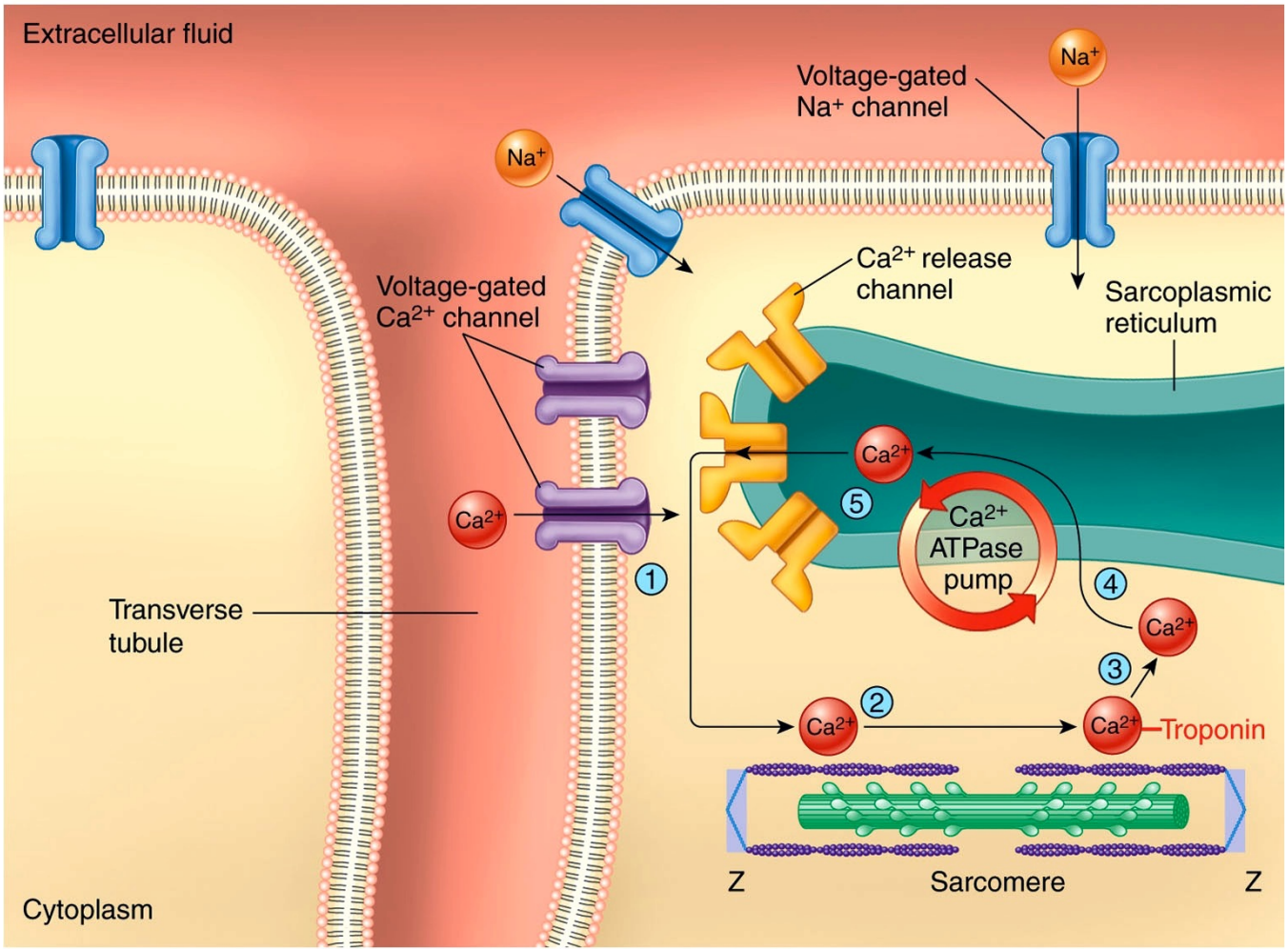

Extracellular fluid
Voltage-gated
Na+ channel
Na+
Na+
Ca2+ release
channel
Sarcoplasmic
reticulum
Voltage-gated
Ca2+ channel
Ca2+
Ca2+
5
Ca2+
ATPase
pump
4
Transverse
tubule
1
Ca2+
3
2
Ca2+
Ca2+
Troponin
Z
Sarcomere
Z
Cytoplasm

