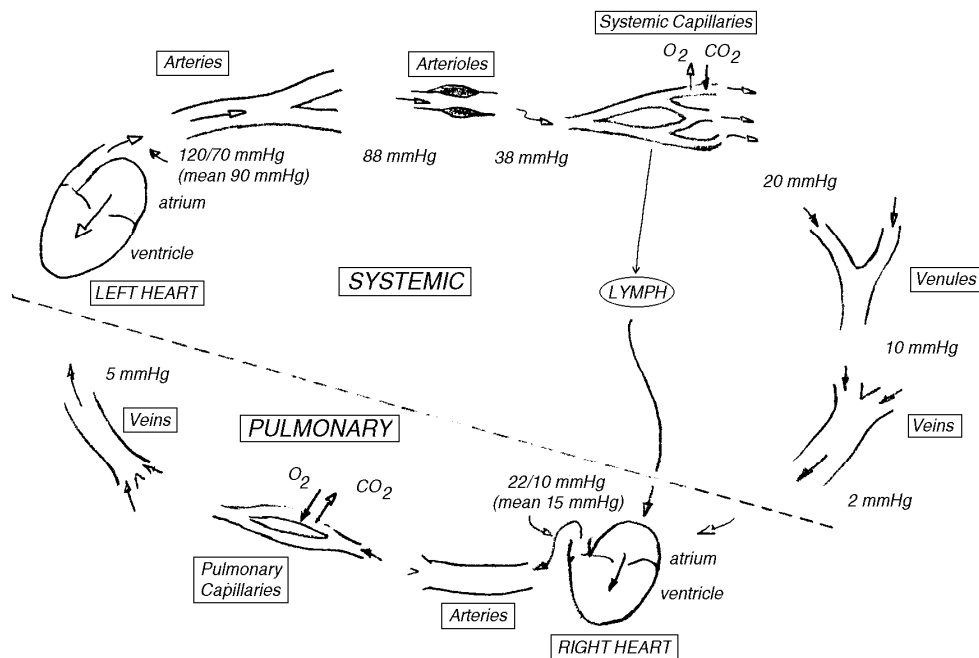


## INTRODUCTION

### A. Cardiovascular System Functions

1. Transport metabolic substrates from their source (e.g. alimentary tract, lungs, liver) to the tissues that utilize them (e.g. muscles, brain)
2. Transport metabolic end products (e.g. carbon dioxide, urea, heat) to the organs that dispose of them (e.g. lungs, kidneys, liver, skin)
3. Transport endocrines from the organs that secrete them to their target tissues
4. Provide a short diffusion distance between the vascular system and the cells
5. Contribute to maintaining the consistency of the cells' internal environment (e.g. interstitial fluid) – Homeostasis

### B. General Schematic (note pressure drop from arteries to veins)



### C. Components

1. **Heart:** develop the pressure needed to move blood around the cardiovascular system (overcome blood viscosity); continuously refresh capillary blood
2. **Arteries:** distribute blood pumped by the heart to the microvascular bed
3. **Arterioles** and associated structures: sites of controlled resistance; control the flow to individual vascular beds
4. **Capillaries:** exchange material between blood and interstitial fluid
5. **Venules** and **Veins:** collect blood from vascular beds and return it to the heart
6. **Lymphatics:** collect fluid and other substances from tissue and return it to the circulation

INTRODUCTION (continued)

