ME 498 / ME 599

Biological Frameworks for Engineers

Class Organization

- HW7 assigned
- Exam 2 will be assigned on Wed
- Tiny Workhorse presentations

Who?	What?	When?
Alex	Actin	Nov 30th
Adam	Dynein	Nov 30th
Brian	F0F1-ATPase	Nov 30th
Kevin	Kinesin	Dec 2nd
Grier	Myosin II	Dec 2nd
Evan	Prestin	Dec 2nd

Biological Frameworks for Engineers

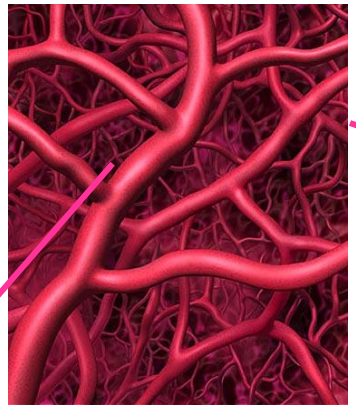
ME 498 / ME 599

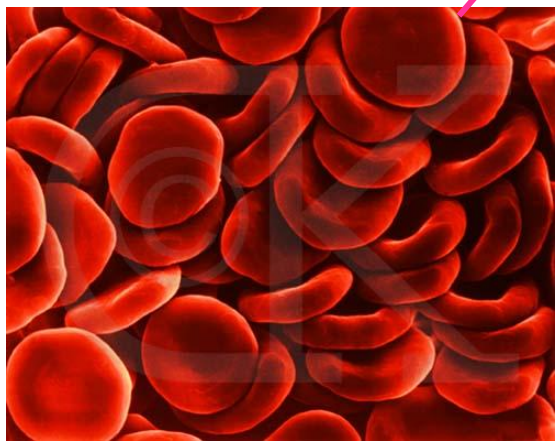
Cardiovascular System

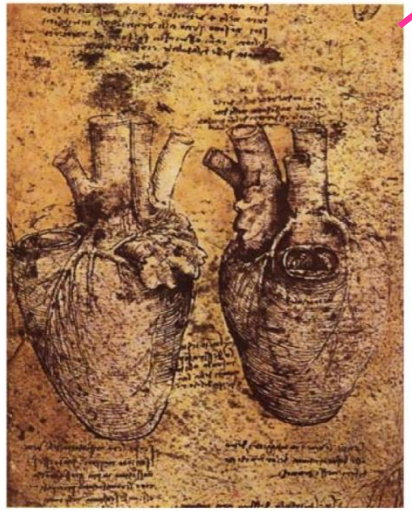
UNIVERSITY OF WASHINGTON

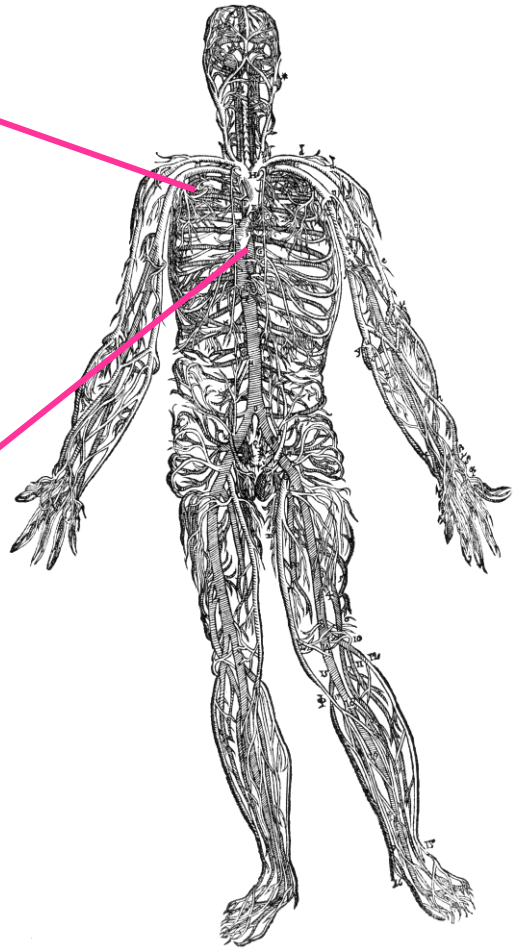
System

- Blood
- Blood vessels
- Heart



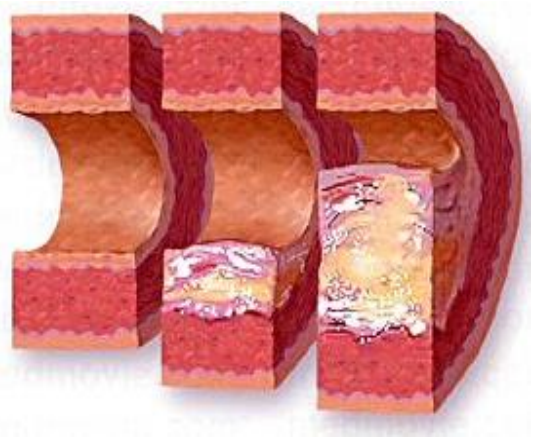