Figure 12.34

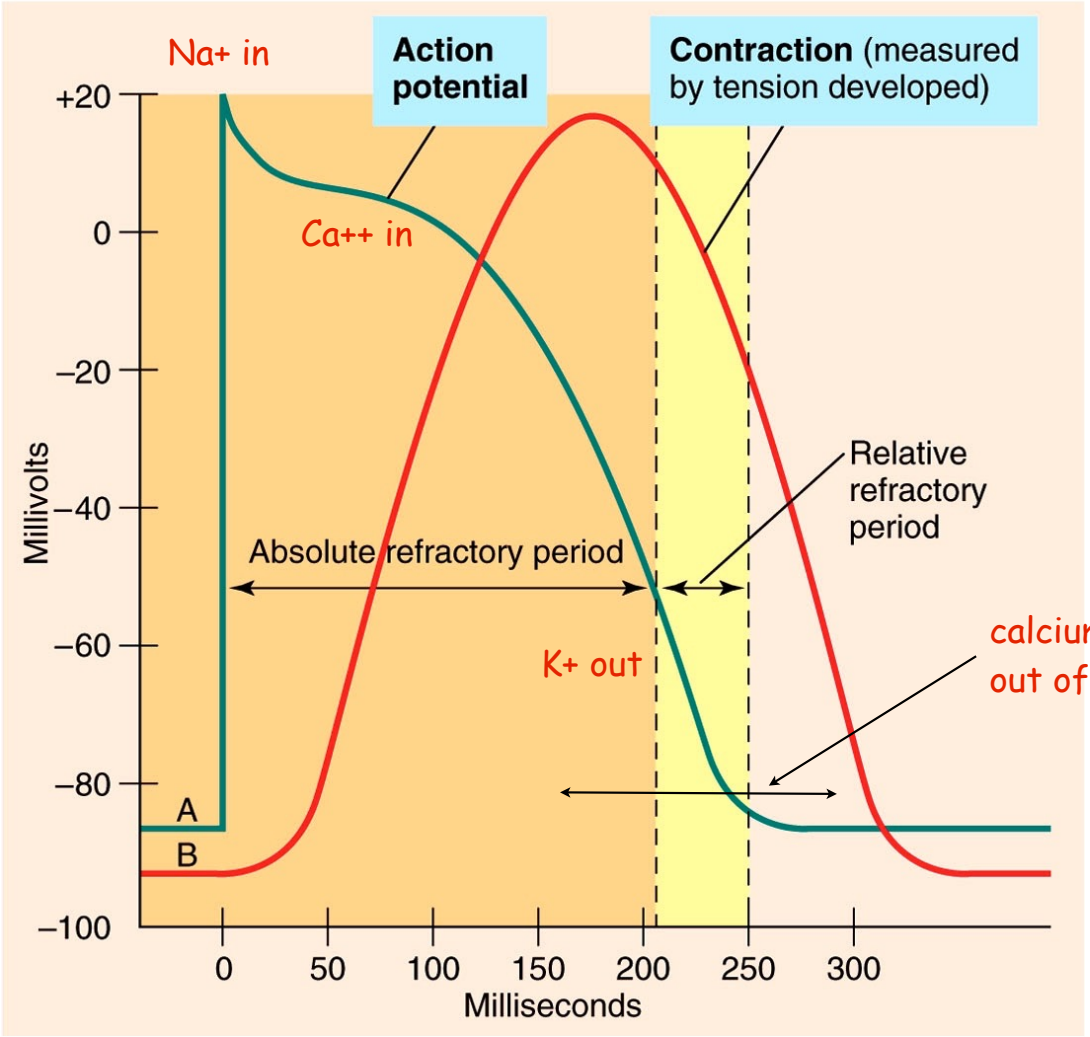

Na+ in
Action potential
Contraction (measured by tension developed)
+20
0
−20
−40
−60
−80
−100
Millivolts
Ca++ in
Relative refractory period
Absolute refractory period
calcium pumped out of cytoplasm
K+ out
A
B
0
50
100
150
200
250
300
Milliseconds

Figure 13.21

Contraction of Cardiac Muscle (Myocardium)

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HCN channels open when hyperpolarized (**H**yperpolarization-activated **C**yclic **N**ucleotide-gated channels)
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Ca++ binds to troponin to allow contraction
Ca++ ATPase pump returns Ca++ into sarcoplasmic reticulum
Na+/Ca++ exchanger pumps Ca++ from cytoplasm into extracellular fluid

Conduction of action potential across heart and Electrocardiogram (ECG)

Action Potential (AP) spreads from pacemaker cells in **SA node**.

Myocardium forms a functional **syncitium**, via **gap junctions**

AP spreads rapidly across atria to cause depolarization and atrial systole (contraction). **[P wave]**

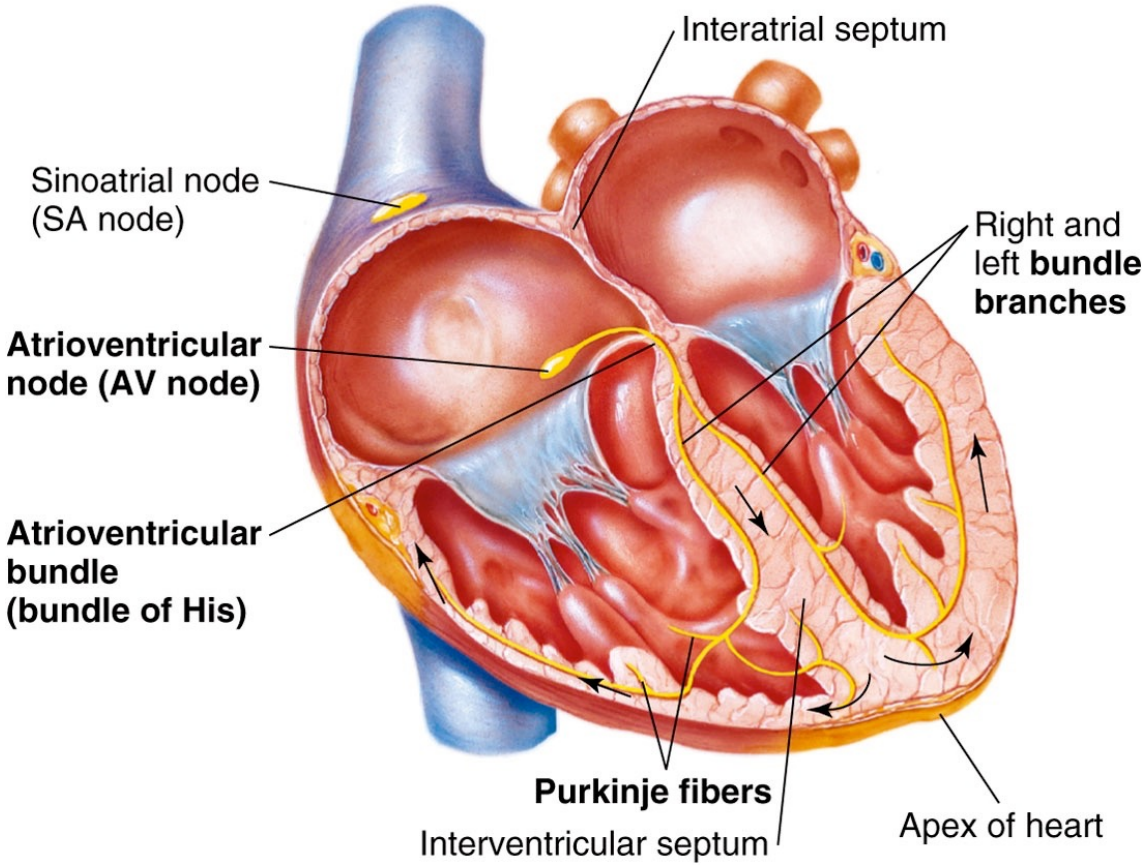
AP cannot cross directly to ventricles: must pass through **atrioventricular node** (AV node).

Slow conduction through AV node causes delay between atrial and ventricular contraction.

AP spreads from AV node through bundle of His and along Purkinje fibers in the walls of the ventricles. [Atria repolarize.]

Ventricles depolarize and contract. **[QRS wave]**

Ventricles repolarize. **[T wave]**


Interatrial septum
Sinoatrial node
(SA node)
Right and
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branches**
**Atrioventricular
node (AV node)**
**Atrioventricular
bundle
(bundle of His)**
Purkinje fibers
Interventricular septum
Apex of heart

