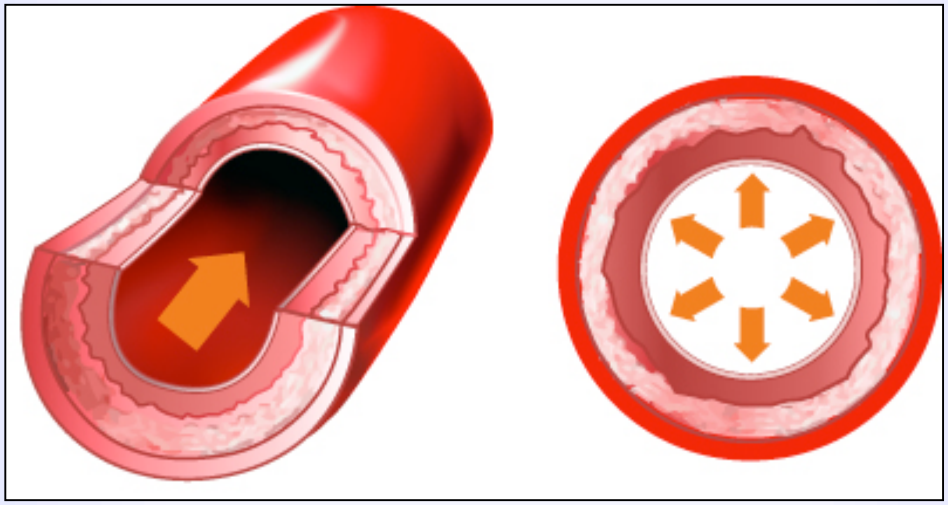
Vascular mechanics modeling

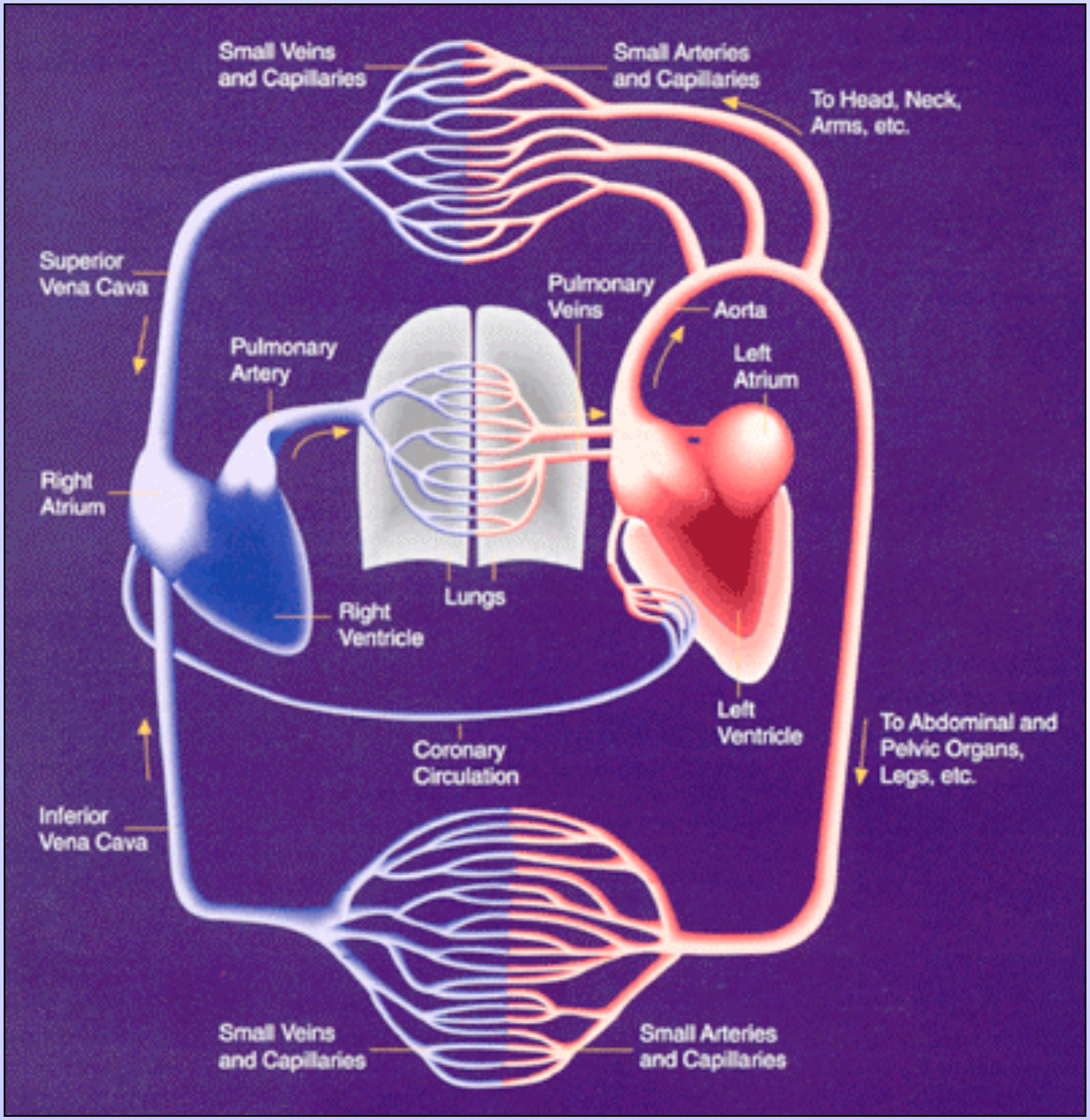


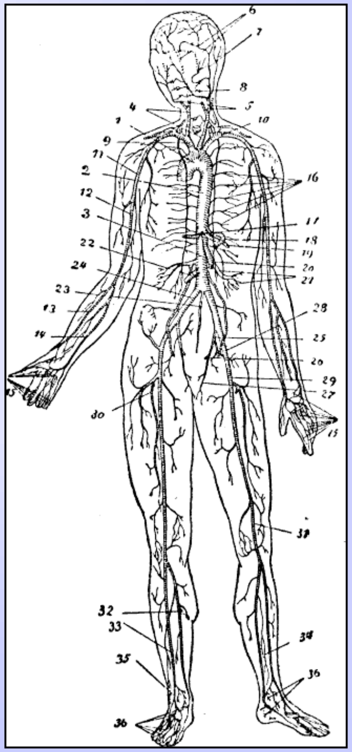
Maxwell Neal

NSR Modeling Course

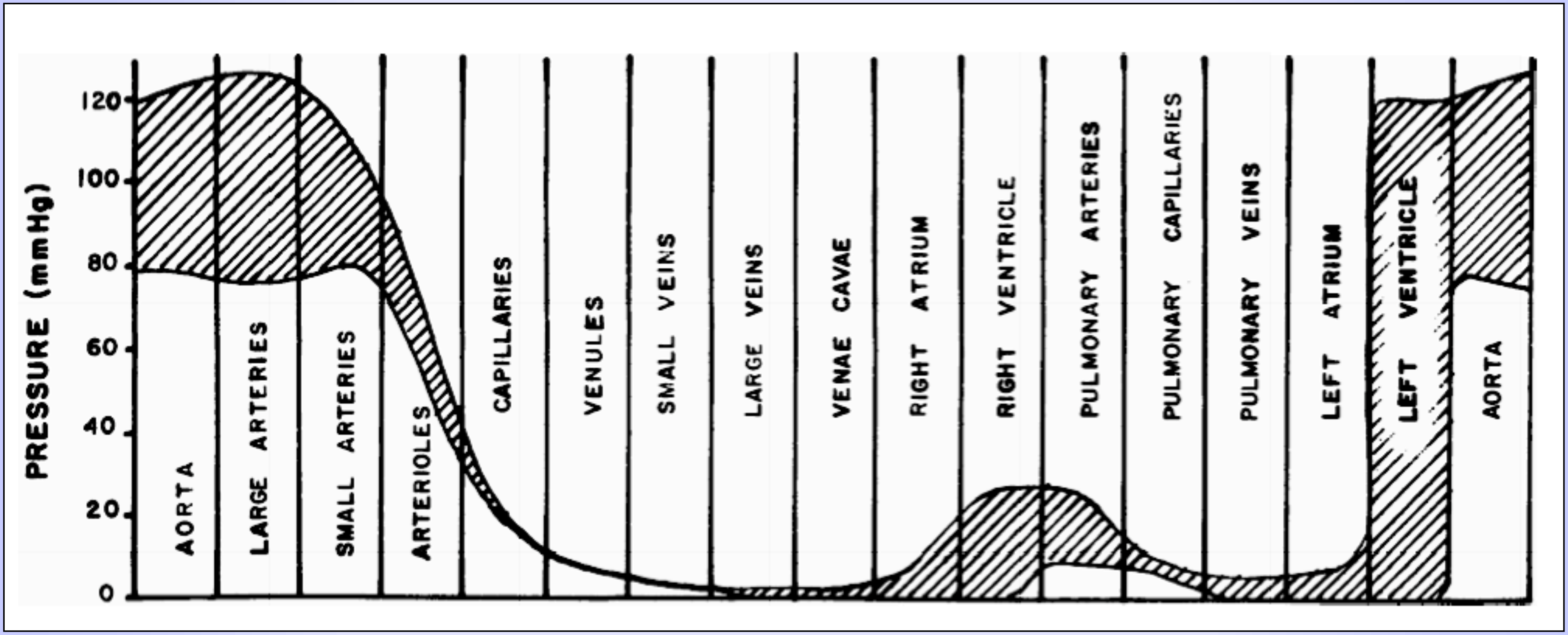
Aug 29th, 2008

The human cardiovascular system

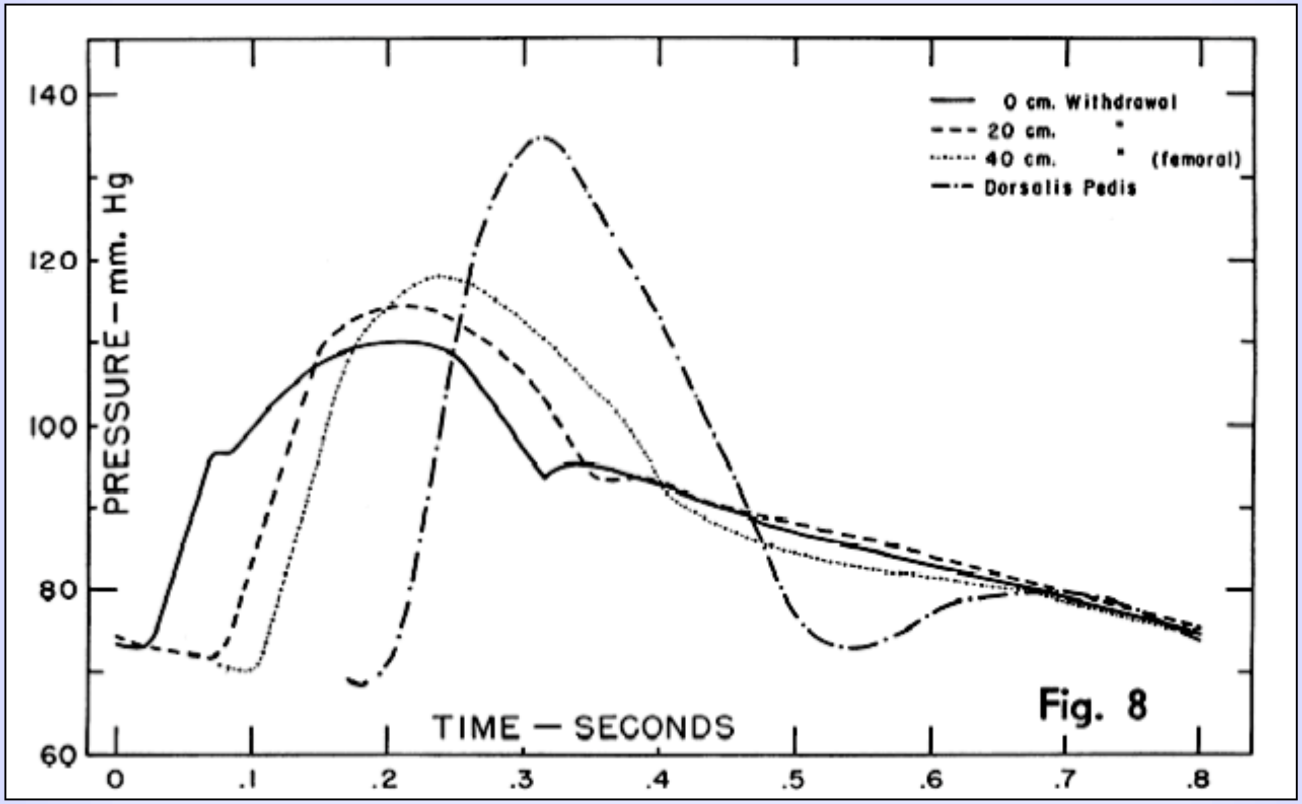




Blood pressures in the systemic circulation

