Cardiovascular Physiology and the Peripheral Vascular System

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Learning Objectives

How does the cardiovascular system normally function?

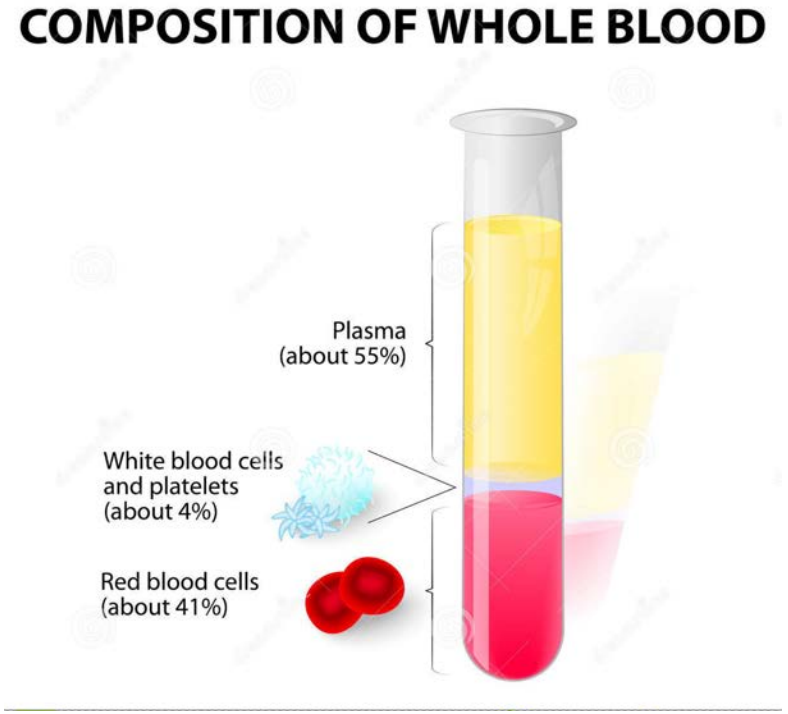
1. Learn the components of blood
2. Learn the architecture of the blood vessels
3. Learn how the heart distributes blood to the rest of the body

The Components of Blood

- Plasma
- Red Blood Cells (Erythrocytes)
- White Blood Cells (Leukocytes)
- Platelets

The Components of Blood

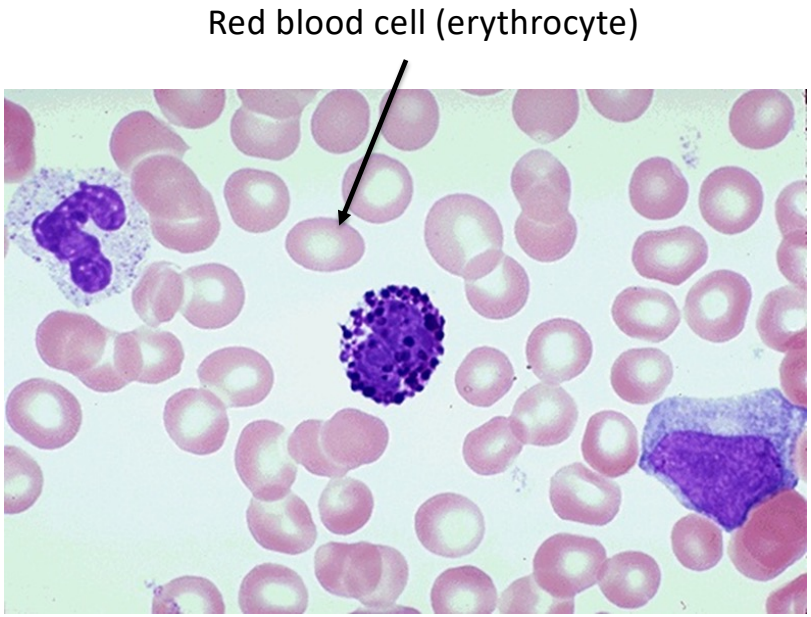
- Plasma – the fluid matrix that contains that blood components
- Plasma contains:
  - Clotting Factors – mediate hemostasis and thrombosis
  - Serum – contains other proteins, antibodies, hormones, etc.



https://www.dreamstime.com/stock-photo-blood-plasma-formed-elements-test-tube-composition-whole-hematocrit-red-cells-erythrocytes-white-cells-image37786150

The Components of Blood

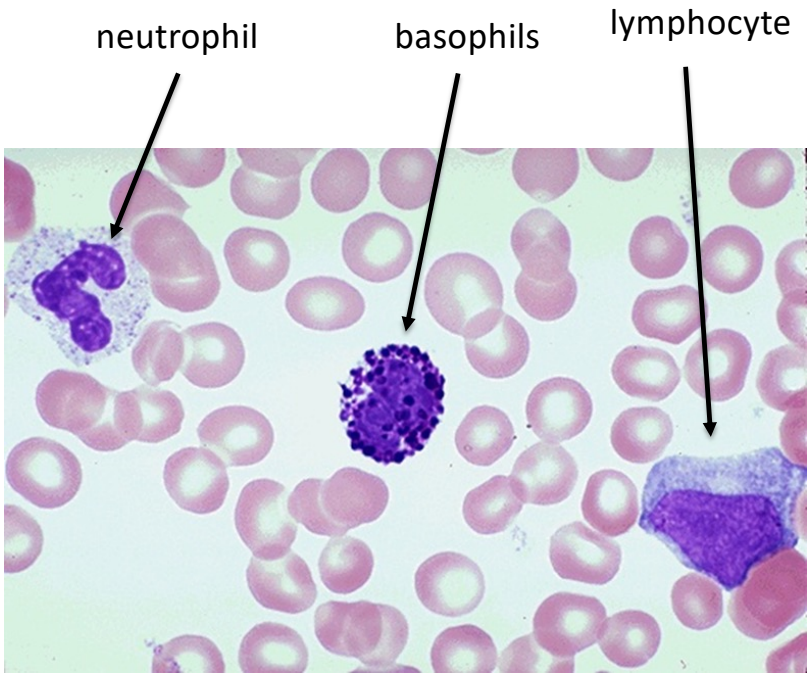
- Red Blood Cells (Erythrocytes)
  - No nucleus
  - Carry oxygen to the body and remove carbon dioxide
  - Too few red blood cells results in anemias
    - Iron-deficiency anemia
    - Sickle cell anemia
    - Hemolytic anemia
    - Fanconi anemia



https://webpath.med.utah.edu/HISTHTML/NORMAL/NORM023.html

The Components of Blood

- White Blood Cells (Leukocytes)
  - Basophils, Neutrophils, Eosinophils, Monocytes
  - Lymphocytes (B-cells and T-cells)
  - Primary role is to protect the body from infection and aid in inflammation



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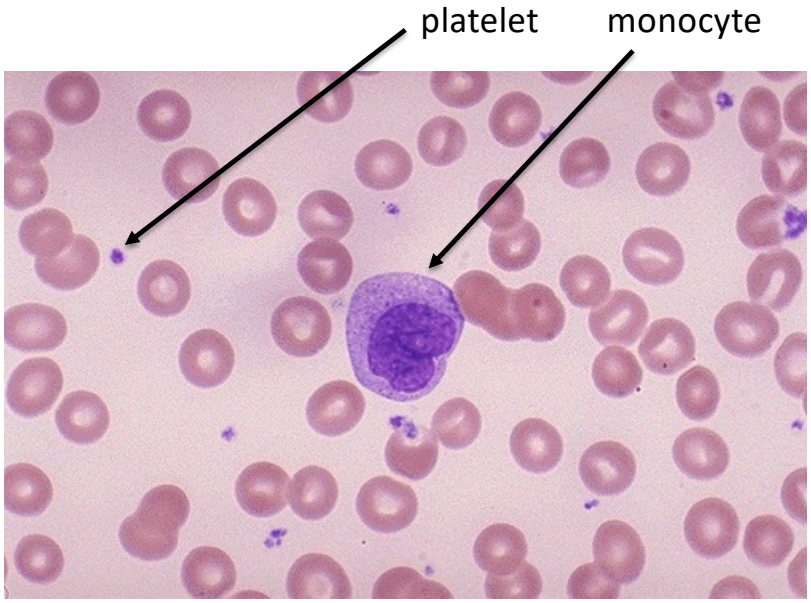
The Components of Blood