D. Pressure, Flow, and Resistance

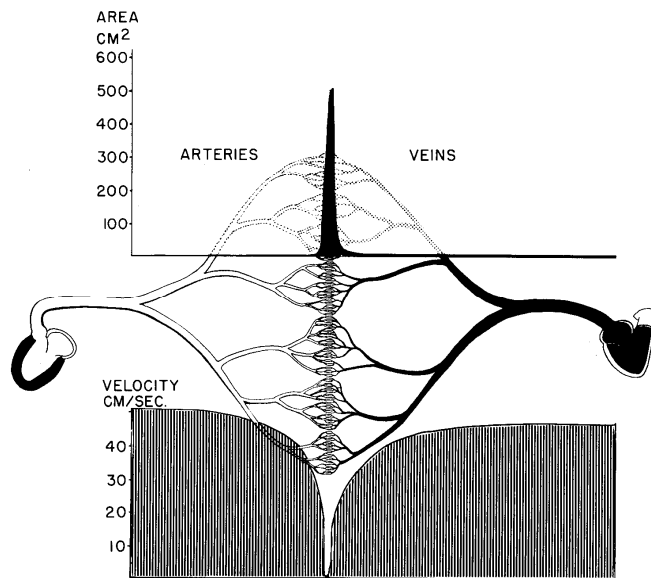
1. Pressure: Force/Area; measured in mmHg (= torr), cmH<sub>2</sub>O, kPa (kilopascals); represents potential energy which can be converted to kinetic energy (movement of blood)

Systolic pressure: highest pressure in a cardiac chamber or blood vessel during a cardiac cycle

Diastolic pressure: lowest pressure in a cardiac chamber or blood vessel during a cardiac cycle

2. Flow

- a. volume flow (Q): volume of blood passing a given location in the circulation per unit time
- b. Cardiac Output: Q of either ventricle (not both); same as Q at any level of the circulation (typically 5 liters/min for a young adult of average size at rest)
- c. velocity of individual cells in the circulation (v): depends cross sectional area (A); decreases as A increases



D. Pressure, Flow, and Resistance (continued)

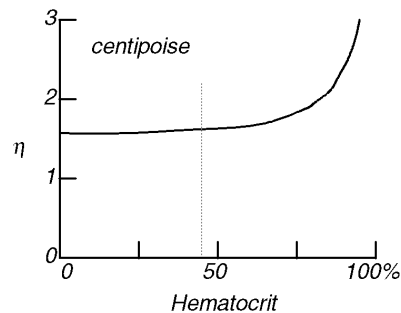
3. Resistance (R): frictional resistance to blood flow; due to blood viscosity

Pressure → difference $\Delta P$ potential energy	Flow → $Q$ kinetic energy	Heat dissipation of energy (friction, viscosity)
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- a. define:  $R = \Delta P / Q$ , where  $\Delta P$  = pressure difference

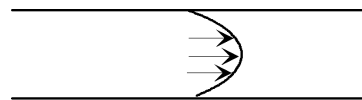
- b. factors determining resistance

- 1) length of vessel (L):  $L \uparrow \Rightarrow R \uparrow$
- 2) radius of vessel (r):  $r \downarrow \Rightarrow R \uparrow$
- 3) viscosity of fluid ( $\eta$ ):  $\eta \uparrow \Rightarrow R \uparrow$

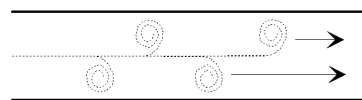


For blood, viscosity depends mainly on hematocrit (= blood cell volume as a fraction of total blood volume)

- 4) flow pattern, which, in turn, depends on flow velocity
  - a) laminar (also called "streamline" flow: normal flow in the circulatory system streamline, smooth & steady velocity profile, minimum & constant R, silent
  - b) turbulent: occurs as high flow velocities (e.g. coarctation, stenosis); may also occur in exercise; eddies (whirlpools), varying velocity, greater R which increases with velocity, causes sounds, can lead to necrosis by impact on blood vessel walls



*laminar*



*turbulent*

D. Pressure, Flow, and Resistance (continued)

c. Poiseuille's Law for Laminar Flow

$$R = (8/\pi)(\eta)(L/r^4)$$

Since  $\eta$  and  $L$  are generally constant, changes in  $R$  are usually due to changes in  $r$  (radius), particularly since resistance varies as  $r$  to the 4<sup>th</sup> power; that is, a small change in  $r$  can lead to a large change in resistance and flow