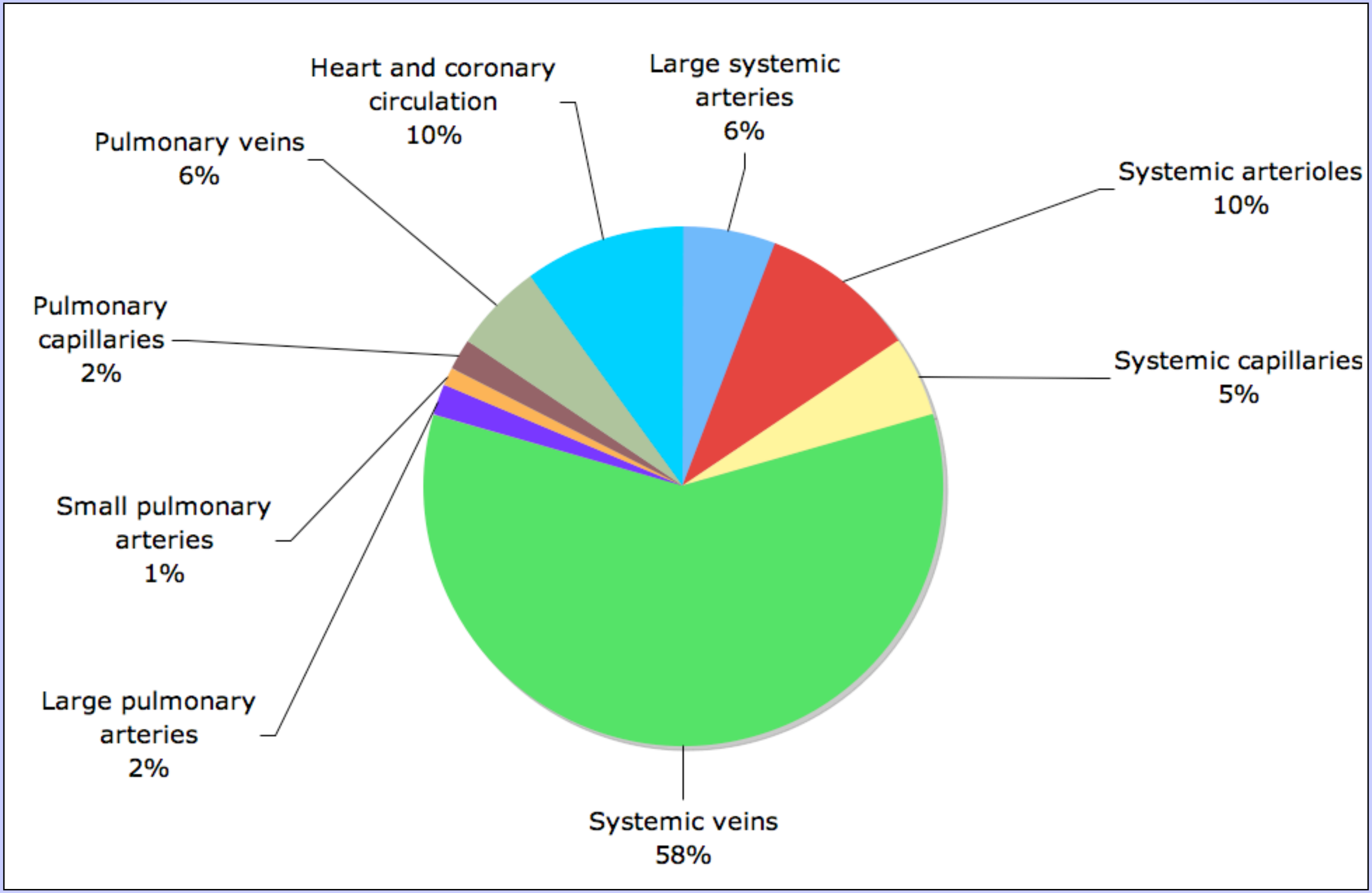


Wave reflections in the arterial tree amplify the arterial pulse pressure



From Remington and Wood*. J. Applied Physiology.* 1956

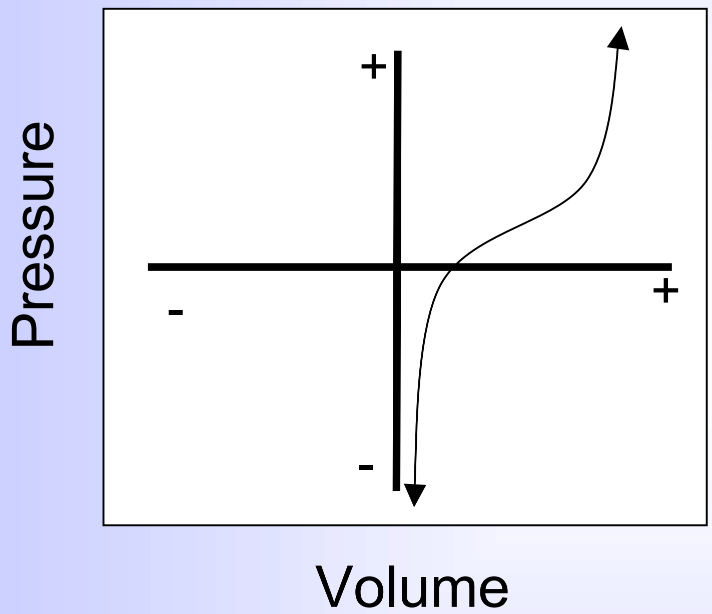
Distribution of blood volumes throughout the circulation

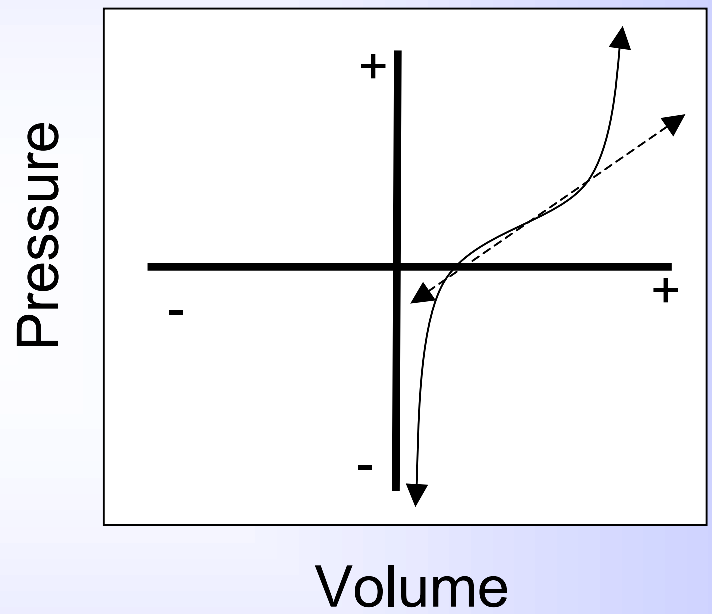


Distribution of blood flows throughout the circulation

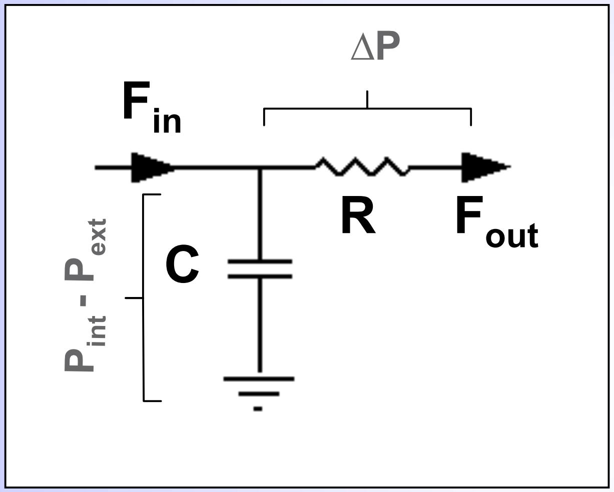