- Platelets
  - Very small anucleate cells
  - Help with hemostasis and thrombosis
  - Help with wound healing



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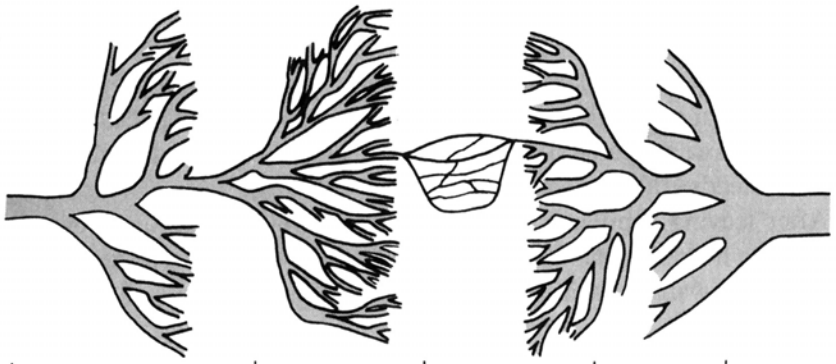
Vasculature: Arteries vs Veins

- Arteries – send oxygen-rich blood to the body from the heart
- Veins – send oxygen-poor blood from the body to the heart

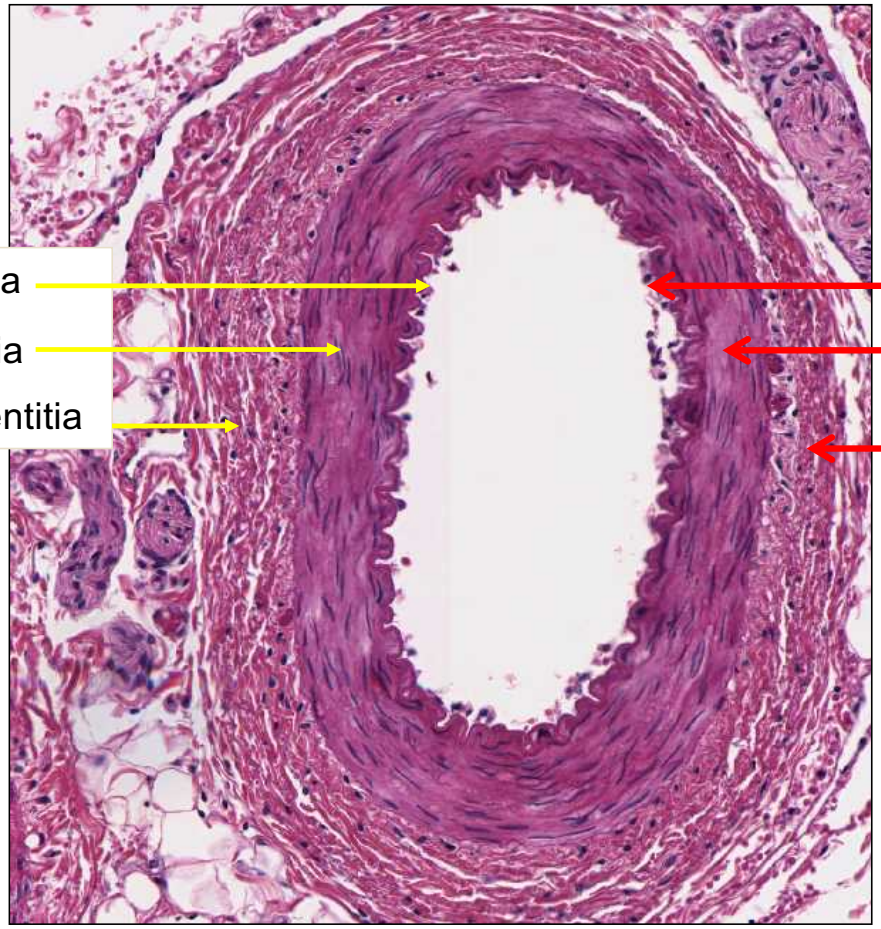


	ARTERIES		ARTERIOLES	CAPILLARIES	VENULES	VEINS	
	Aorta				one-way valves		Venae cavae
internal diameter	2.5 cm	0.4 cm	30 μm	5μm	70 μm	0.5 cm	3 cm
wall thickness	2 mm	1 mm	20 μm	1 μm	2 μm	0.5 mm	1.5 mm
number	1	160	5×10^7	10^{10}	10^8	200	2
total cross-sectional area	4.5 cm^2	20 cm^2	400 cm^2	4500 cm^2	4000 cm^2	40 cm^2	18 cm^2

Figure 7-1 Structural characteristics of the peripheral vascular system.

Mormon and Heller, 1997

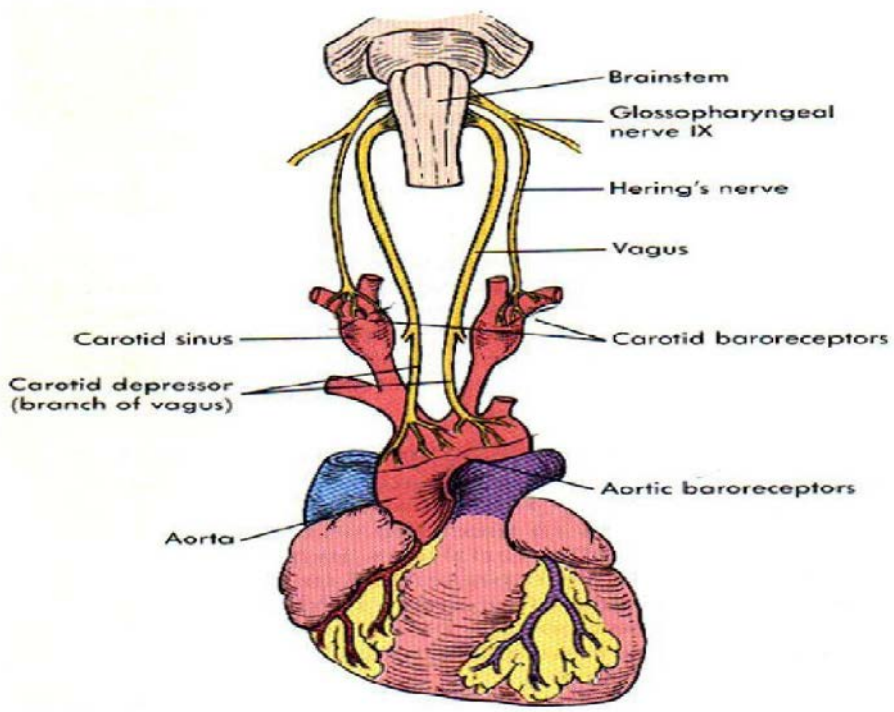
Medium artery human (VM-UNC)



Sympathetic Nerve Stimulation

- Baroreceptors sense changes in blood pressure
  - They then send signals via the sympathetic nerves that either constrict vessels to increase pressure or relax vessels to decrease pressure