ARTERIAL SYSTEM

A. Functional Anatomy

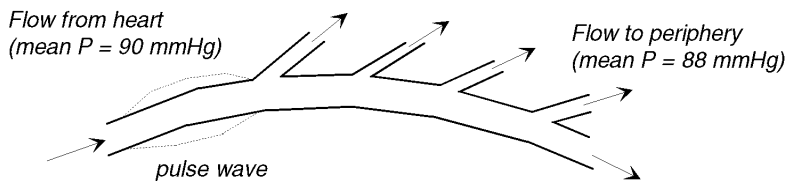
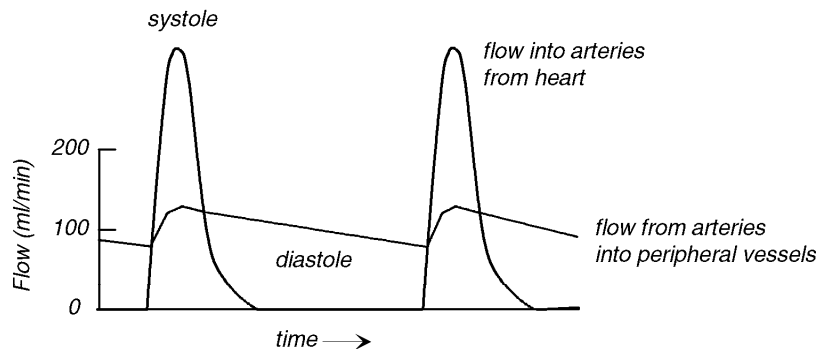
1. Heavy, elastic walls: smooth muscle, elastic fibers, fibrous tissue (loss of tissue results in aneurysm)
2. Low resistance to flow: normal pressure drop required to move full cardiac output along the total length of the arteries is only about 2-3 mmHg

B. Normal Pressures

1. Systemic arterial typical value (young adult at rest): 115/75
2. Pulmonary arterial: 22/8 mmHg

C. Pressure Reservoir and Pulse Damping Function

1. Due to elasticity, converts intermittent heart pumping action to continuously maintained pressure



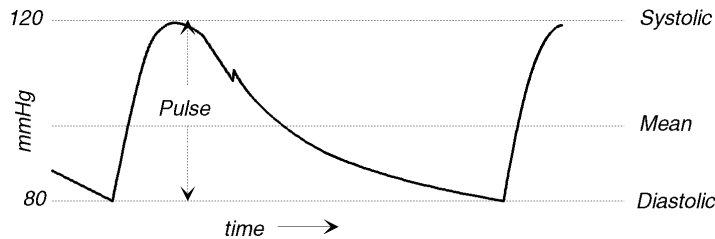
Thus, there is continuous capillary flow, despite the pulsating nature of cardiac ejection

Note: the arterial pulse wave is what is felt when palpating an artery

ARTERIES (continued)

Note: Inflow into the arterial system is determined by ventricular stroke volume. Outflow from the arterial system is determined by pressure and peripheral resistance ( $Q = \Delta P/R$ )

2. Arterial pulse pressure (Systolic minus Diastolic) is associated with the elasticity of the arterial system; since elasticity decreases with age, pulse pressure generally increases with age
3. Shape of the pulse wave: aorta and large systemic arteries