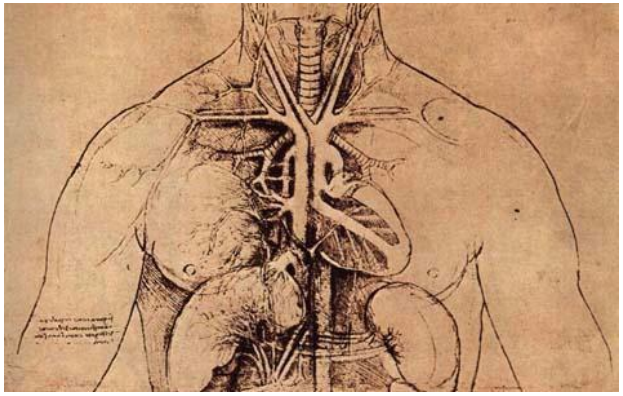


Function

- Transport
- Protective
- Regulatory

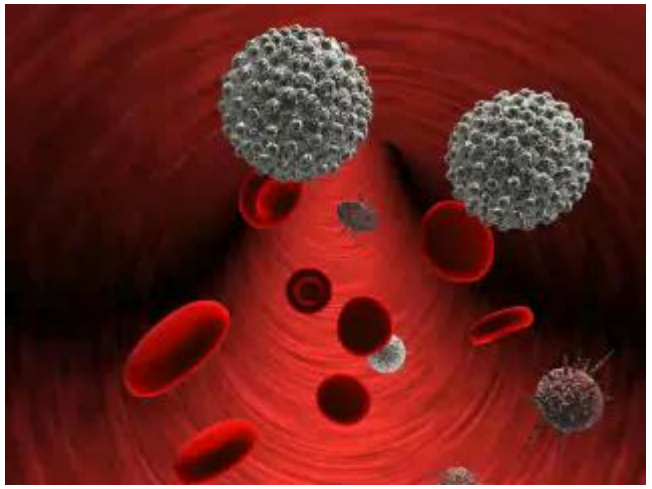


Atherosclerosis



Rusty Pipe?

Blood Composition



Plasma - 55% (v/v)

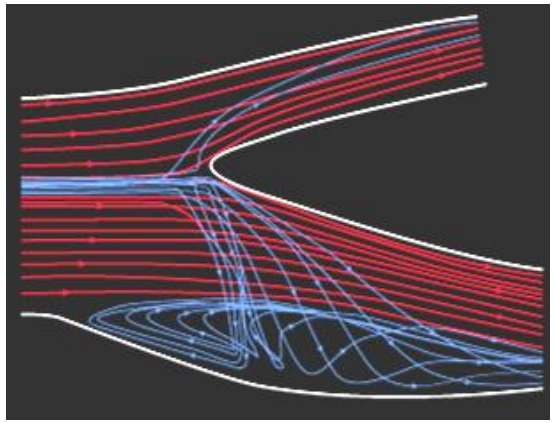
- water - 91-92%
- proteins - 7-8% (albumin, antibodies, fibrinogen)

Cells - 45% (v/v)

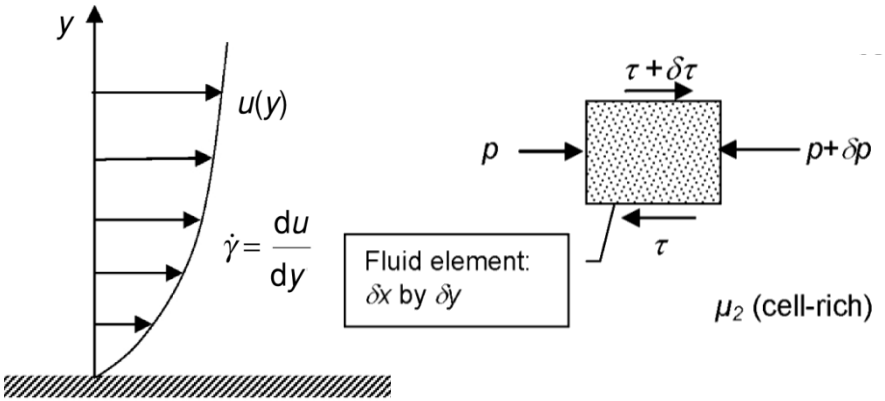
- Erythrocytes (red blood cells - RBC) – about 5 billion/mL. 8 μm disc dia. Marrow produces 2.5 million/sec. Flexible. Anuclear.
- Leukocytes (white blood cells - WBC) – about 4-11 million/mL. 7-22 μm round dia. Uni- or polynuclear
- Thrombocytes (platelets) – about 0.25-0.5 billion/mL. 2-4 μm disc dia. Anuclear.