Arterial Baroreceptors



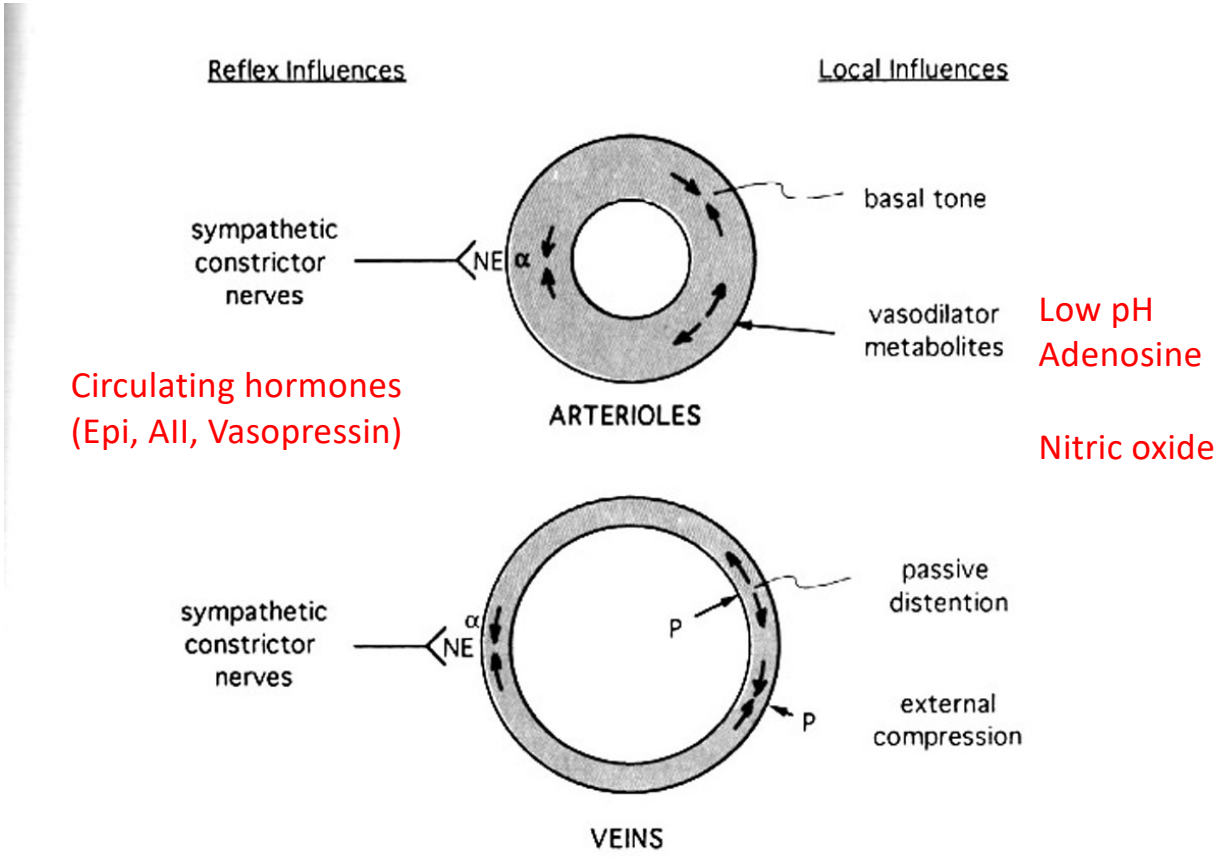


Figure 8-5 Primary influences on arterioles and veins. NE, norepinephrine; α, alpha adrenergic receptor; P, pressure.

Circulating hormones (Epi, AII, Vasopressin)

Low pH
Adenosine

Nitric oxide

Mormon and Heller, 1997

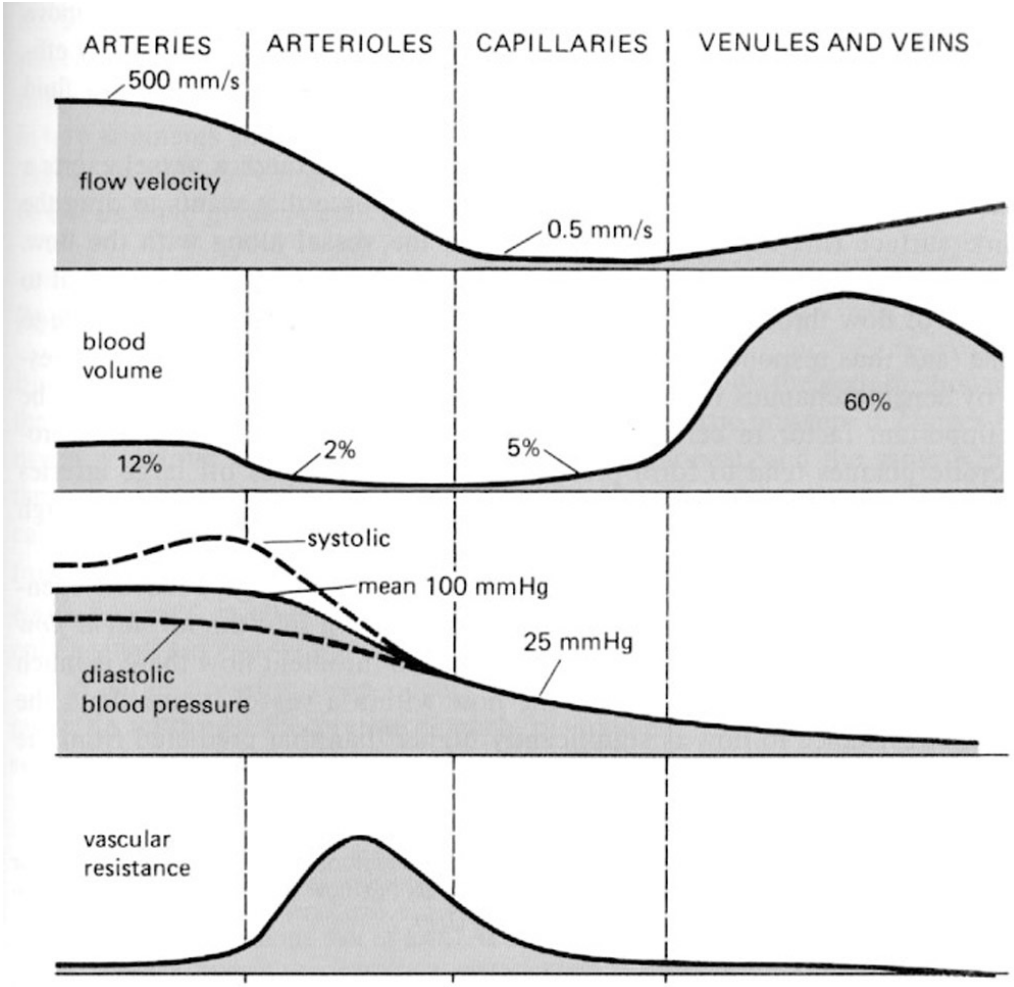


Figure 7-4 Flow velocities, blood volumes, blood pressures, and vascular resistances in the peripheral vasculature from aorta to right atrium.

Mormon and Heller, 1997

The Heart

https://www.youtube.com/watch?v=GMBSU-2GK3E

National Geographic Video

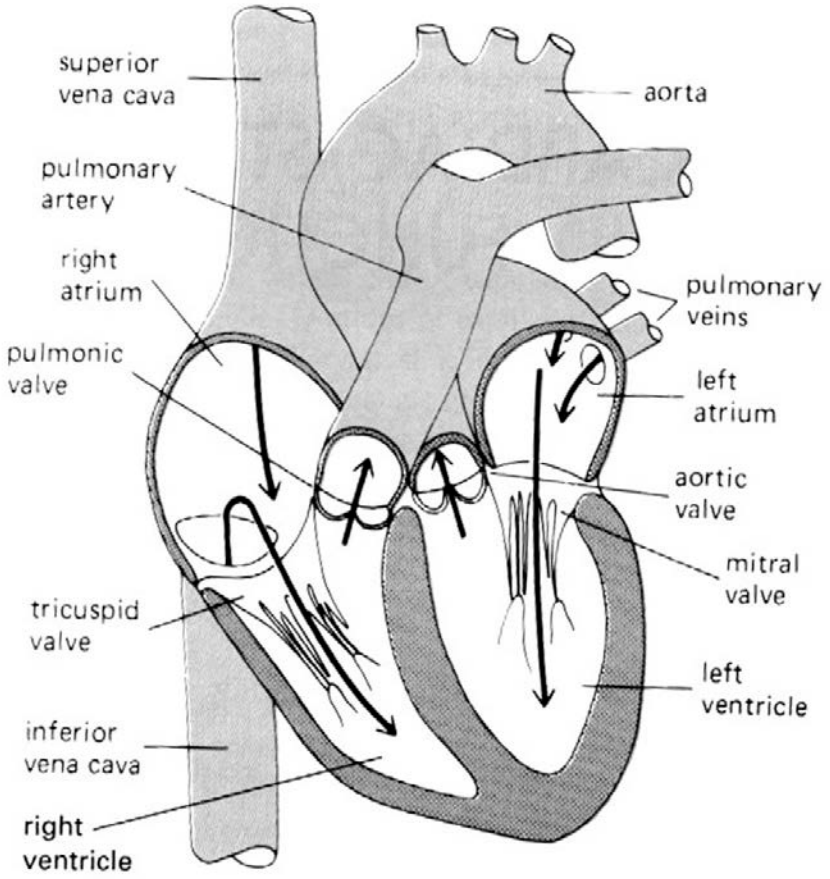


Figure 2-1 Pathway of blood flow through the heart.