Figure 13.20

Figure 42.7 The control of heart rhythm

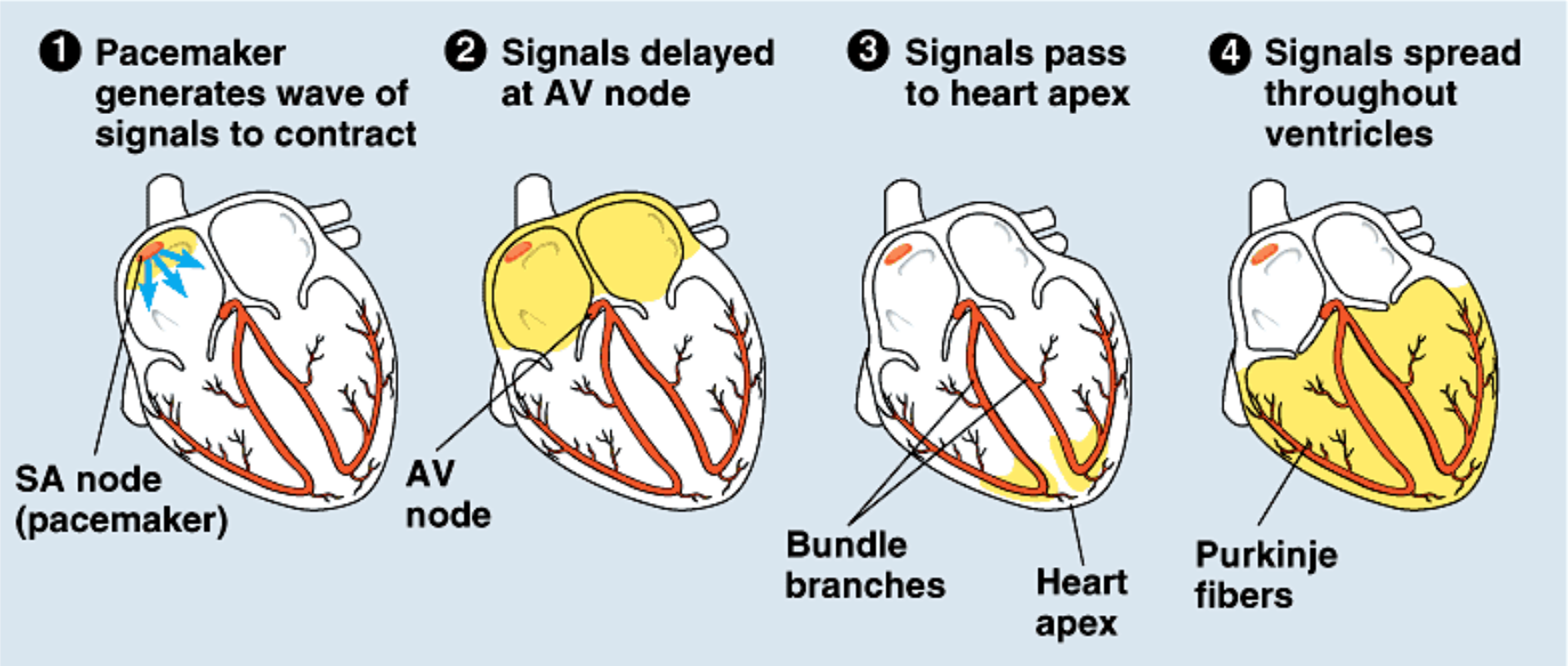
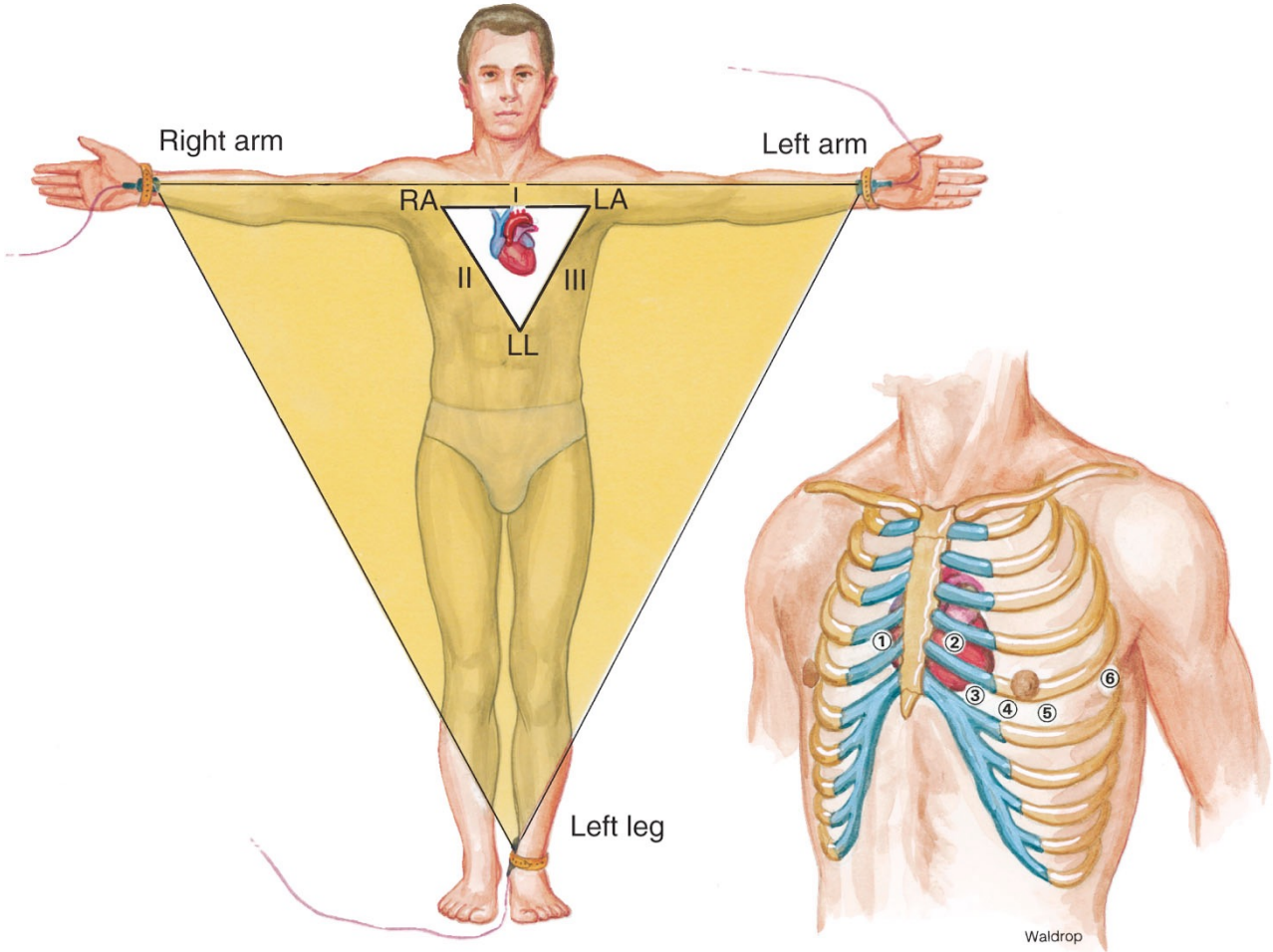
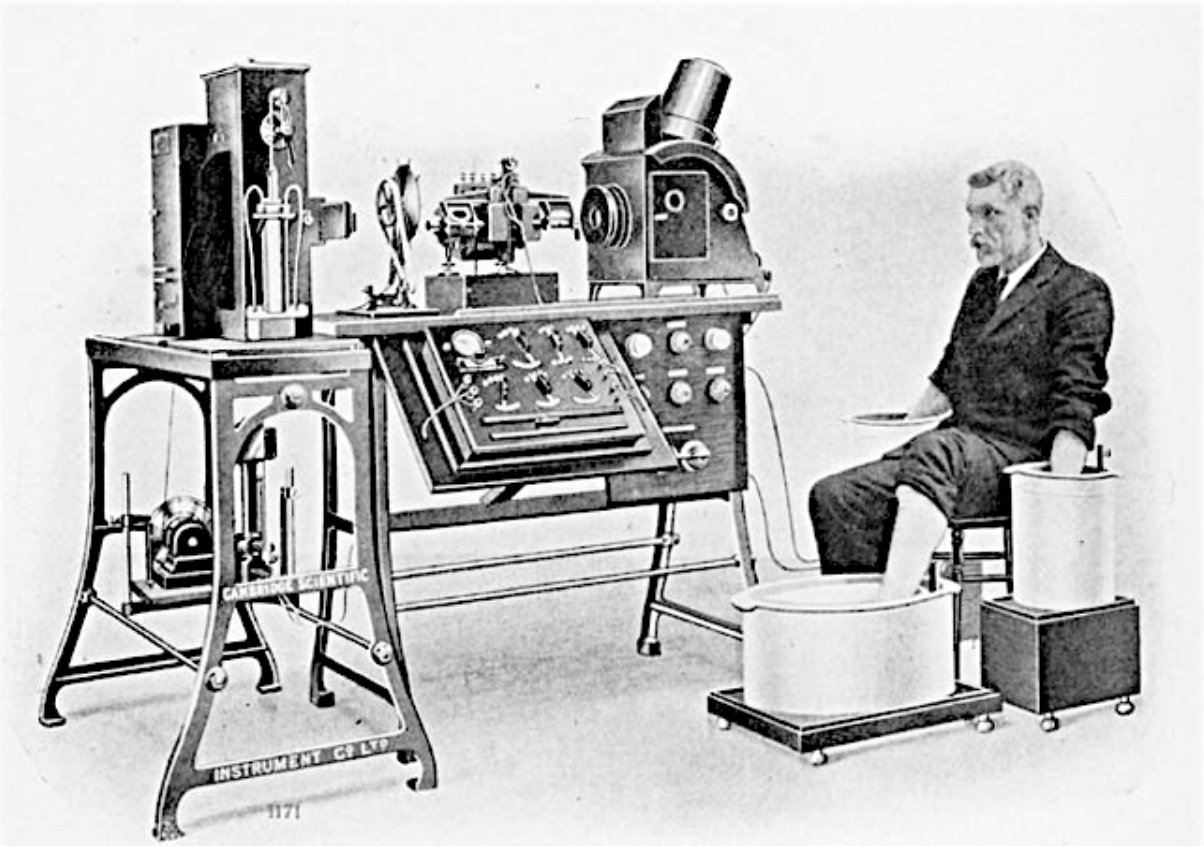