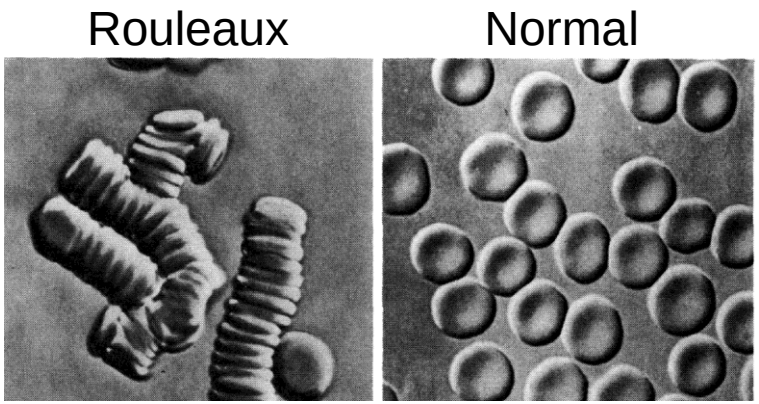
Hemodynamics

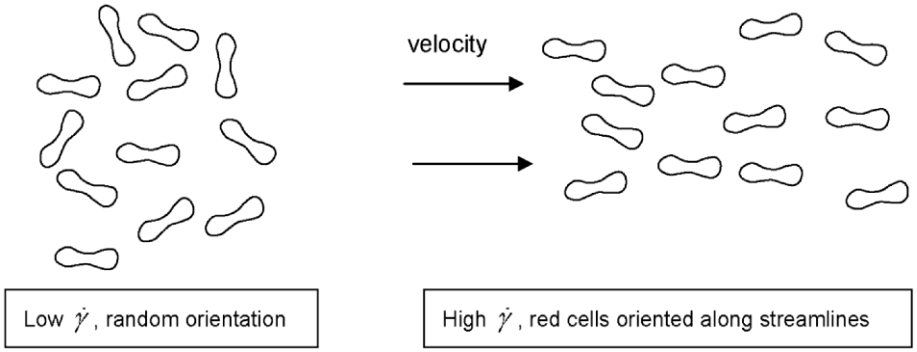
- Viscous
- Non-Newtonian
- Pseudo-plastic
- Laminar and Turbulent
- Spatially and Temporally Changing



Blood Rheology

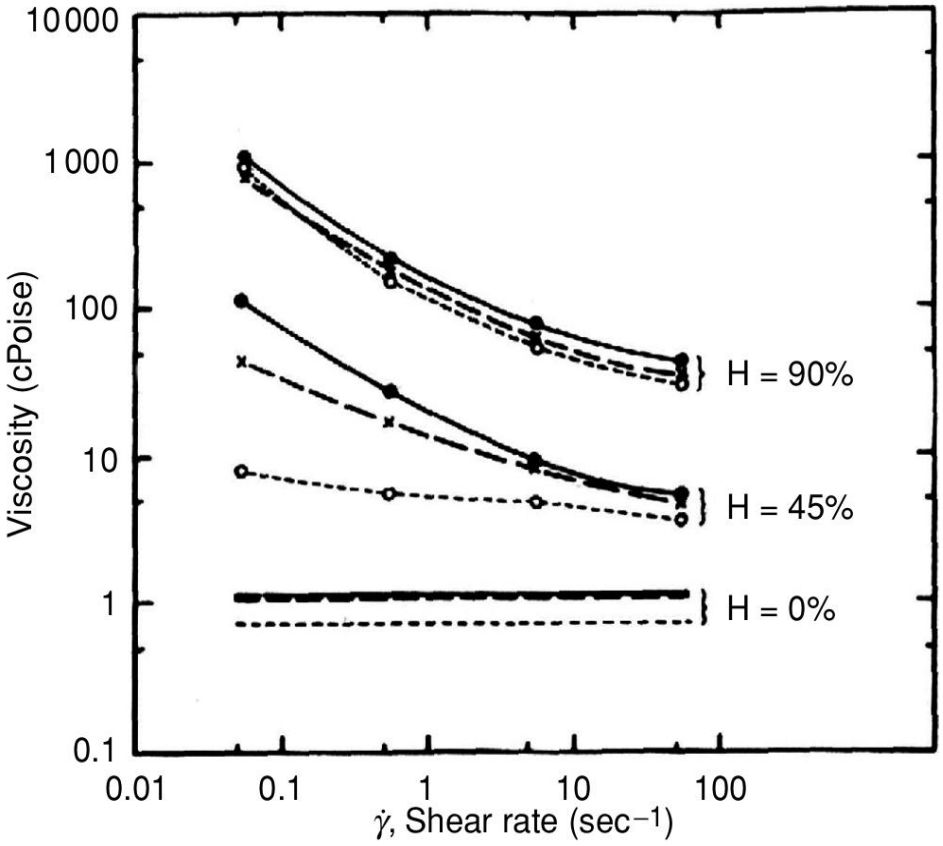






Characteristic	Low shear rate	High shear rate
Rouleaux behavior	Rouleaux formation enhanced; effective viscosity μ_{eff} is increased	Rouleaux break up; effective viscosity μ_{eff} is decreased
Individual red cell orientation	Red cells are randomly oriented; μ_{eff} is increased	Red cells are aligned with streamlines; μ_{eff} is decreased