Mormon and Heller, 1997

How the Blood Travels

- Blood that's pumped out of the heart travels through the arteries to the organs and the rest of the body
- Oxygen-rich blood is delivered through the capillaries in exchange for the oxygen-poor blood
- The oxygen-poor blood then travels to the lungs through the veins where it is re-oxygenated before it returns to the heart

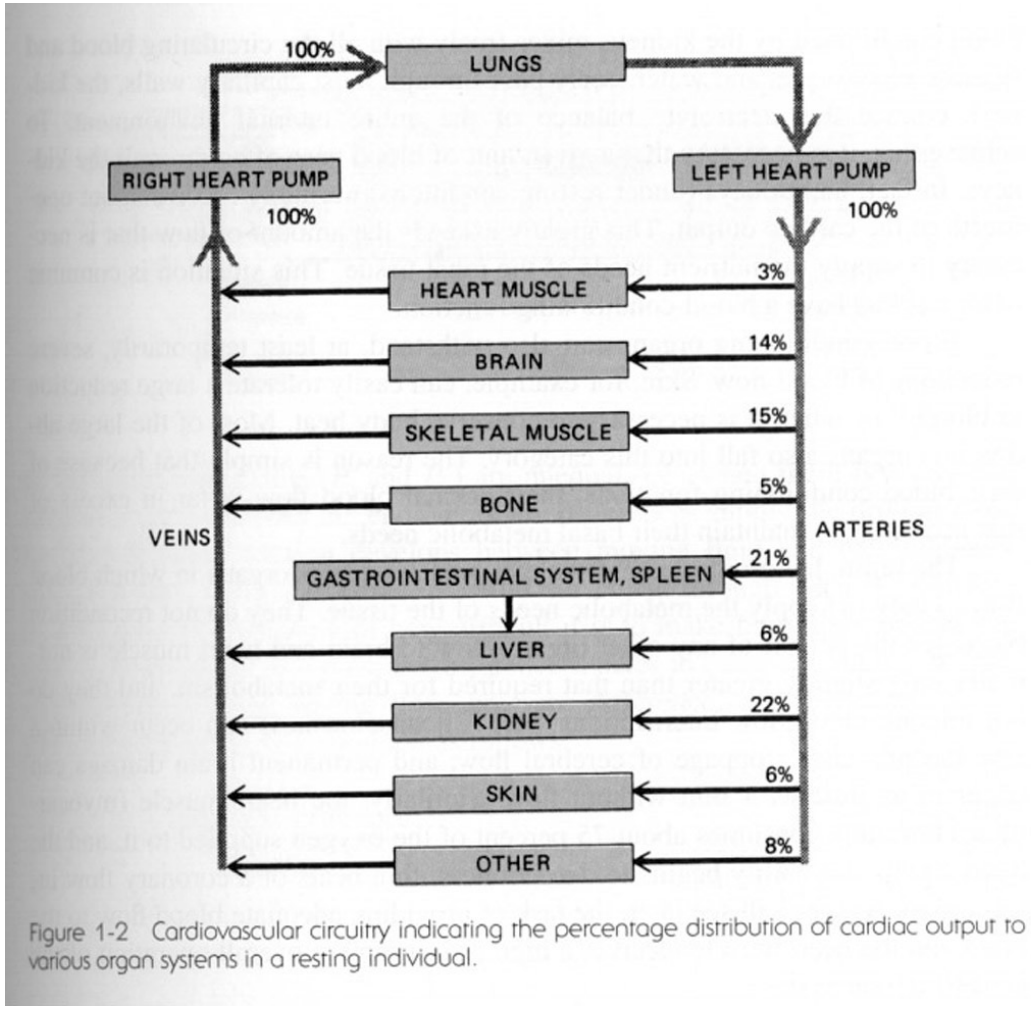
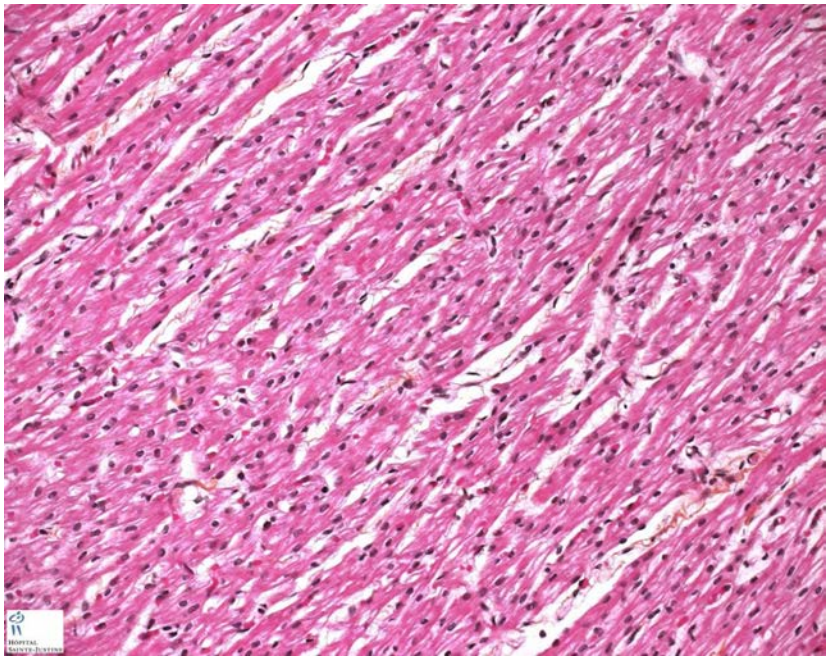


Figure 1-2 Cardiovascular circuitry indicating the percentage distribution of cardiac output to various organ systems in a resting individual.

Mormon and Heller, 1997

Cardiomyocytes

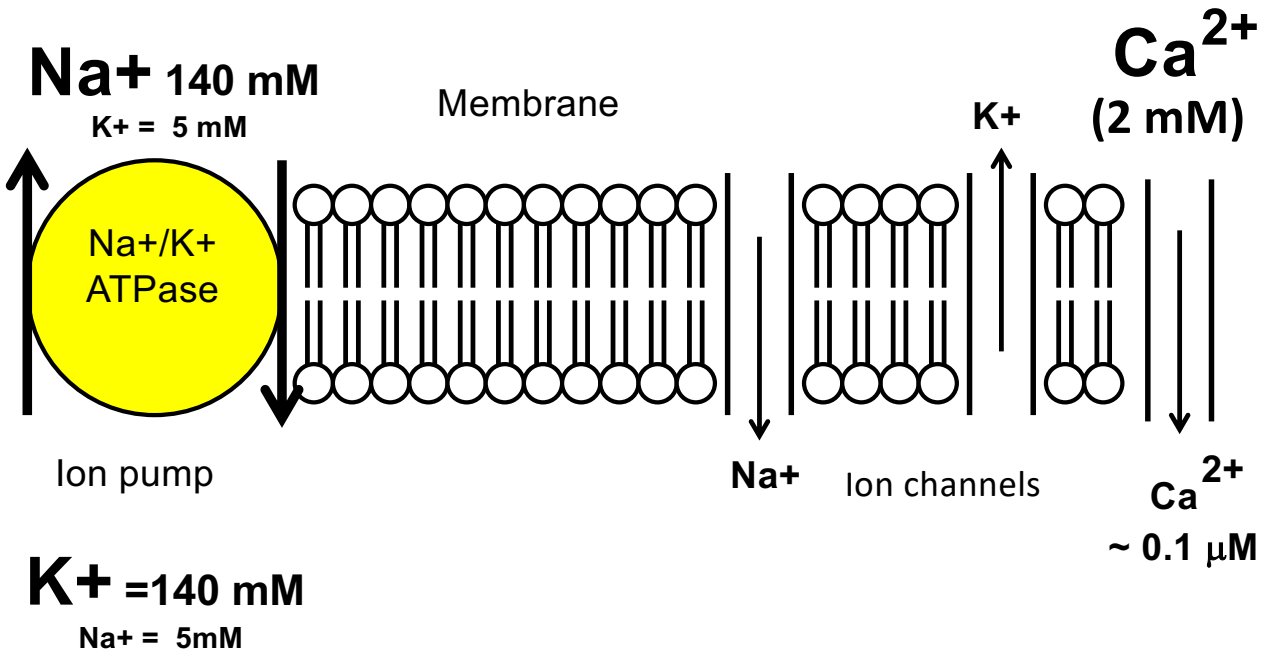
- Cardiomyocytes
  - The primary cellular unit of the heart
  - Responsible for the heart contracting
    - The contraction is governed by a rhythmic opening and closing of calcium ion channels and sodium potassium pumps
    - These pumps create a gradient of electricity that causes the cardiomyocytes to pull on each other in a single direction (this causes the heart to contract or “pump”)
    - Disrupting this electrical gradient results in arrhythmias



https://www.humpath.com/spip.php?article3277

Electrical properties of cardiac cells

- Electrical signals are sent from the SA node (the pacemaker of the heart)