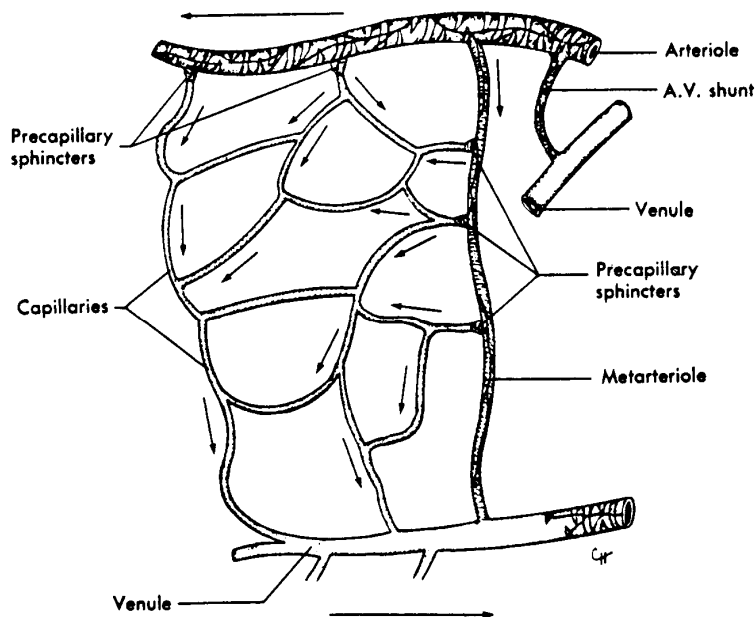


Pulse = Systolic – Diastolic

Mean =  $\frac{1}{3}$  Systolic +  $\frac{2}{3}$  Diastolic (approximate)  
= Diastolic +  $\frac{1}{3}$  Pulse

ARTERIOLES AND RELATED VESSELS

A. Functional Anatomy



arteriole: continuous smooth muscle coat

metarteriole: arteriole-like vessel, but with intermittent smooth muscle coat

precapillary sphincters: smooth muscle at the beginning of a capillary

arterio-venous anastomoses (a-v shunt): direct connections between arterioles and venules

Note: sympathetic axons innervate arterioles and arterio-venous anastomoses but not metarterioles or precapillary sphincters

ARTERIOLES AND RELATED VESSELS (continued)

- B. Resistance (systemic arterioles): variable, low to high depending upon vasomotor state
- C. Function: to act as variable resistance valves to distribute blood to each vascular bed accordance with its needs (and the needs of the body)

vasomotion = change in vessel diameter  
 vasoconstriction = diameter decrease → increase resistance → decrease flow  
 vasodilation = diameter increase → decrease resistance → increase flow  
 (or vasodilatation)

D. Nervous Control (Autonomic Nervous System)

1. Sympathetic Nervous System

- a. mediated by norepinephrine released from postganglionic nerve terminal
- b. binds to alpha receptors on arteriole smooth muscle
- c. action: vasoconstriction (usually)
- d. functions include
  - 1) arteriole tone at rest
  - 2) diversion of blood away from "vegetative" organs in stress

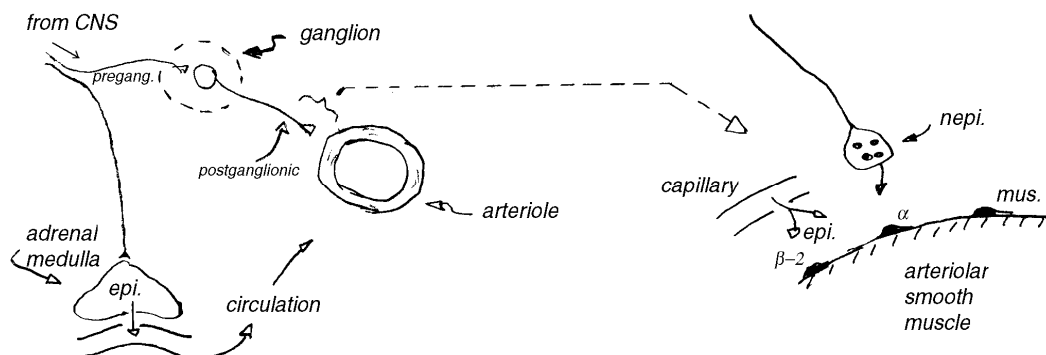
2. Adrenal Medulla (activated by sympathetics)

- a. mediated by epinephrine released from the adrenal medulla
- b. binds to both alpha and beta-2 receptors on arteriole smooth muscle
- c. action: depends on whether alpha or beta-2 receptors predominate (all arterioles have alpha receptors but only some tissues have beta-2 receptors)

alpha → vasoconstriction  
 beta-2 → vasodilation (smooth muscle relax)