Blood Viscosity



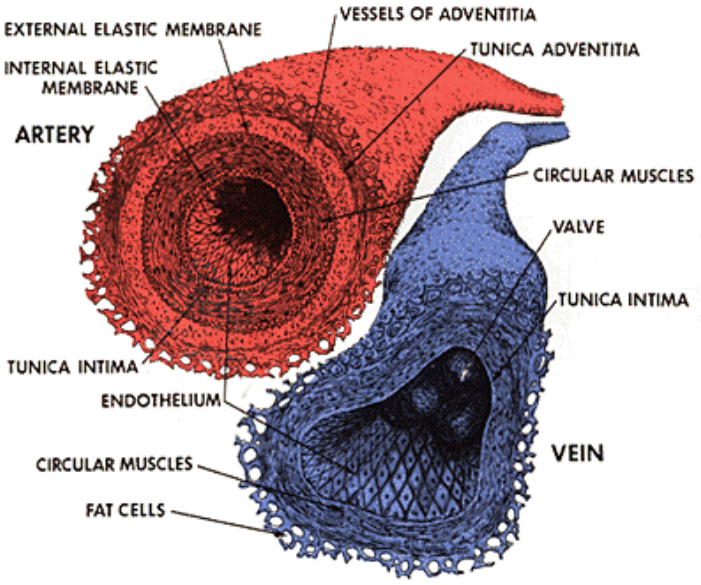
μ_{plasma} = 1.2 cP

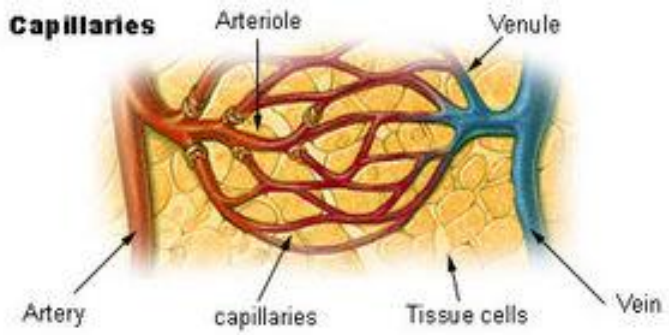
10 Poise = Pa*s

Plot of effective viscosity versus shear rate for blood of differing hematocrits (H). Note the Newtonian behavior of the fluid at zero hematocrit, and the logarithmic vertical scale. •, whole blood; ×, defibrinated blood (i.e., blood from which the clotting protein fibrinogen has been removed); ○, washed cells in Ringer's solution. The points are determined from a fifth-order polynomial curve fit to experimental data. From Chien *et al.* J App Physiol, **21** (1966), 81-87.