Resting membrane potential ~ - 90 mV

Opening/Closing channels changes potential

Channels are responsive to signals (depolarization, PT modification, etc)

Excitation/Contraction Coupling

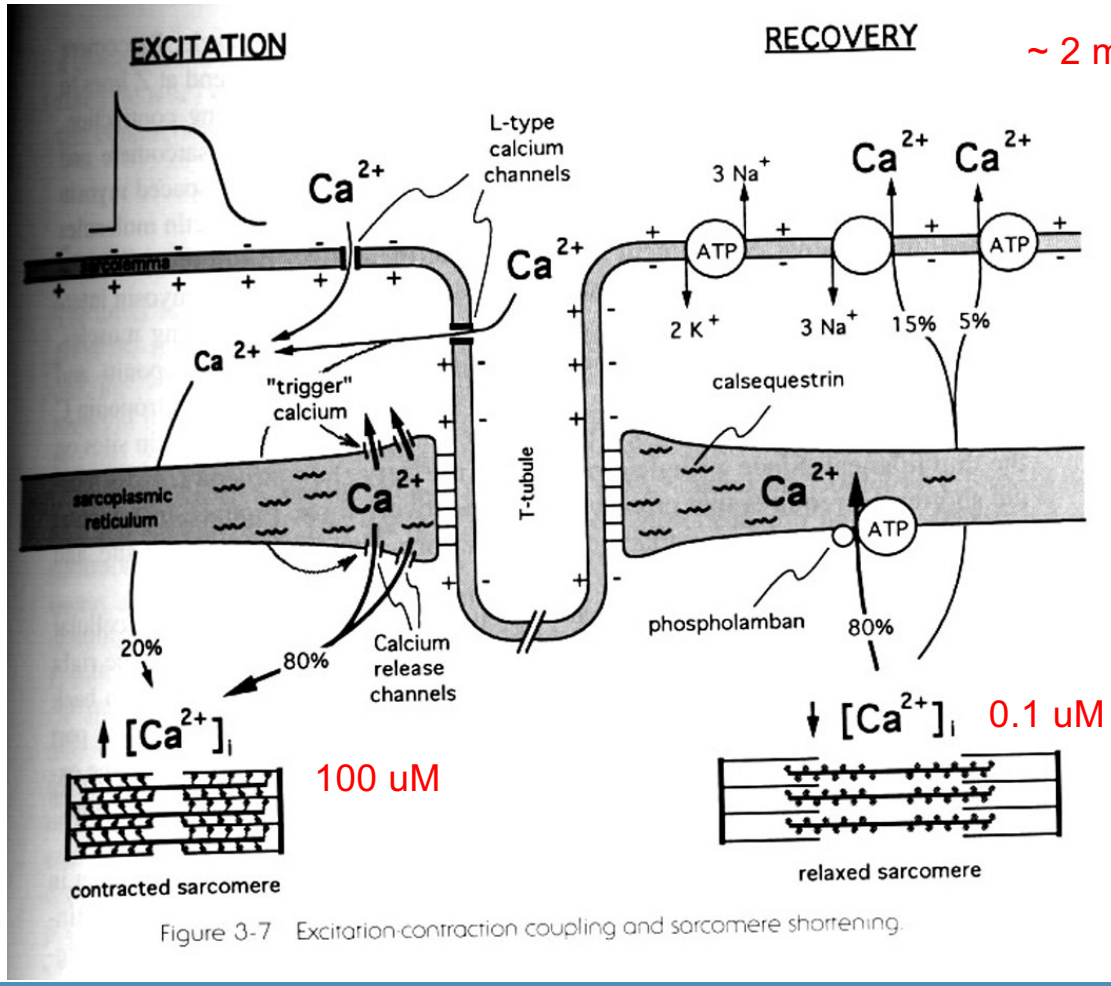


Figure 3-7 Excitation-contraction coupling and sarcomere shortening.

Mormon and Heller, 1997

Cardiac electrical conduction

- EKGs are used as a diagnostic tool by measuring electrical activity and heart rate
  - P wave = atrial depolarization
  - QRS complex = ventricular depolarization
  - T wave = ventricular repolarization
- Normal heart rate = 60 – 100 bpm (82 bpm)

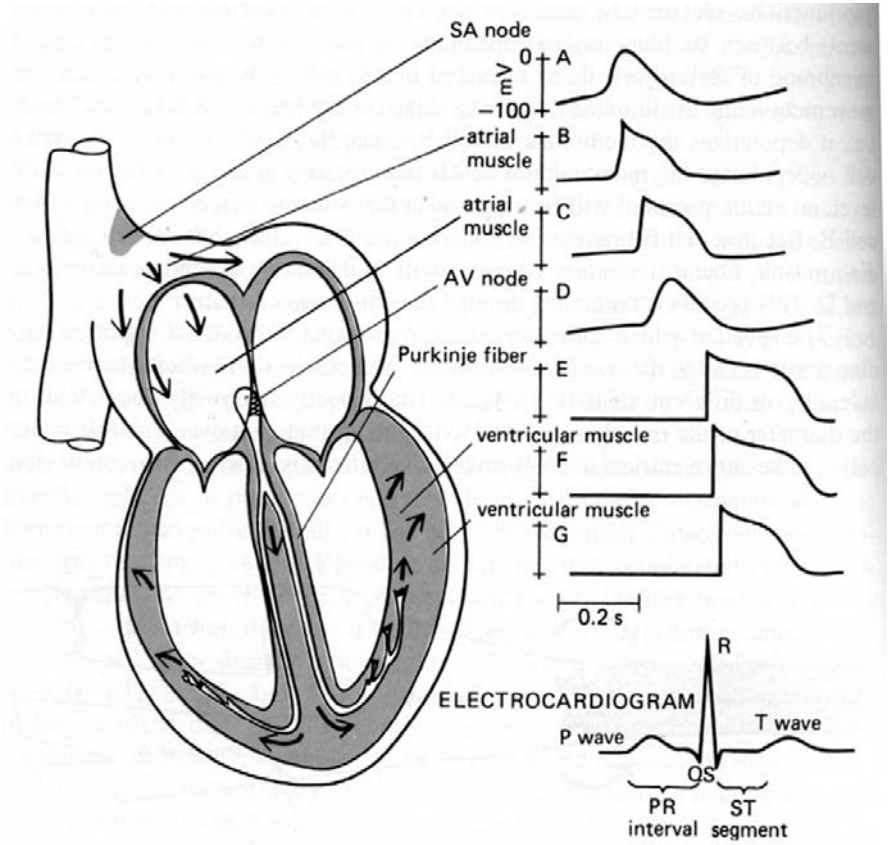


Figure 3-5 Electrical activity of the heart: single-cell voltage recordings (traces A to G) and lead II electrocardiogram.