Compartment	% of total cardiac output
Coronary circulation	4
Cerebral circulation	12
Peripheral circulation	84
Pulmonary circulation	100

Pressure-volume curves of circulatory vessels are curvilinear but models often use linear approximations





The 3-element Windkessel uses circuit laws to simulate a compliant tube



Analogs

Charge : Volume (V)

Voltage : Pressure drop (Pd)

Current : Flow (F)

Capacitance : Compliance (E)

(1/Capacitance = Elastance)

Ohm's Law for fluids

$$F_{out} = \Delta P/R$$

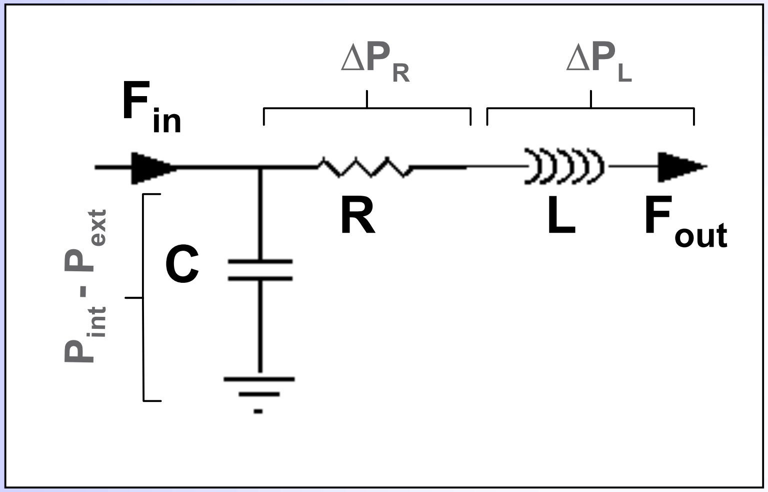
Law of compliance

$$P_{int} - P_{ext} = (V - V_{rest})/C$$

Kirchoff's Conservation Law

$$dV/dt = F_{in} - F_{out}$$

The 4-element Windkessel adds fluid momentum



Analogs

Charge : Volume (V)