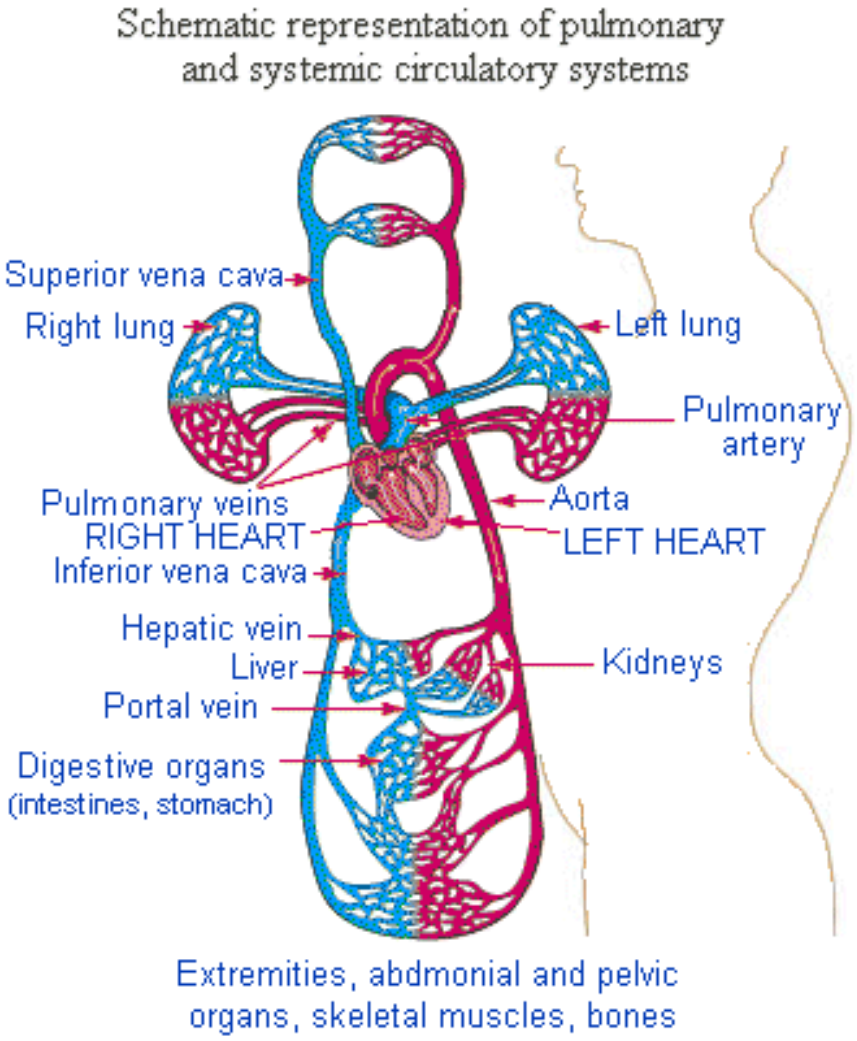
Anatomy - Vasculature

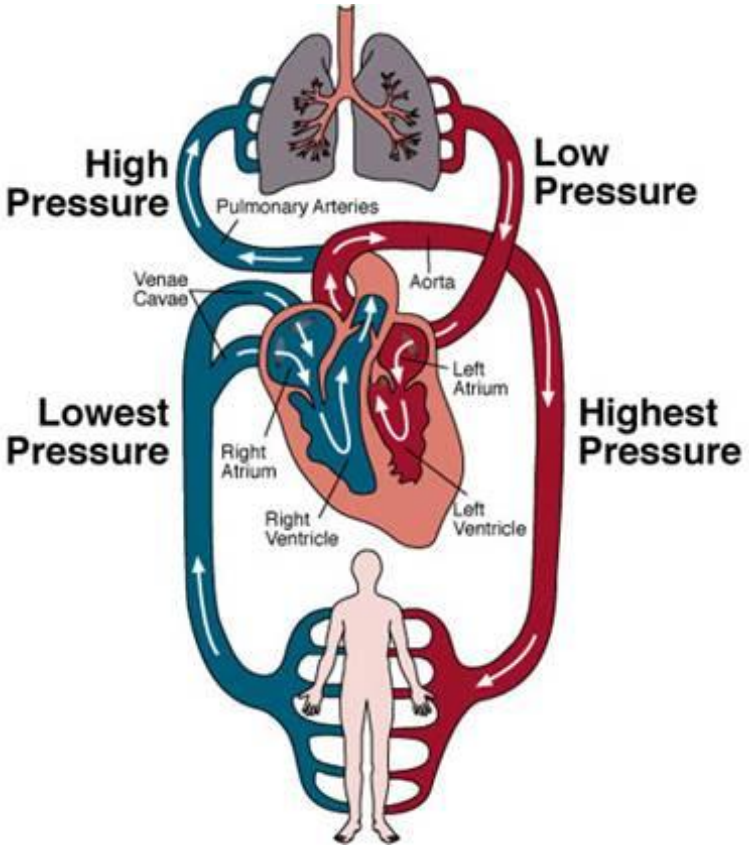
- Arteries
  - Thick walled, pressure reservoir
  - Collagen, elastin and smooth muscle cladding
- Arterioles
  - Determines most of the resistance of the system (smooth muscle)
  - Major role in determining rate of flow to different tissues
- Capillaries
  - Site of exchange between blood and tissues
  - Thinnest, most porous walls
  - 40,000 km of capillaries in adult human
- Venules
  - Small vessel carries deoxygenated blood
  - Formed by joining of several capillaries
  - Porous sites where WBCs emigrate to inflammed or infected tissue
- Veins
  - Larger diameter, Volume reservoir (~2/3)
  - Lowest blood pressure
  - Flap-like valves because blood runs against gravity back to heart