Figure 13.24

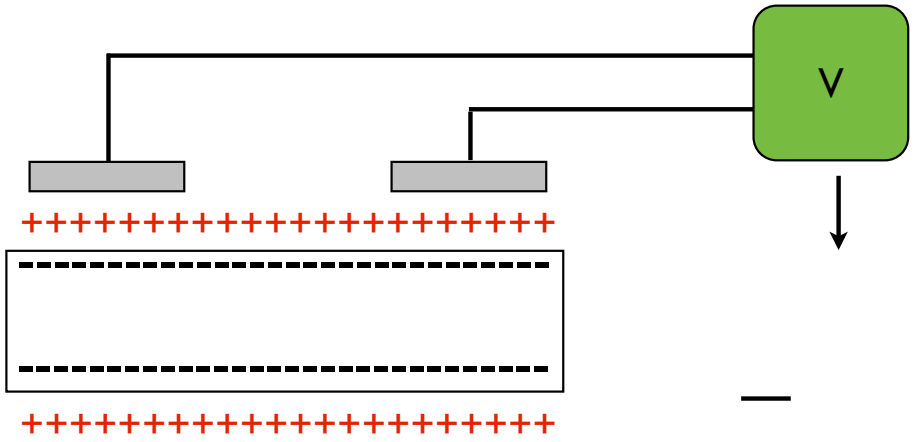


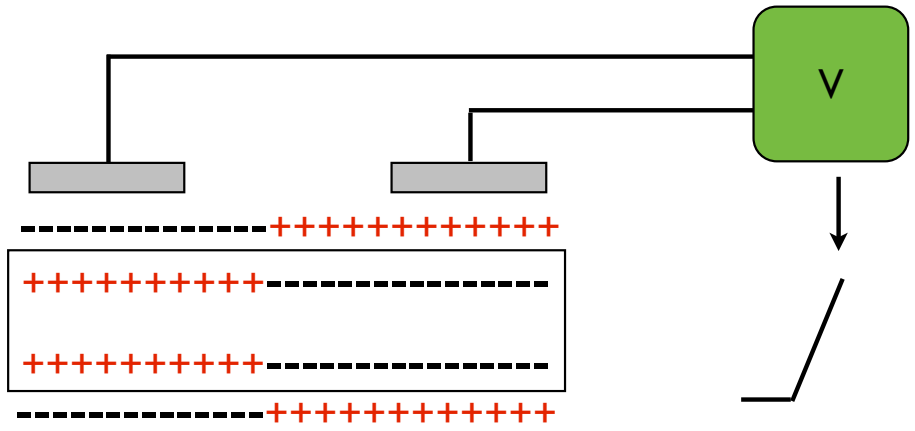


PHOTOGRAPH OF A COMPLETE ELECTROCARDIOGRAPH, SHOWING THE MANNER IN WHICH THE ELECTRODES ARE ATTACHED TO THE PATIENT, IN THIS CASE THE HANDS AND ONE FOOT BEING IMMERSED IN JARS OF SALT SOLUTION