Voltage : Pressure drop (Pd)

Current : Flow (F)

Capacitance : Compliance (E)

(1/Capacitance = Elastance)

Inductance : Inertance

Ohm's Law for fluids

$$F_{out} = \Delta P_R / R$$

Law of compliance

$$P_{int} - P_{ext} = (V - V_{rest})/C$$

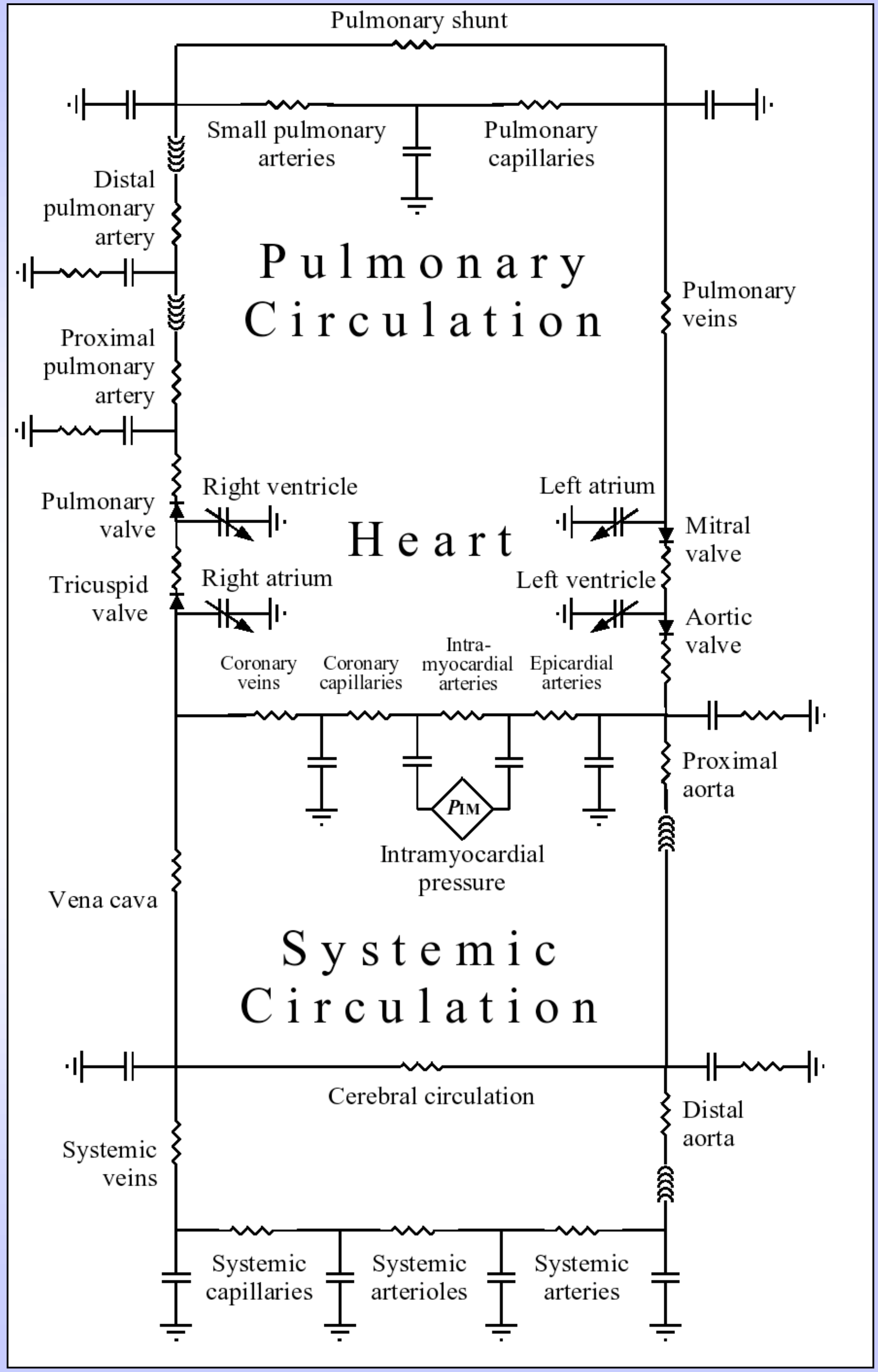
Law of inertance

$$dF_{out}/dt = \Delta P_L / L$$

Kirchoff's Conservation Law

$$dV/dt = F_{in} - F_{out}$$

Electrical analog schematic of spheart.proj



More detailed models of the arterial tree have been used to simulate pulse pressure amplification