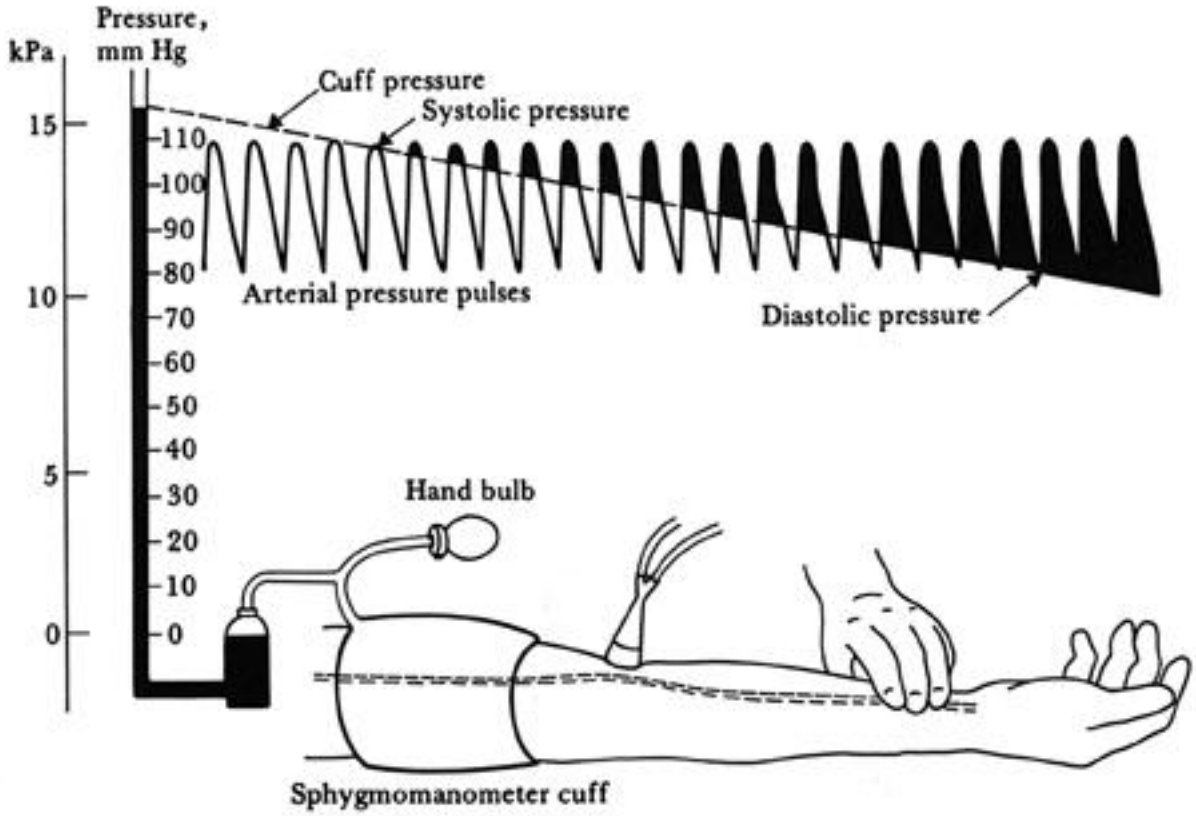


Cardiovascular Anatomy





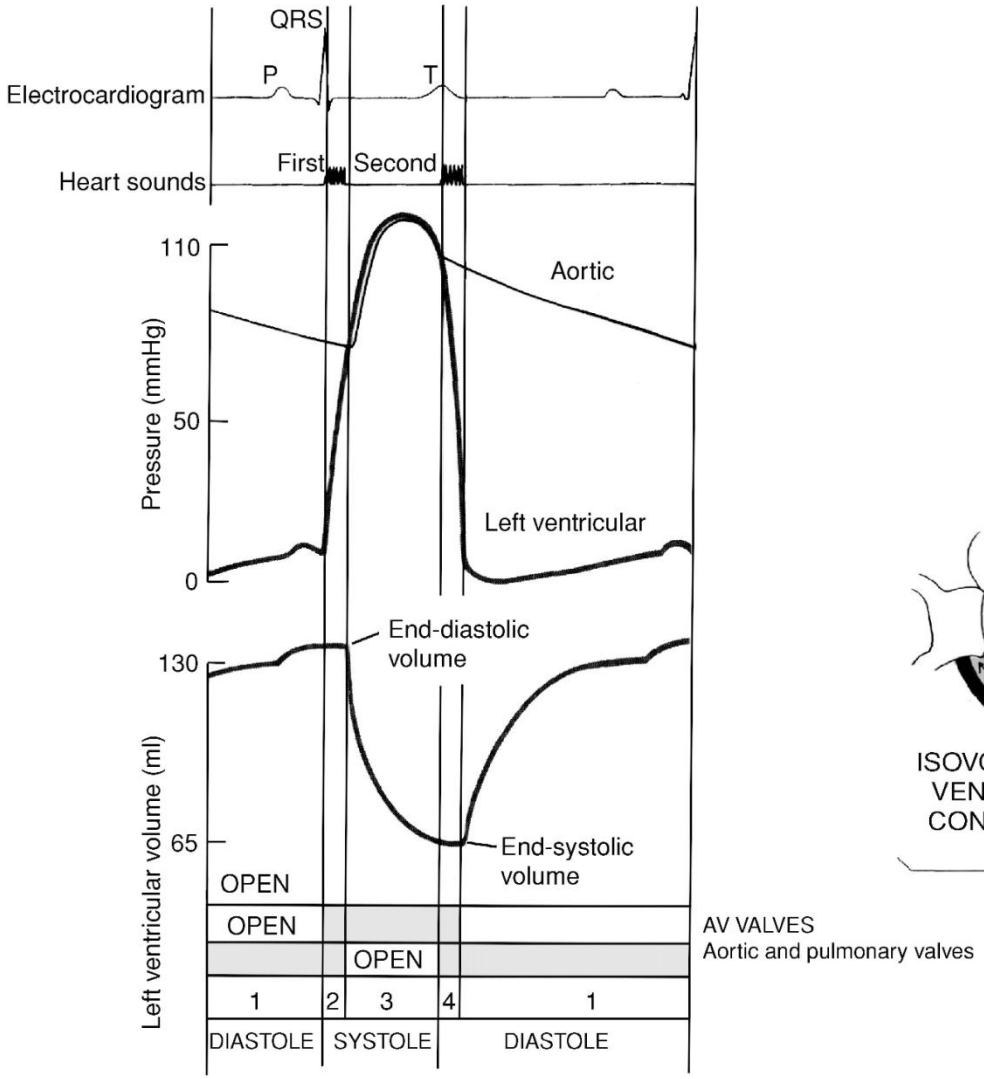
Blood Pressure Measurement

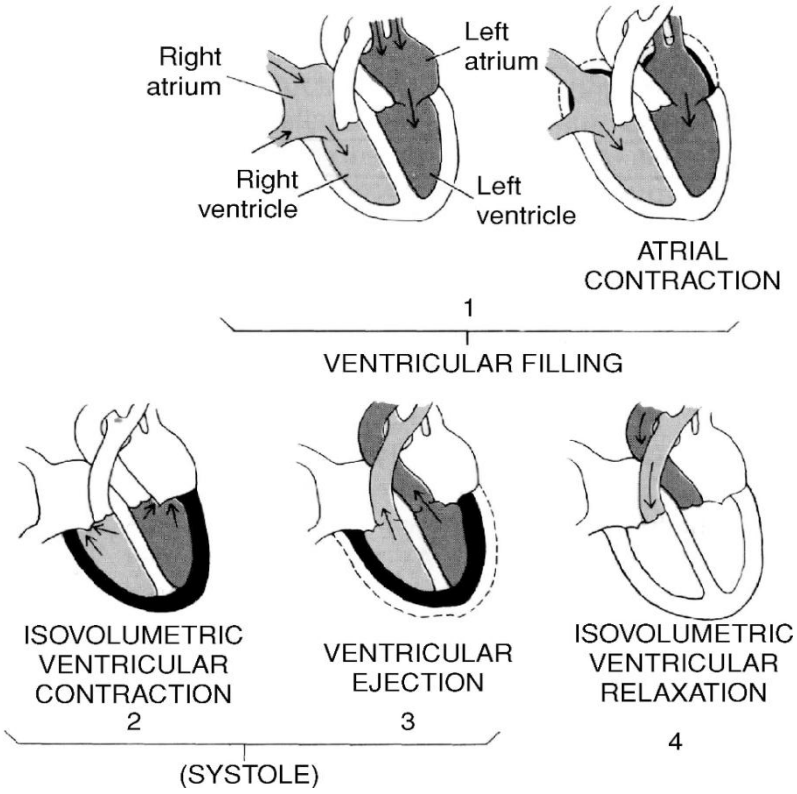


Ventral contraction

Ventral relaxation

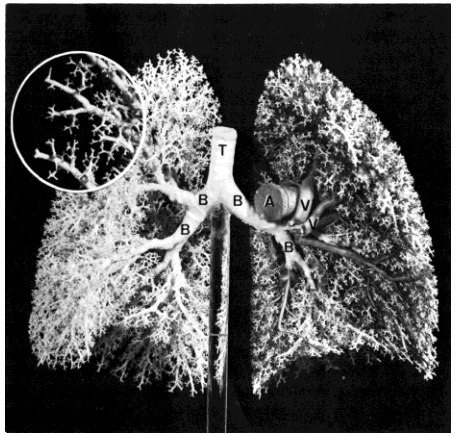
Cardiac Cycle



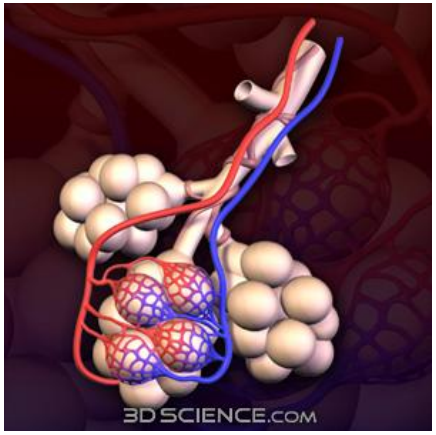


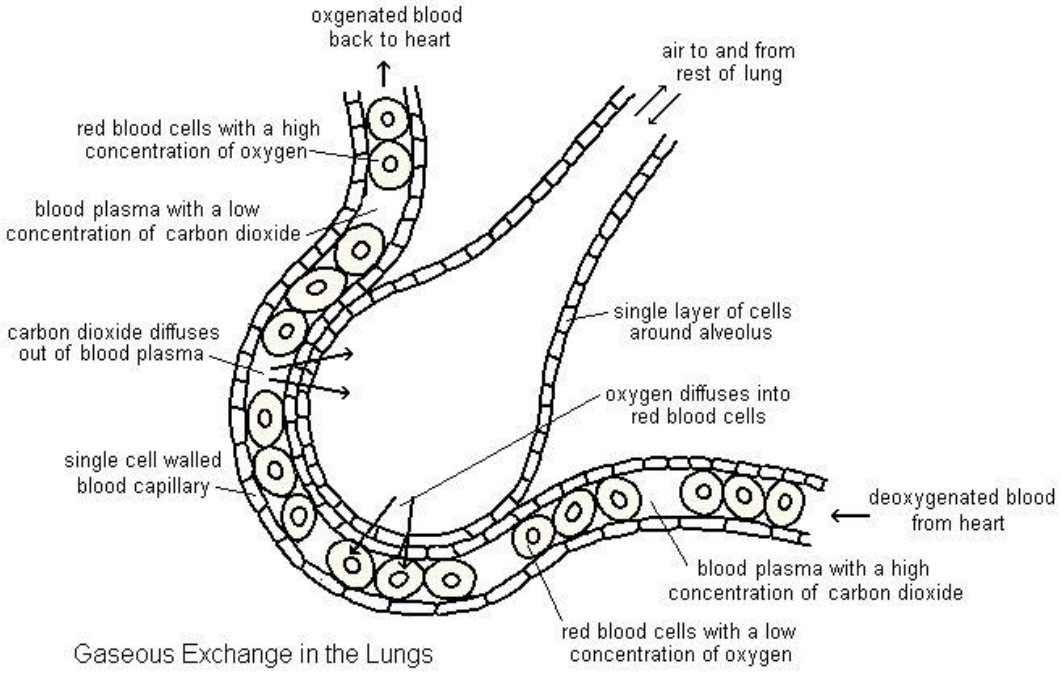
Pulmonary Cycle

Airways

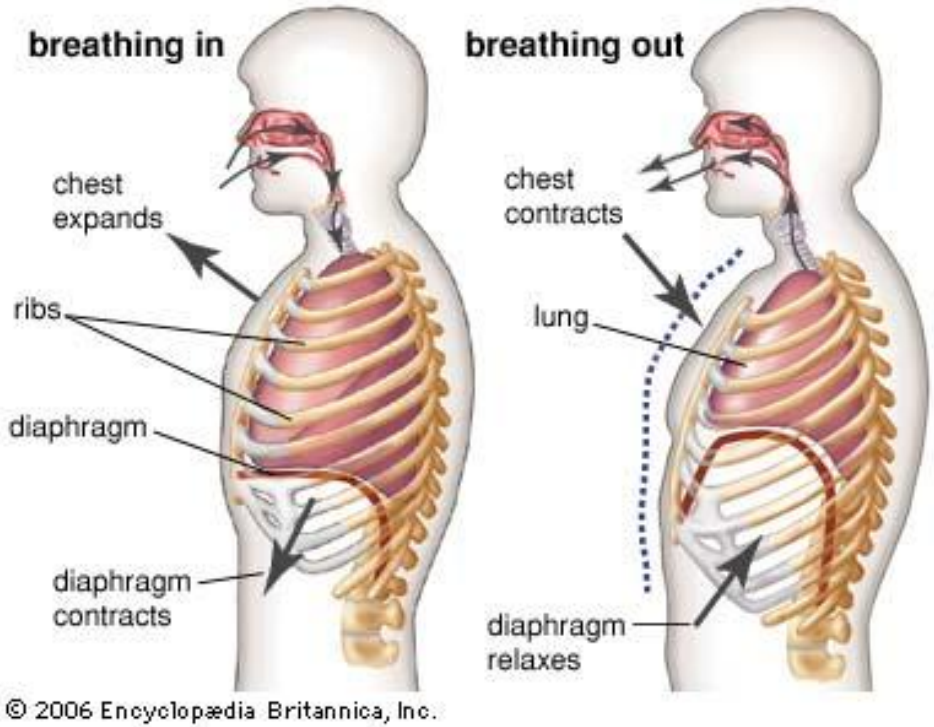