Mormon and Heller, 1997

Action Potentials

Ventricular myocyte SA node

Electrical measurement

Corresponding permeabilities

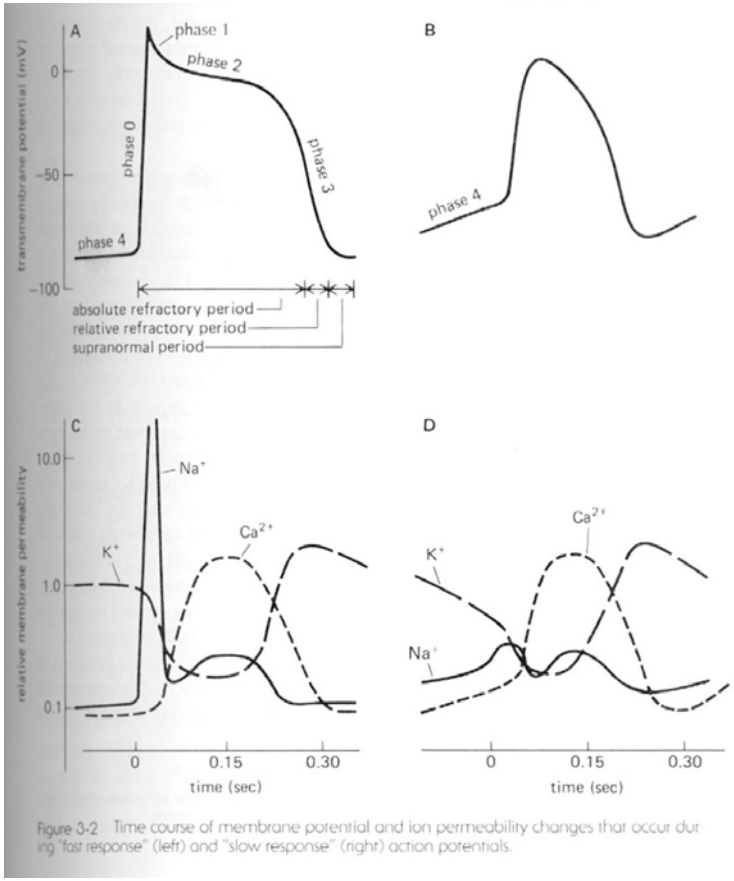
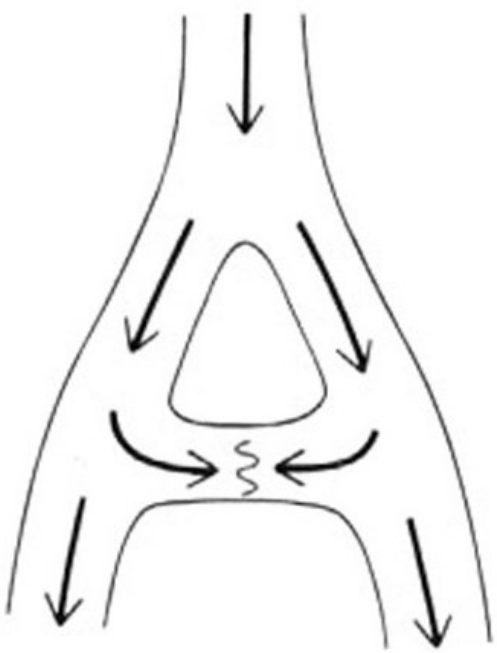


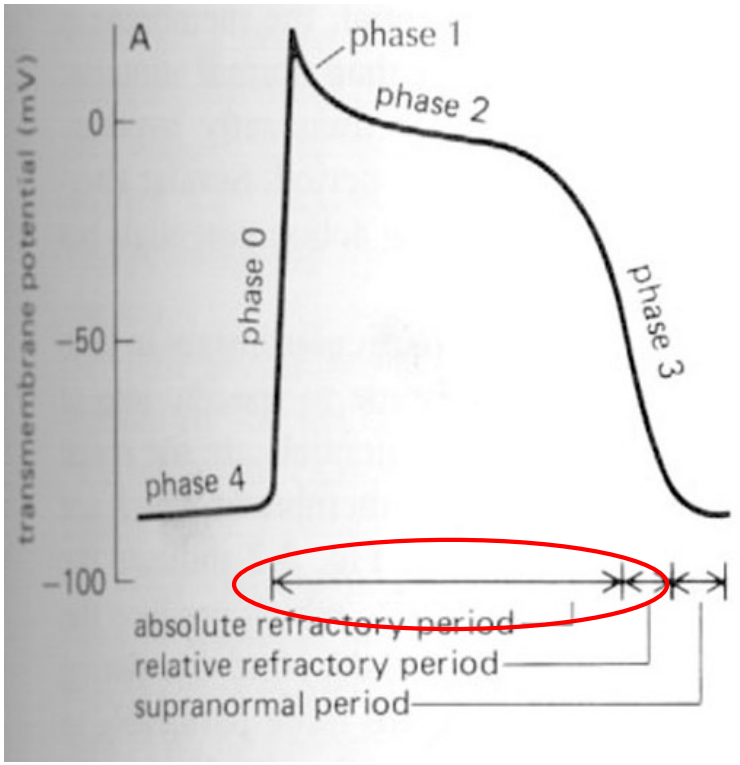
Figure 3-2 Time course of membrane potential and ion permeability changes that occur dur ing "fast response" (left) and "slow response" (right) action potentials.

Mormon and Heller, 1997

Refractory period helps prevent arrhythmia



normal pathway



Mormon and Heller, 1997

Cardiovascular Physiology Terms

- Cardiac Output (CO) - the volume of blood being pumped by heart per unit of time
  - CO = HR x SV
- Venous Return (VR) – flow of the blood back to the heart
  - VR = CVP – RAP
- Central Venous Pressure (CVP) – pressure in the vena cava
- Stroke Volume – volume of blood pumped by left-ventricle per beat
- Sympathetic Activity – increase in vasoconstriction and muscular contraction that increase stroke volume