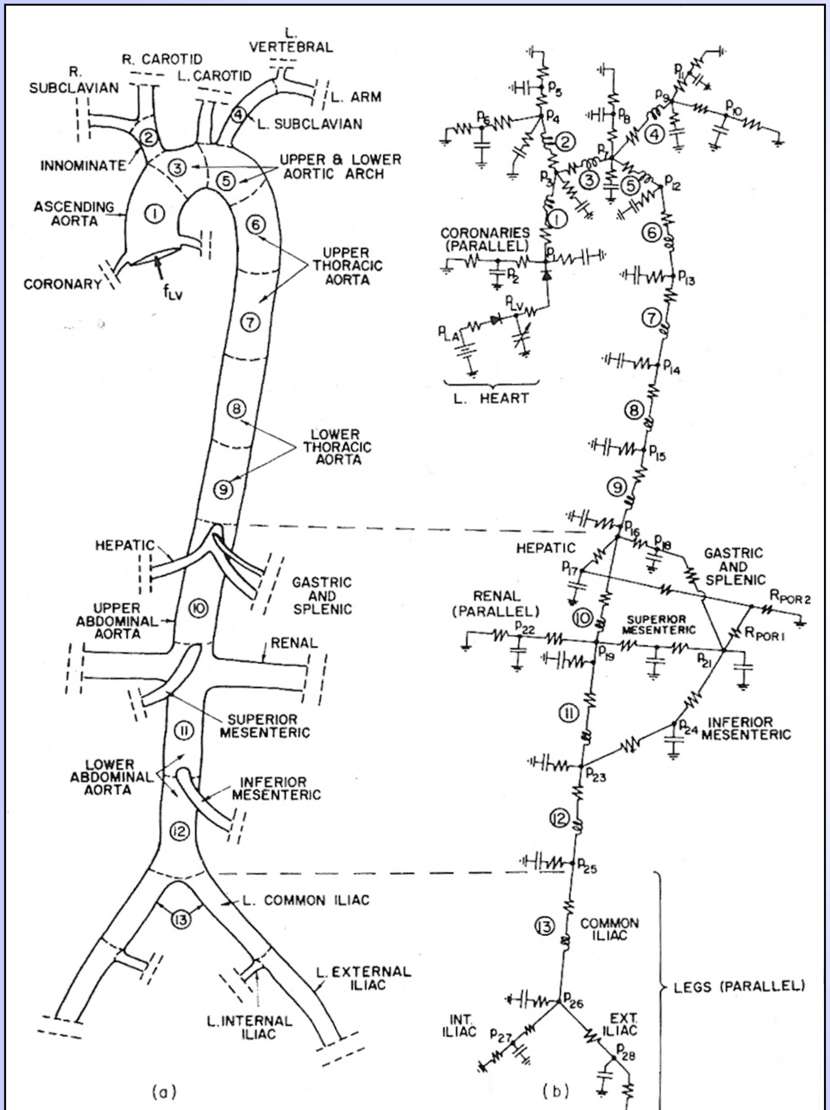
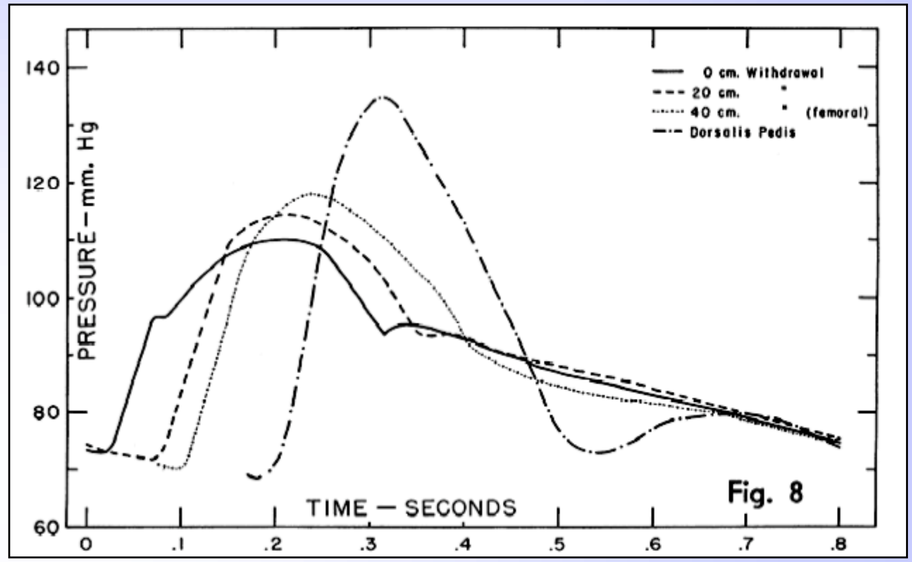
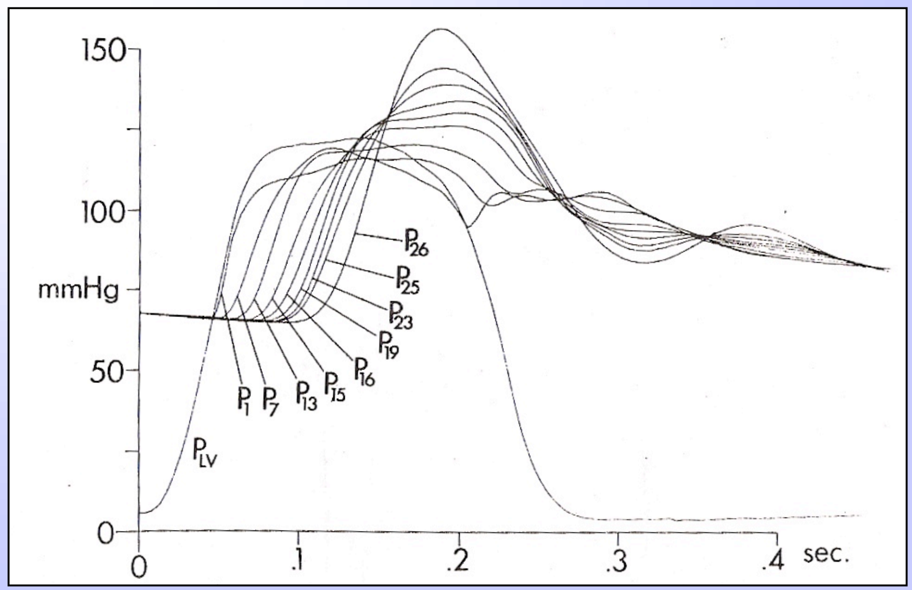


Fig. 1. (a) Human systemic arterial system showing division into segments for modeling. (b) Lumped fluid-circuit representation.