Alveoli





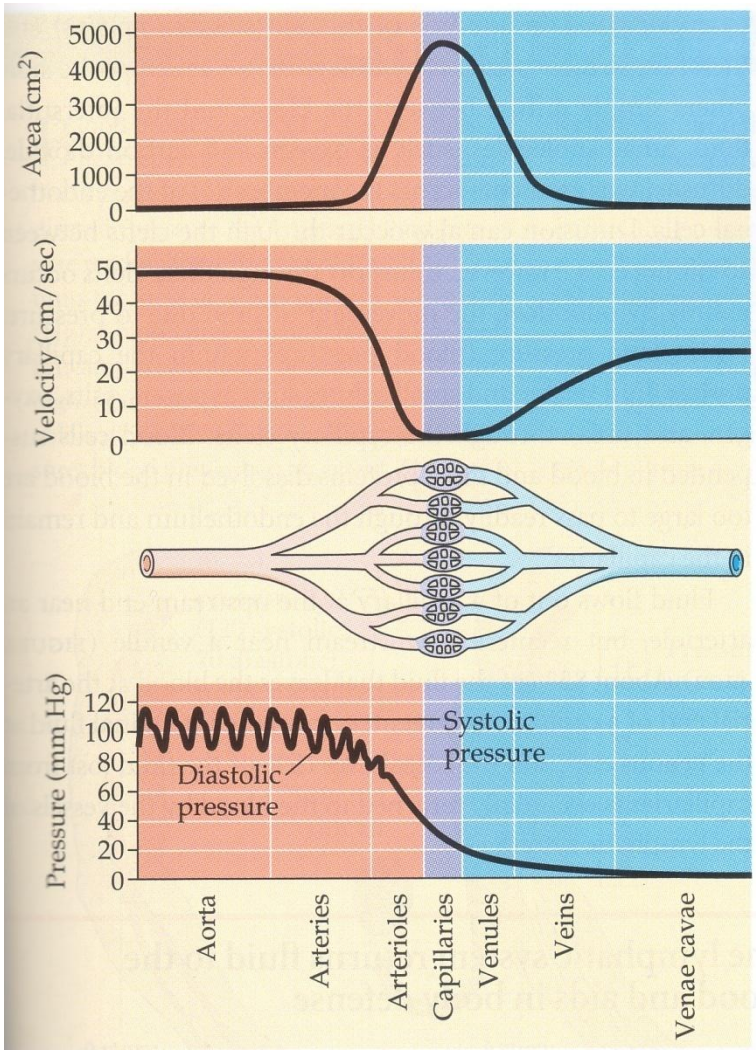
Pulmonary Cycle



Closely regulated, involuntary reflex

- Nerve endings in aorta and carotid arteries sense gas composition (O_2, CO_2)
- Medulla cross-references with brain tissue levels
- O_2 drop or CO_2 rise triggers respiratory muscles (diaphragm and intercostals) and increased heart rate

Modeling the System



R -inversely proportional to the A^2

Q -inversely proportional to the L
-proportional to P and A

P -driving force from heart
-proportional to Q and R

Modeling the System

- Blood pressure = Cardiac output x Peripheral vascular resistance
  - (BP = CO x PVR)
- Cardiac output = Blood Velocity
  - (CO = HR x SV)
- Blood Velocity (Poiseuille's Law)
  - (CO = Q = $\pi(P_1-P_2)R^4/8\mu L$)
- Vascular Resistance
  - (PVR = $8\pi\mu L/A^2$)

Questions?