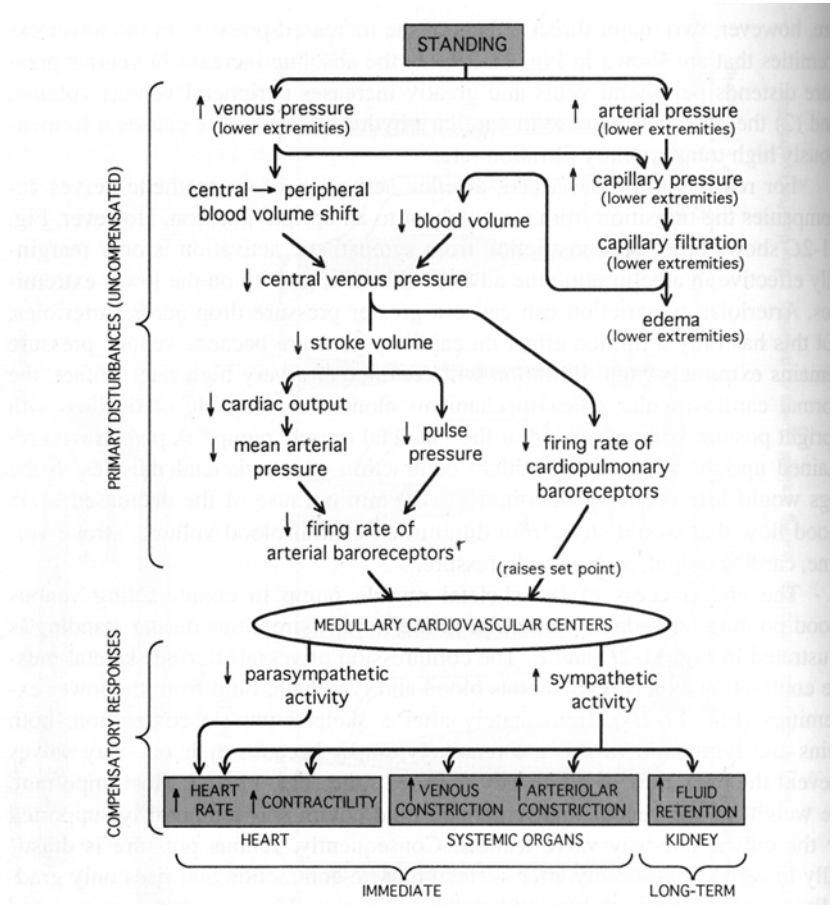
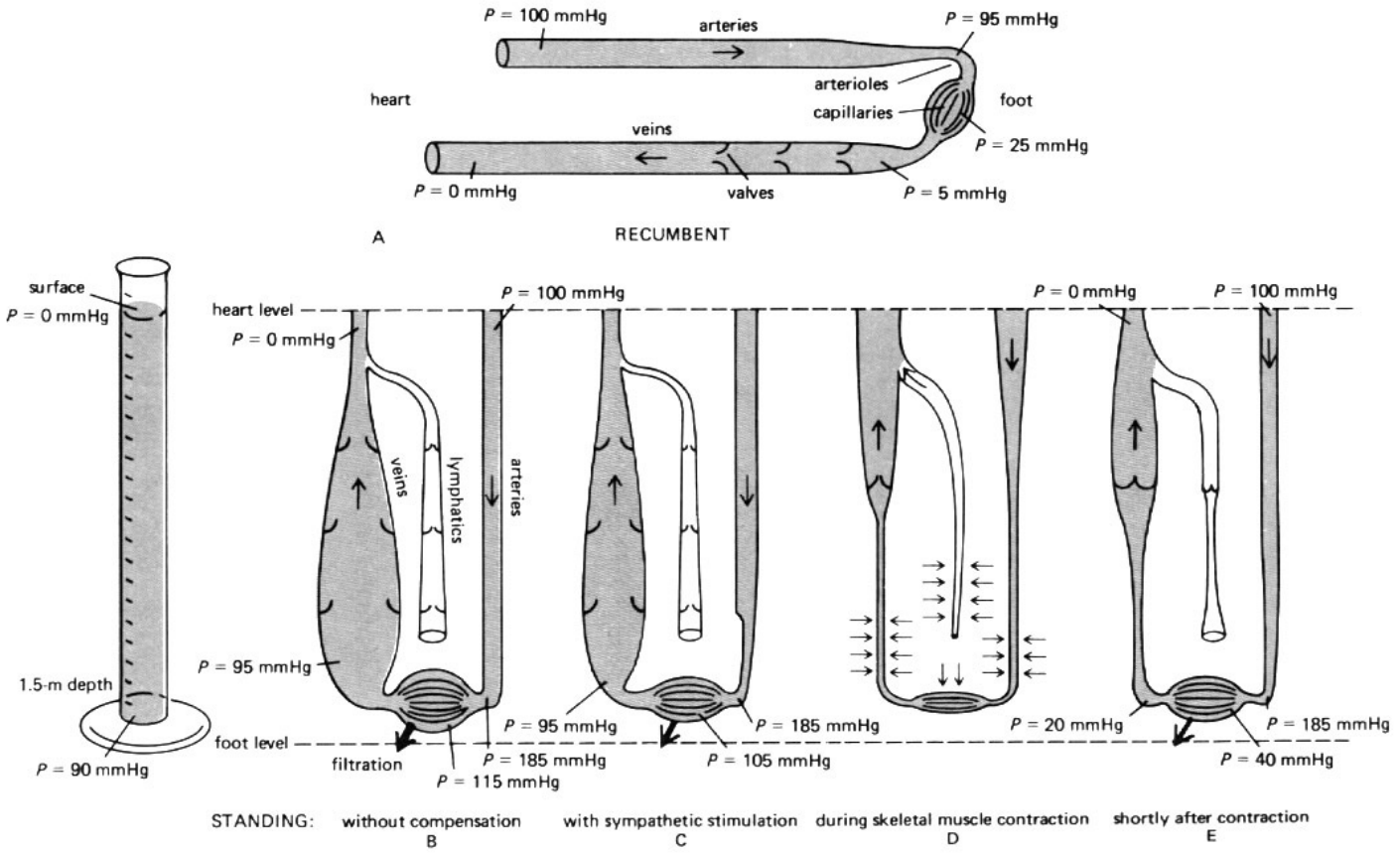


Figure 11-3 Cardiovascular mechanisms involved when changing from a recumbent to standing position.

Mormon and Heller, 1997

Body position, gravity, and muscle pump



Mormon and Heller, 1997

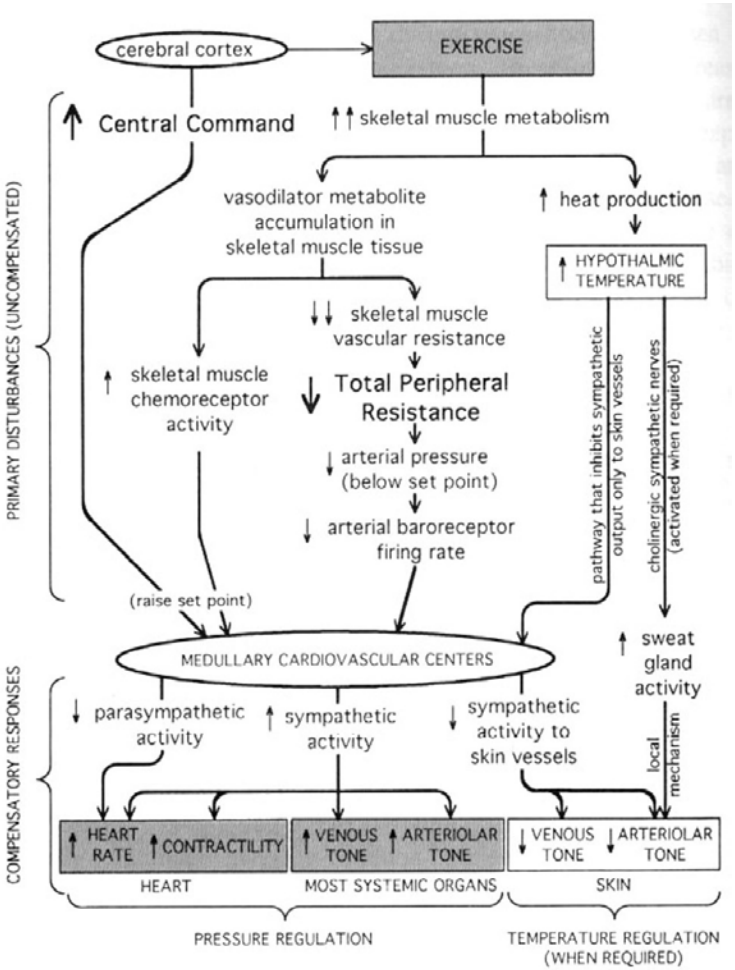
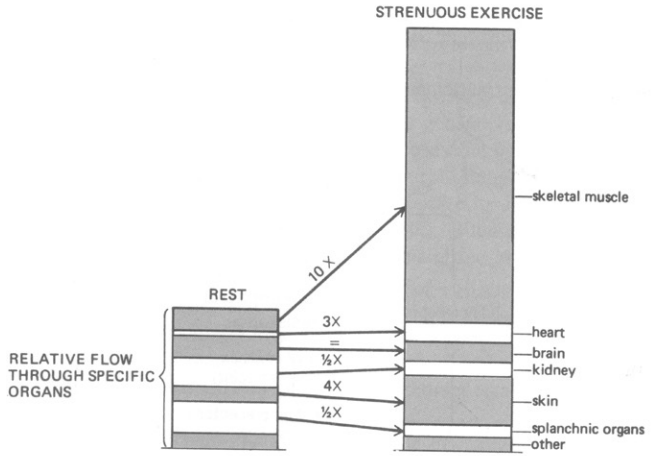


Figure 11-5 Cardiovascular mechanisms involved during exercise.