1911

http://en.wikipedia.org/wiki/Image:Willem_Einthoven_ECG.jpg


V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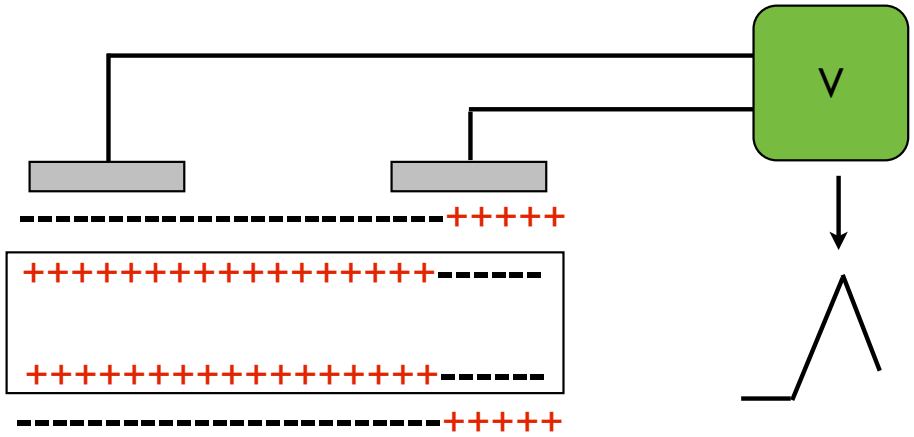
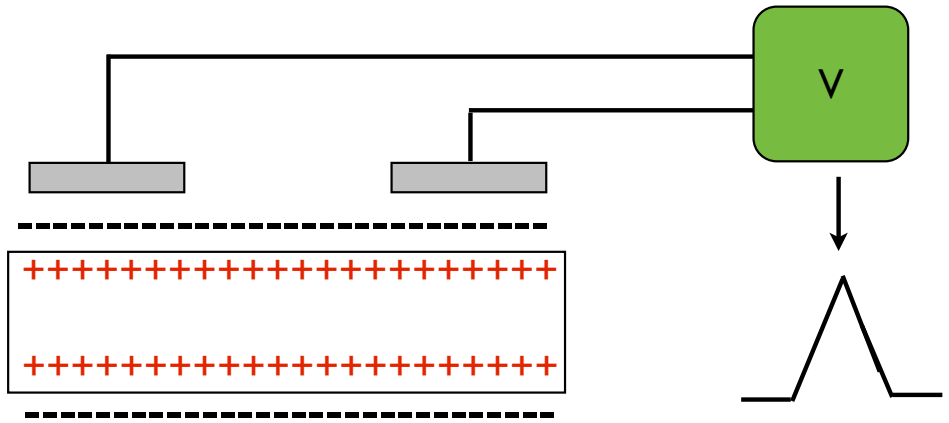