Data

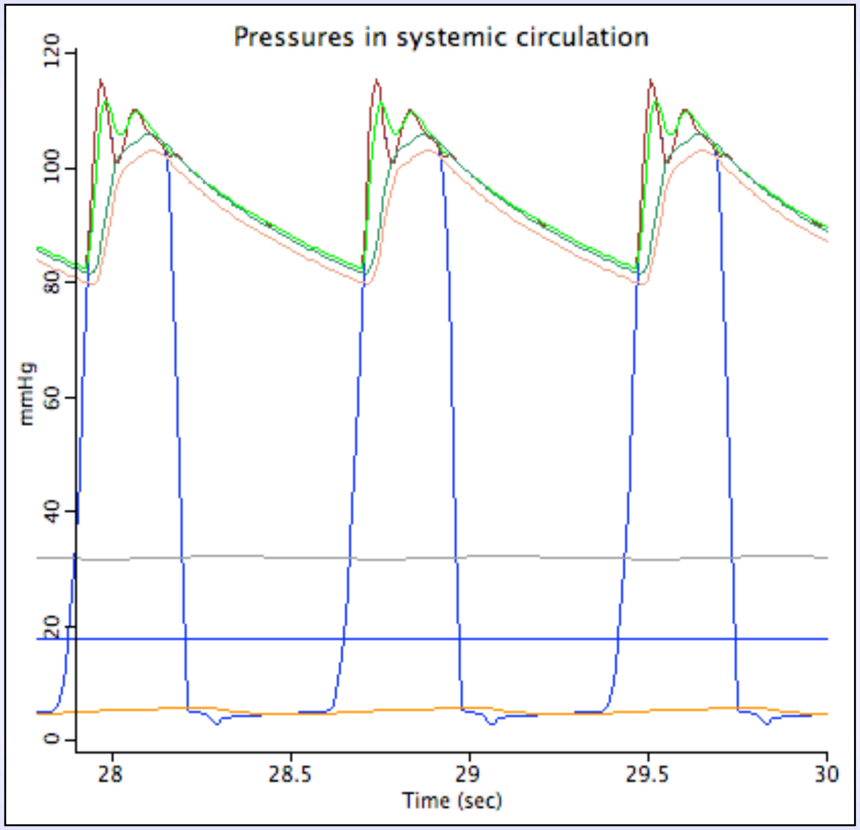


Simulation



From Snyder and Rideout. *J. Biomechanics*. 1968

Time to open spheart_1.proj

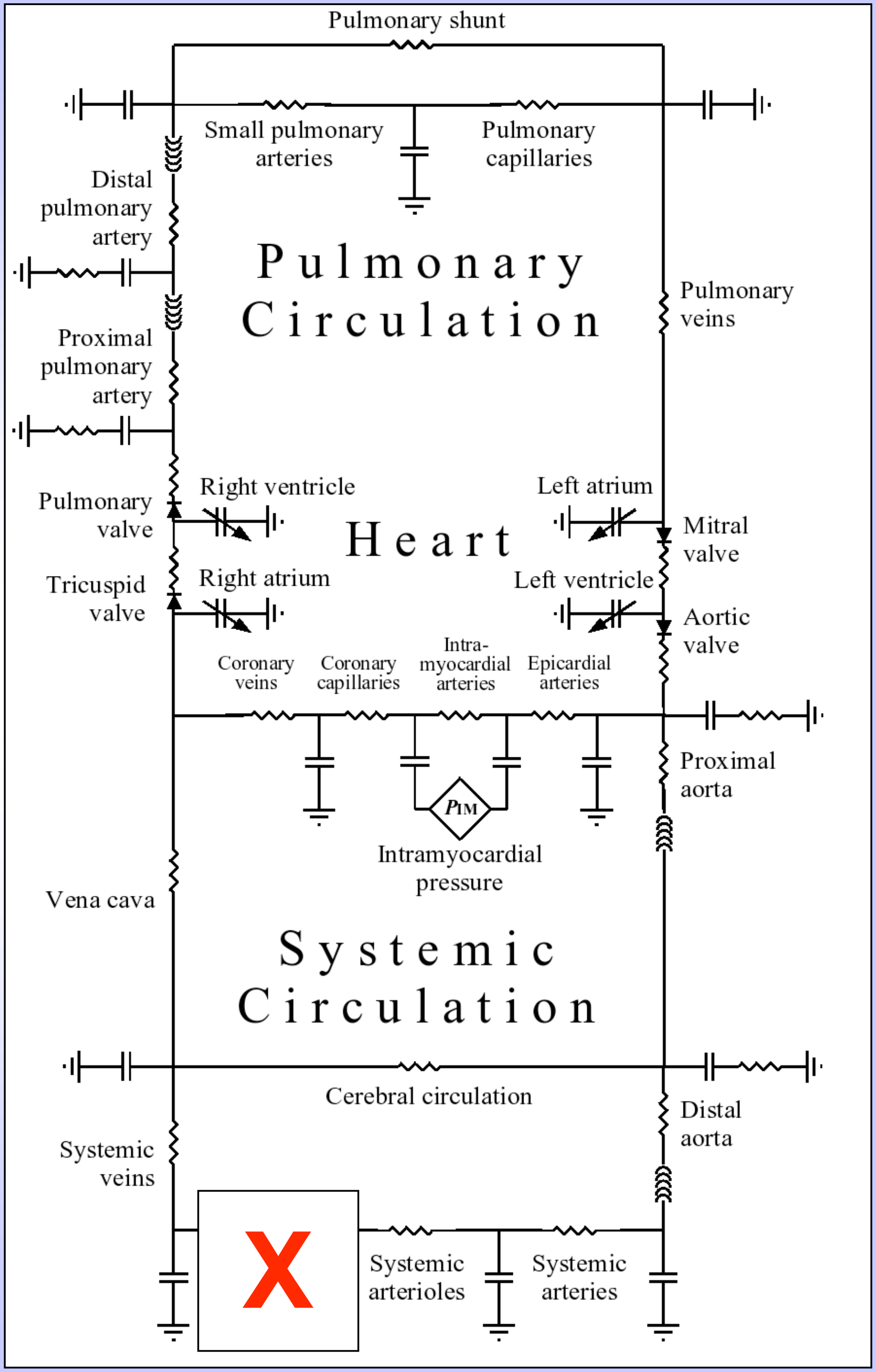


Electrical analog schematic of spheart_1.proj

Your mission:

Code a new 3-element Windkessel with volume-dependent resistance for the peripheral systemic capillary segment.

Use Poiseuille's Law and the Law of parallel resistors to estimate the number of capillaries in this segment.

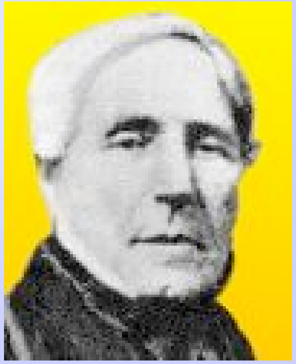


Poiseuille's Law relates fluid resistance to vessel length, vessel radius, and fluid viscosity.

$$\Delta P = 8*Len_e*Visc * F / \pi*r^4$$

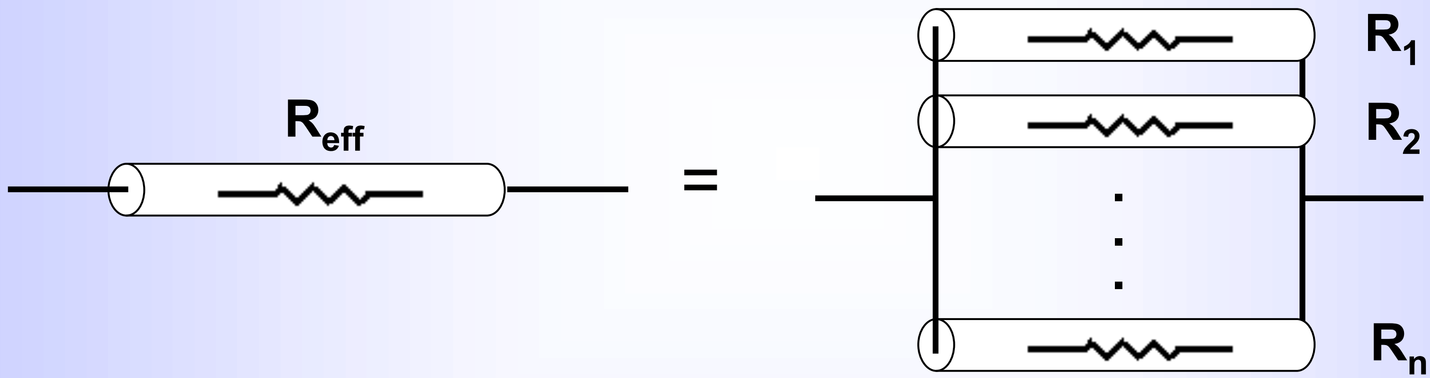
or

$$\mathbf{R = 8*Len_e*Visc / \pi*r^4}$$



The law of parallel resistors

$$1/R_{eff} = 1/R_1 + 1/R_2 \ldots + 1/R_n$$



If all n parallel resistances are equal

$$\mathbf{R_{eff} = R_1/n}$$

Use a 3-element Windkessel capillary segment in spheart_1.proj to estimate the number of capillaries in the human peripheral circulation

Declare time-dependent variables (use these codewords):

•Radius of one capillary (um): **rcap**

•Volume of all peripheral capillaries (ml): **Vsc**

•Lumped resistance of capillary segment (mmHg*sec/ml): **Rsc**