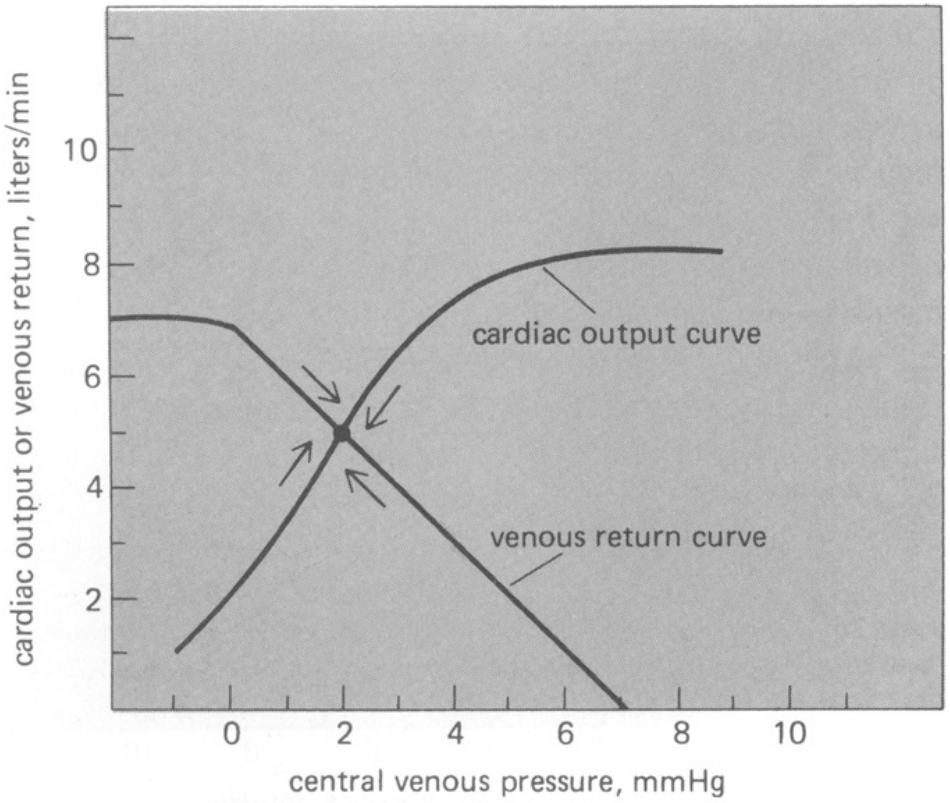


cardiac output	6 liters/min	18 liters/min
heart rate	70 beats per minute	160 beats per minute
ejection fraction	60%	80%
arterial pressure	120/80 mmHg	150/80 mmHg
central venous pressure	2 mmHg	2 mmHg

Figure 11-4 Cardiovascular adjustments to strenuous exercise.

Mormon and Heller, 1997

Relationship between venous return and CO



Central venous pressure is always inherently driven to the equilibrium value that makes CO=VR

Mormon and Heller, 1997

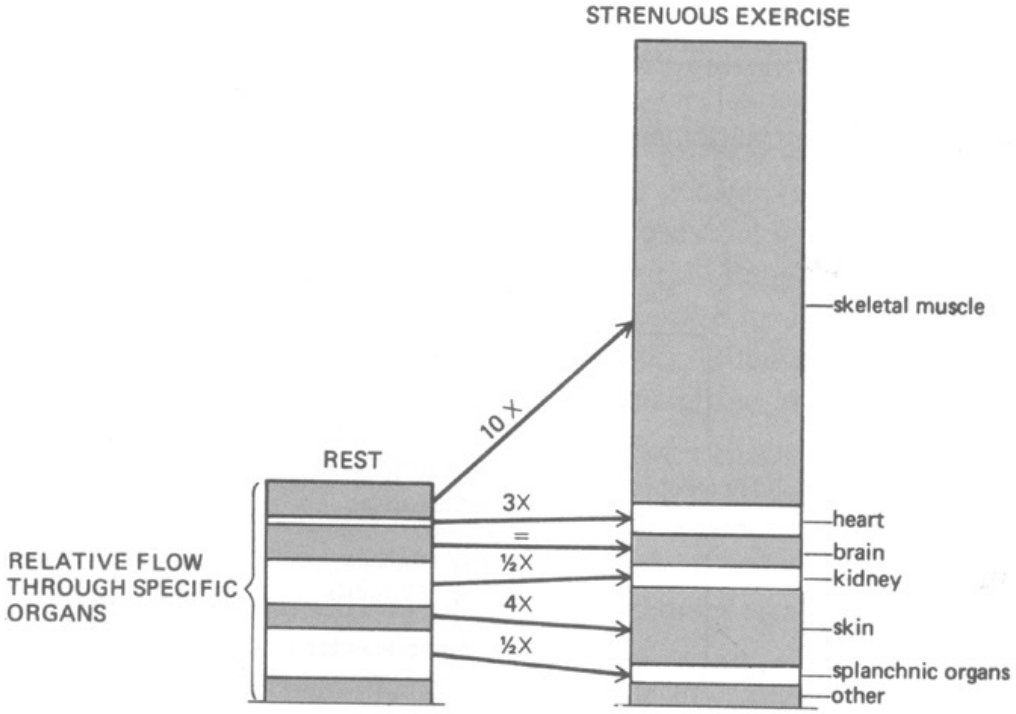


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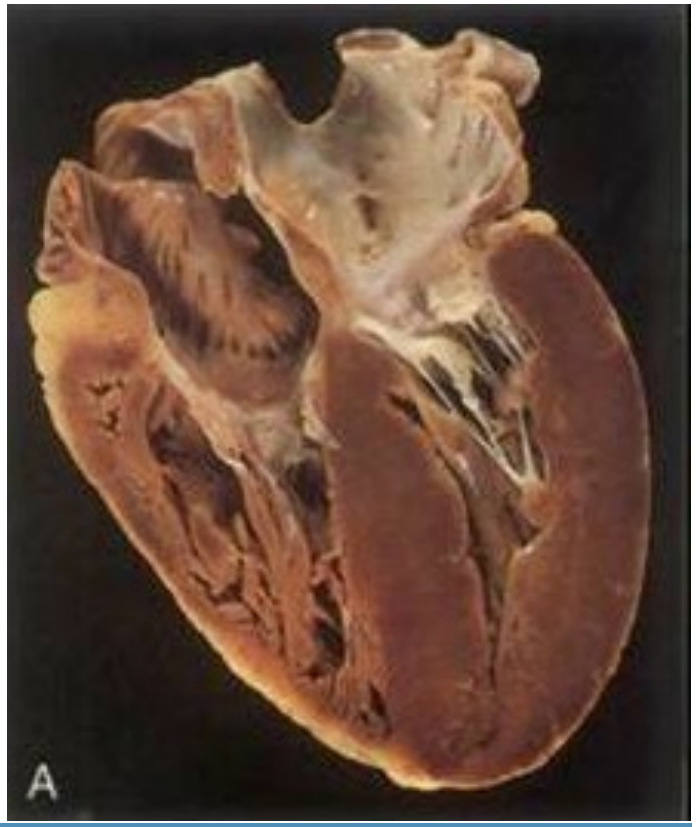
Figure 11-4 Cardiovascular adjustments to strenuous exercise.

Mormon and Heller, 1997

Cardiovascular Pathology Examples

- Cardiac Hypertrophy
  - Physiological – increased exercise, bigger and stronger heart
  - Pathological – pumping against increased pressure constantly, bigger and weaker heart



(Webpath)

Cardiovascular Pathology Examples

- Atherosclerosis – fatty deposits line the vessel wall and weaken/obstruct it
- Thrombosis – blood clots form that can obstruct vessels
- Heart Failure – cardiac output falls to low to pump blood through the body
- Hypertension – High blood pressure weakens the heart and vessels
- Aneurysms – Vessel rupture
- Arrythmias
  - Tachycardia – abnormal heart beat that is too fast (resting ≥ 100 bpm)
  - Bradycardia – abnormal heart beat that is too slow (resting ≥ 60 bpm)
  - Flutter – regular rapid circuits in the atrium; can lead to atrial fibrillation
  - Fibrillation – irregular heart rhythm that causes the atria to contract irregularly
  - Heart Block –a delay or complete block of electric impulse from the SA node (pacemaker)
- Heart Attack
- Stroke

https://www.doctorshealthpress.com/heart-health-articles/arrhythmia-causes-types-symptoms-treatments/#:~:text=Types%20of%20Arrhythmia%201%20Tachycardia.%20Tachycardia%20is%20a,circuits%20in%20the%20atrium.%20...%20More%20items...%20

Questions?

References

1. Cardiovascular Physiology, David E. Mohrman and Lois Jane Heller 1997
2. https://www.doctorshealthpress.com/heart-health-articles/arrhythmia-causes-types-symptoms-treatments/#:~:text=Types%20of%20Arrhythmia%201%20Tachycardia.%20Tachycardia%20is%20a,circuits%20in%20the%20atrium.%20...%20More%20items...%20
3. https://www.humpath.com/spip.php?article3277
4. https://www.dreamstime.com/stock-photo-blood-plasma-formed-elements-test-tube-composition-whole-hematocrit-red-cells-erythrocytes-white-cells-image37786150
5. https://webpath.med.utah.edu
6. https://www.youtube.com/watch?v=GMBSU-2GK3E