V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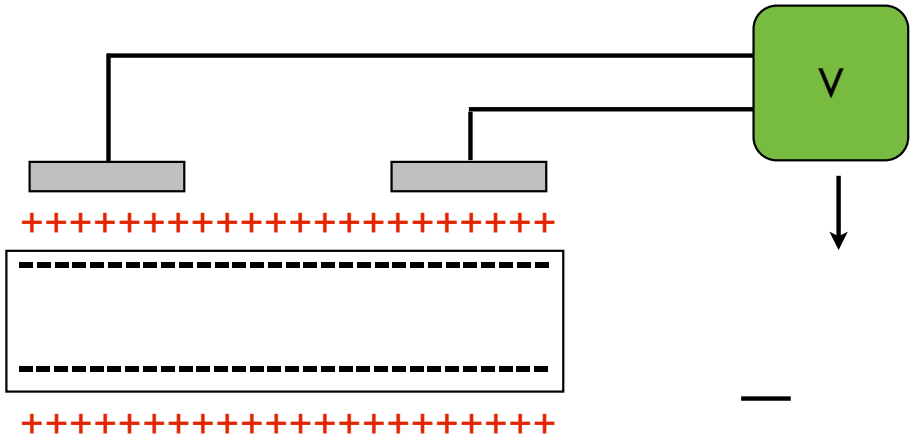
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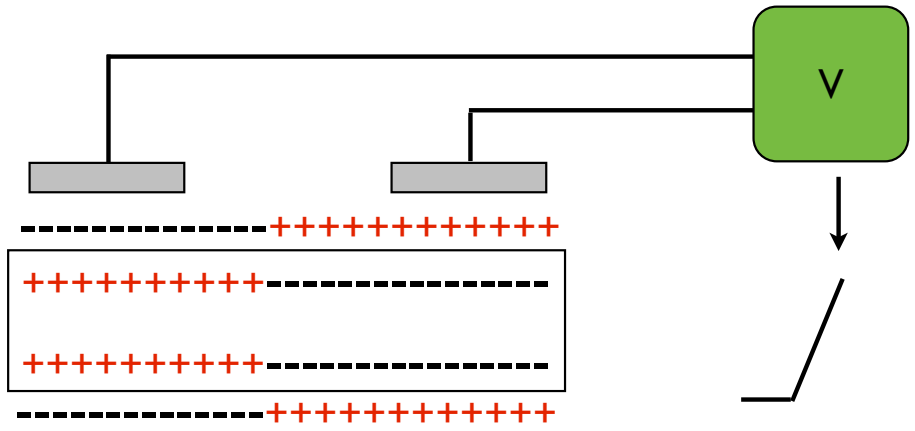
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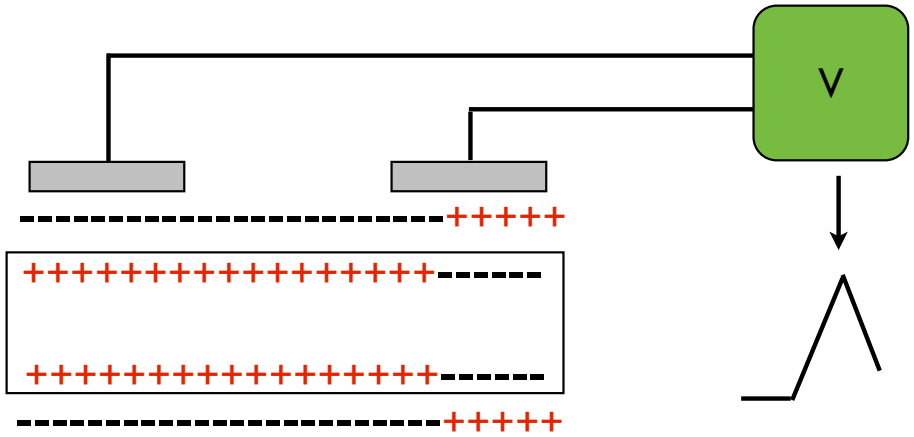
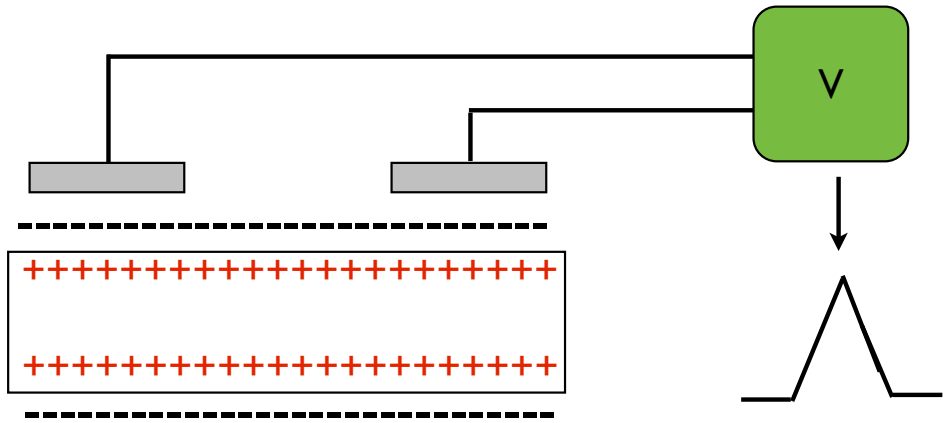
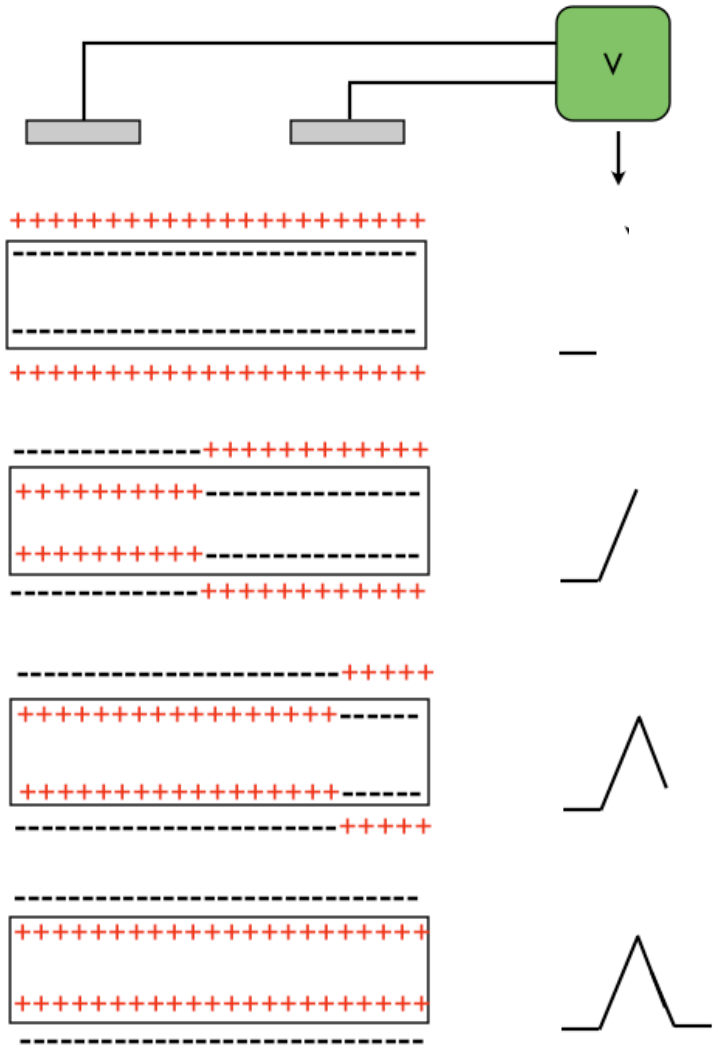
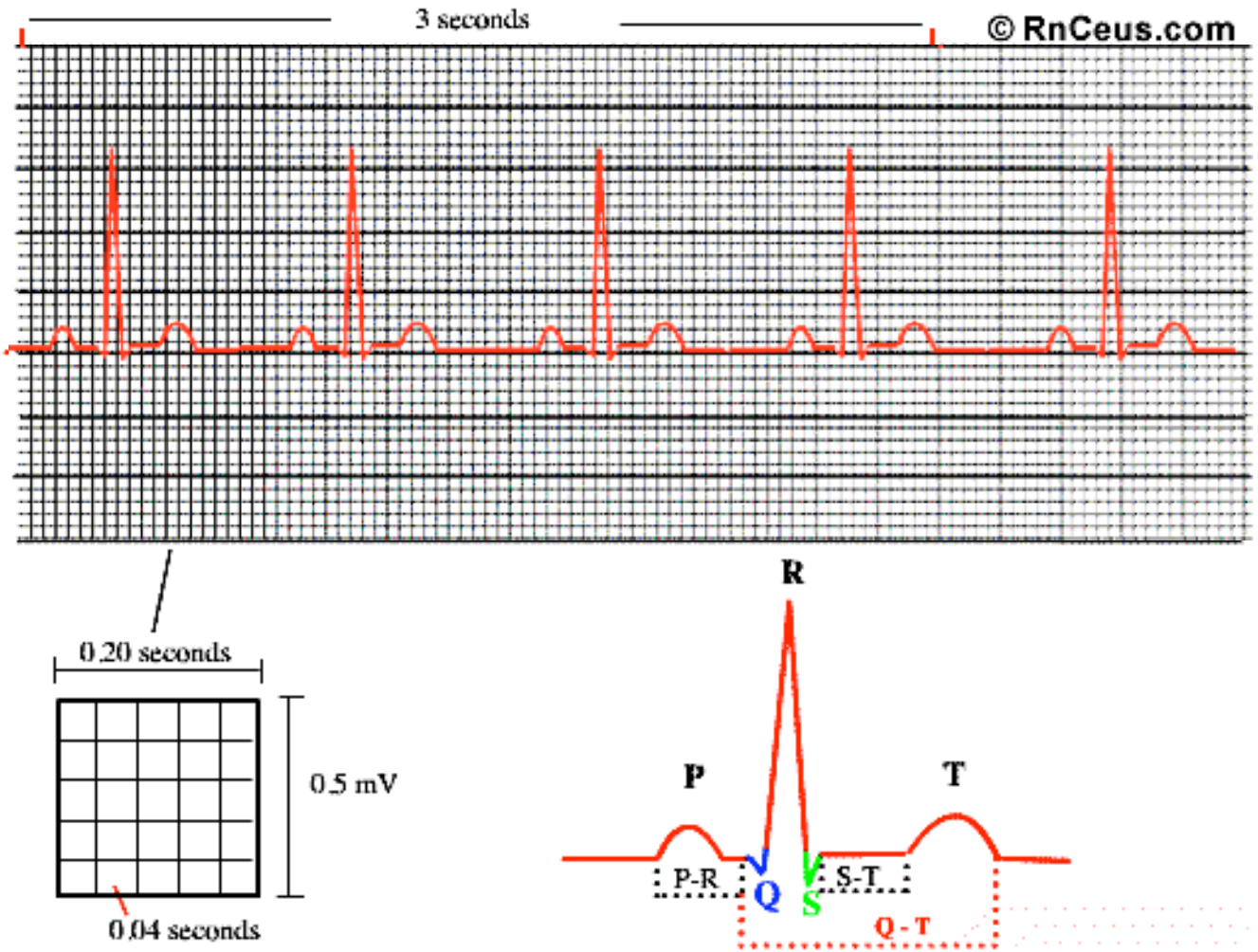