•Internal pressure for capillaries (mmHg): **Psc**

•Blood flow through capillaries (ml/sec): **Fsc**

Declare constant parameters (your own codewords):

•Blood viscosity (cp): **5**

•Capillary length (cm): **0.286**

•Initial systemic capillaries volume: **256** (requires a *when(t=t.min) { }* statement)

•Lumped capillary compliance (ml/mmHg): **7.98**

•Total number of capillaries: *???*

Ohm's Law for fluids

$$F_{out} = \Delta P/R$$

Law of compliance

$$P_{int} - P_{ext} = (V-V_{rest})/C$$

Kirchoff's Conservation Law

$$dV/dt = F_{in} - F_{out}$$

Poiseuille's Law of resistance

$$R = 8*Len*Visc / \pi*r^4$$

Volume of one cylinder

$$V = Len *\pi*r^2$$

Law of identical resistors in parallel

$$R_{eff} = R_1/n$$

ASSIGNMENT: Use the equations on the right to solve the variables listed above. Get the model to compile and run. Adjust the number of capillaries until Psc stabilizes around 32 mmHg in the steady state.

Assumptions:

•All capillaries are in parallel

•All capillaries have the same geometry

•All capillaries are cylindrical

•Pressure external to the capillaries is zero

•Unstressed capillary volume is zero

****Super awesome extra bonus points for using the JSim optimizer to estimate the number of capillaries!****