V


V


V



http://www.rnceus.com/ekg/ekghowto.html

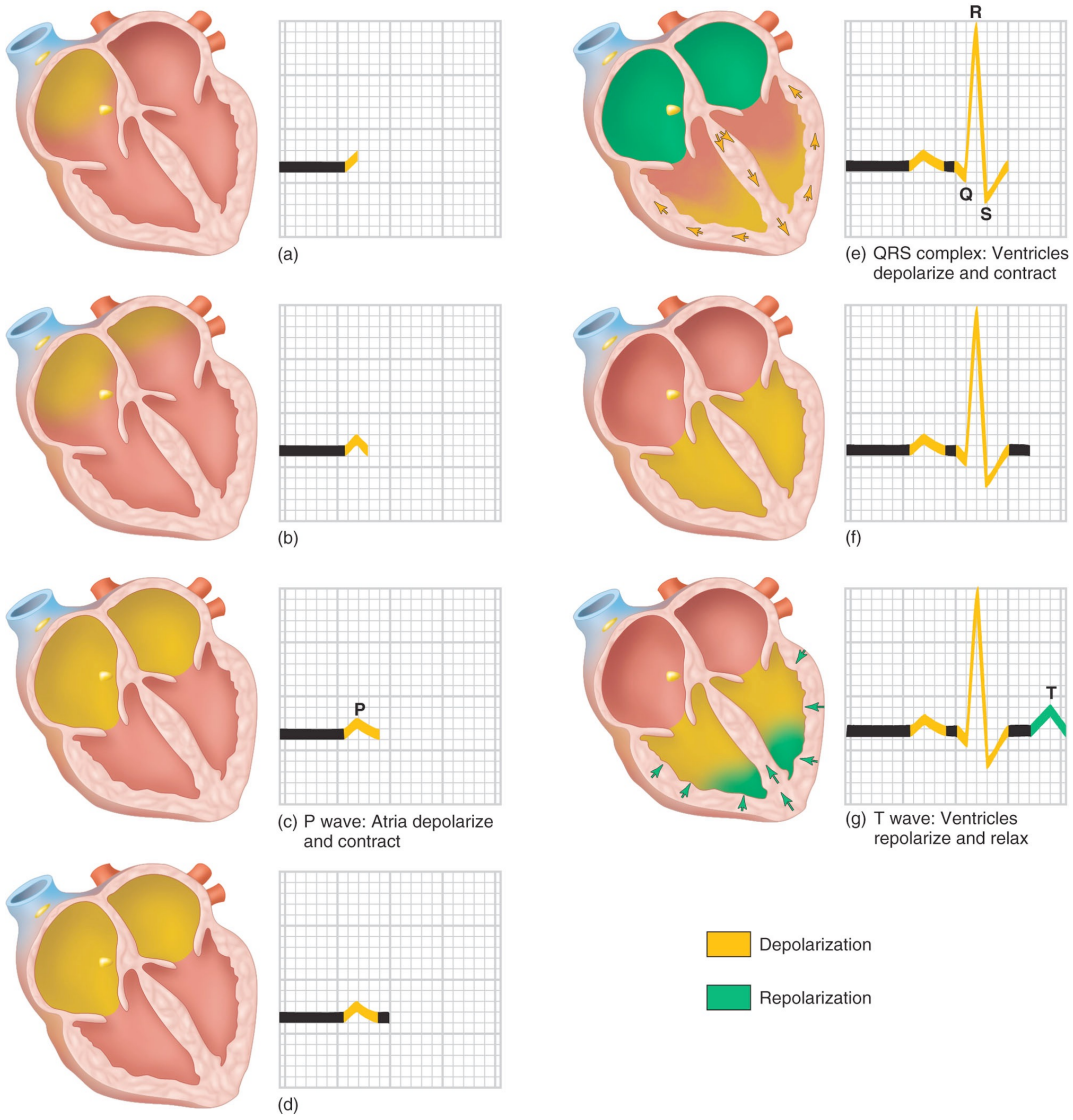

(a)
(b)
P
(c) P wave: Atria depolarize and contract
(d)
R
Q
S
(e) QRS complex: Ventricles depolarize and contract
(f)
T
(g) T wave: Ventricles repolarize and relax
Depolarization
Repolarization

Figure 13.23

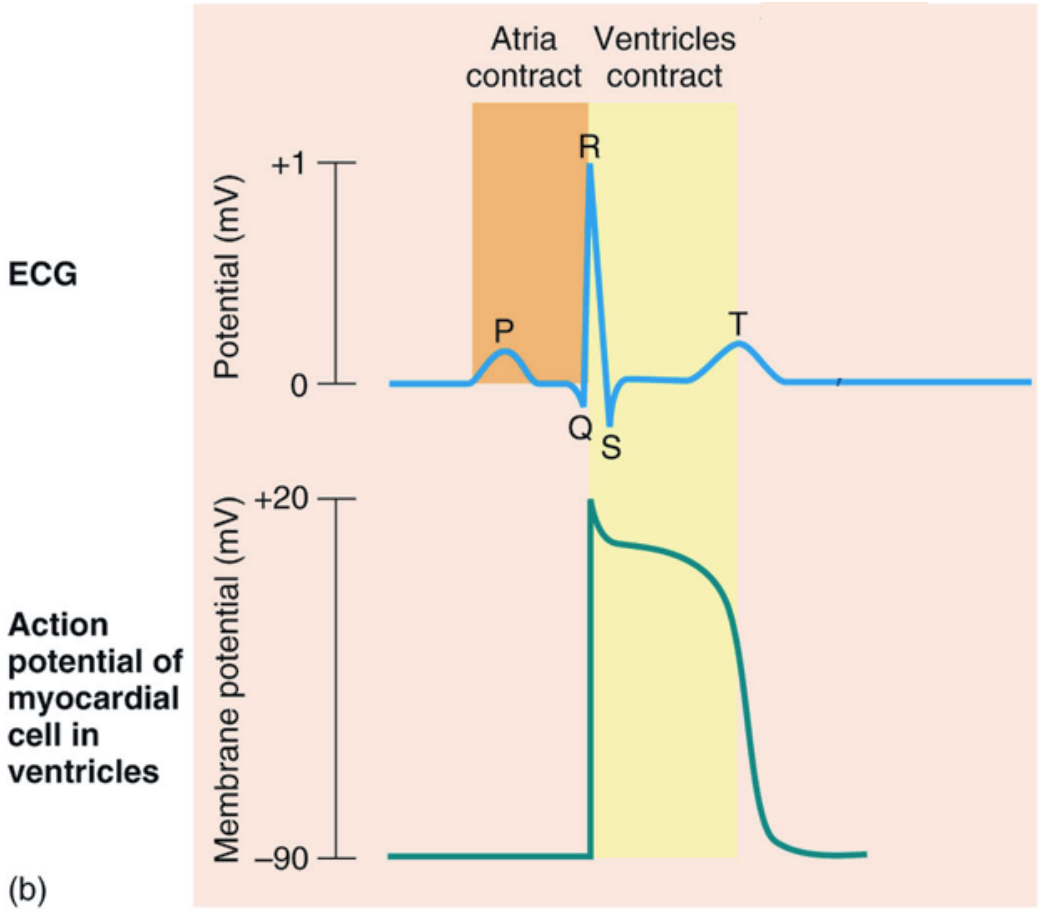
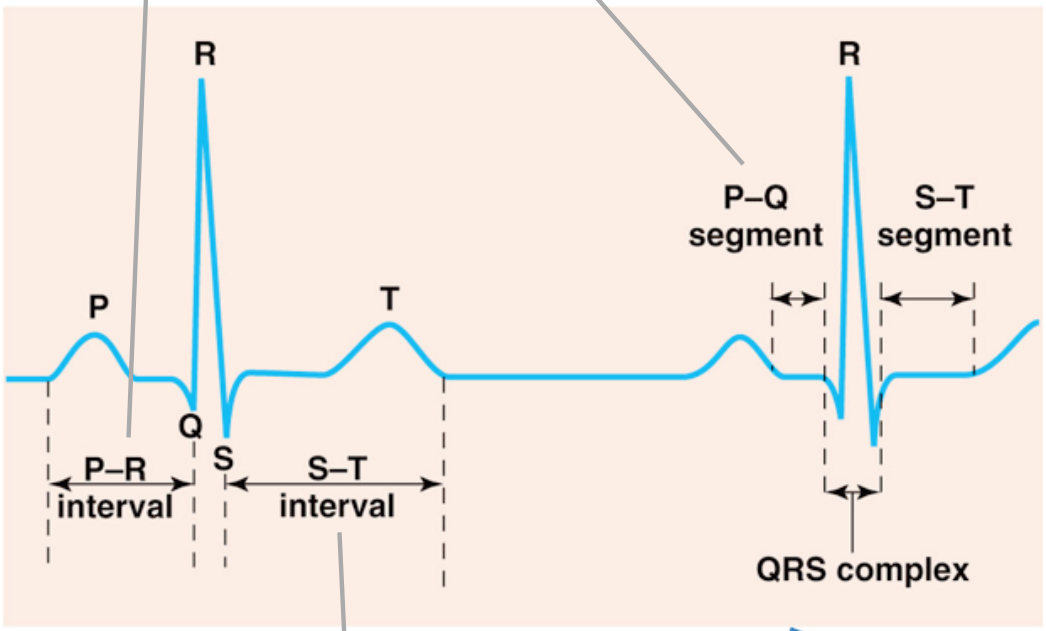

Atria contract
Ventricles contract
ECG
Potential (mV)
+1
0
R
P
T
Q
S
Action potential of myocardial cell in ventricles
Membrane potential (mV)
+20
–90
(b)

Figure 13.22

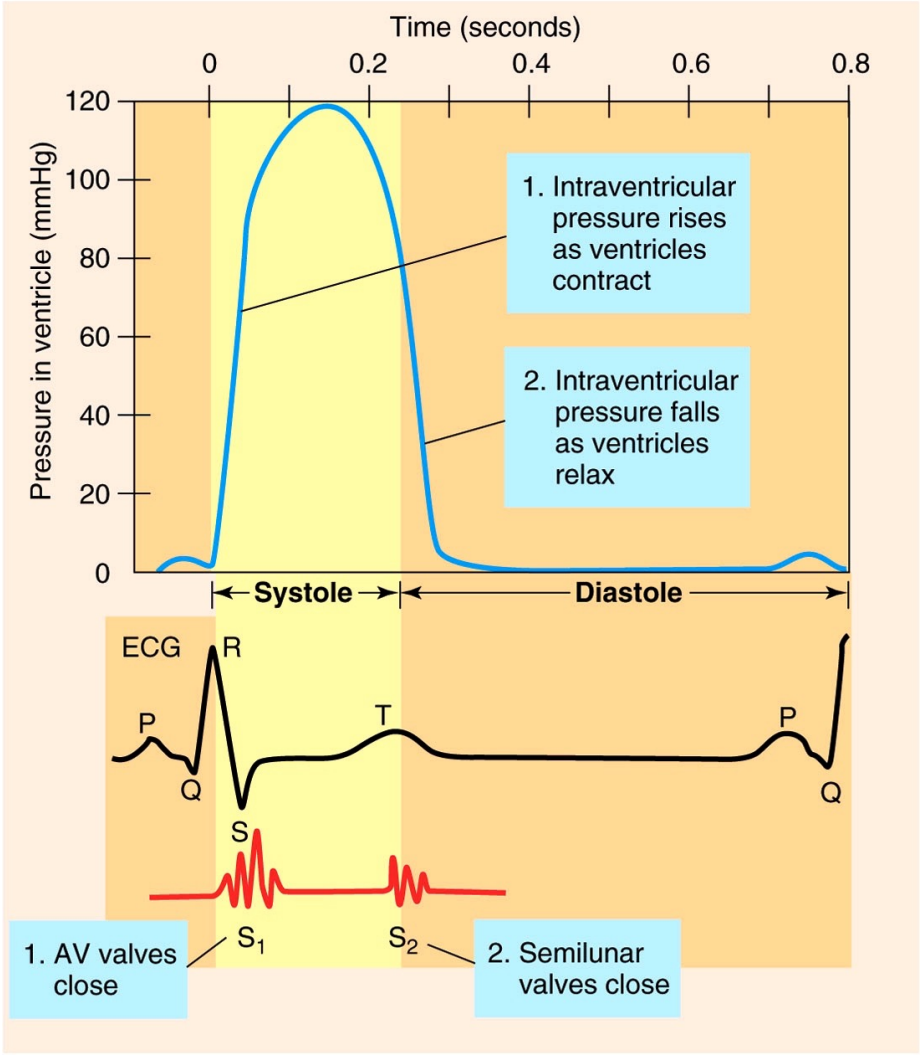
time for AP to spread from atria to ventricles



time for ventricles to depolarize and repolarize (pump Ca++ out of cytoplasm)

Figure 13.22

Figure 13.25


Time (seconds)
0
0.2
0.4
0.6
0.8
120
100
80
60
40
20
0
Pressure in ventricle (mmHg)
1. Intraventricular pressure rises as ventricles contract
2. Intraventricular pressure falls as ventricles relax
Systole
Diastole
ECG
R
P
T
P
Q
Q
S
S_1
S_2
1. AV valves close
2. Semilunar valves close

Events of the Cardiac Cycle

Electrical	ECG	Atria	AV Valves	Ventricles	Semi-Lunar Valves	Blood Flow
between beats		diastole	open	diastrole	closed	into atria (from vena cava, lungs)
SA node fires, spreads to AV node	P	systole	open	diastole	closed	into ventricles
spreads down bundle of His to Apex		systole	open	diastole	closed	
			"lub"			
spreads thru Purkinje fibers	QRS	diastole	closed	systole	open	into lungs, aorta
					"dub"	
between beats	T	diastole	open	diastrole	closed	into atria (from vena cava, lungs)

diastole = relaxed, systole = contracting