Sympathetic + Adrenal Activation

Skin	constrict
Salivary glands	constrict
Mucosa	constrict
Intestine	constrict
Kidney	constrict
Skeletal muscle	dilate
Liver	dilate
Brain	little effect
Lung vessels	little effect
Heart	little direct effect (indirect dilation)



ARTERIOLES AND RELATED VESSELS (continued)

3. Parasympathetic Nervous System

- a. no direct effect (with exceptions)

Note: although acetylcholine is an effective vasodilator (through activation of cholinergic muscarinic receptors), no parasympathetic postganglionic nerves end on blood vessels

- b. can have an indirect effect if secretion or other activity stimulated through release of local vasoactive agents

4. Relation of arteriolar smooth muscle to nervous innervation

- a. the effect of nervous activation is diffuse
- b. nerves are only one of many influences on arteriolar smooth muscle
- c. effects of denervation
- 1) no loss of structural integrity
  - 2) no disability except when reacting to stress
  - 3) possible development of denervation hypersensitivity (increased sensitivity to circulating agents); due mainly to synthesis of more receptors

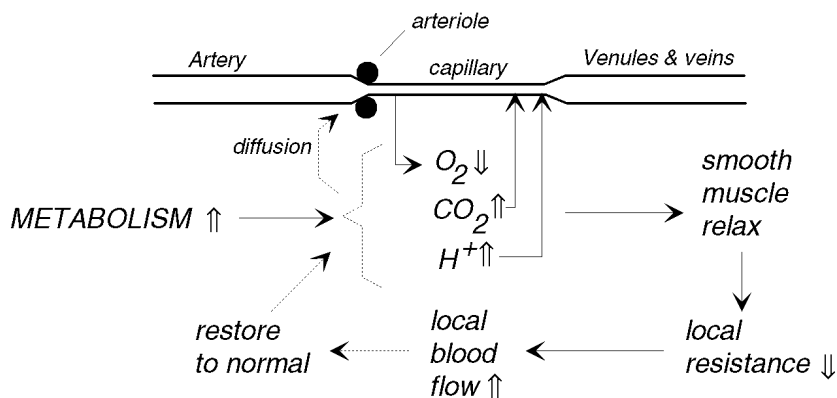
Pathophysiology example: Excess sympathetic activity: Raynaud's disease; note development of denervation hypersensitivity after postganglionic denervation

E. Metabolic Control

1. Metabolites

carbon dioxide  $\uparrow$   $\rightarrow$  vasodilation  
oxygen  $\downarrow$   $\rightarrow$  vasodilation  
pH  $\downarrow$  (or H ion  $\uparrow$ )  $\rightarrow$  vasodilation

2. Role: automatically adjusts blood flow in accordance with local tissue needs (metabolic autoregulation)



## ARTERIOLES AND RELATED VESSELS (continued)

### F. Other

1. Locally released vasoactive agents (paracrines), e.g.

histamine → vasodilation  
bradykinin → vasodilation  
nitric oxide → vasodilation

Roles:

- a. inflammation
- b. response to increased tissue activity

2. Myogenic autoregulation

Arteriolar smooth muscle stretch → vasoconstriction

3. Temperature:  $T \uparrow$  → vasodilation

## CAPILLARIES

### A. Functional Anatomy

1. small, 5-10  $\mu\text{M}$  inner diameter
2. very thin wall -- single cell layer (promotes diffusion)
3. non-contractile

### B. Resistance (systemic capillaries): medium

### C. Function: exchange of substances between blood and interstitial fluid (fluid bathing cells)

## VENULES

### A. Functional Anatomy

1. Small, but larger than capillaries (in the order of 18  $\mu\text{M}$  inner diameter)
2. Connective tissue and smooth muscle wall

### B. Resistance: low

### C. Functions

1. collect blood from capillaries
2. at capillary ends, support diffusion between blood and interstitial fluid

## VEINS

### A. Functional Anatomy

1. Large diameter
2. Connective tissue and smooth muscle (permitting venoconstriction); less elastic tissue than arteries, so flaccid when not full; easily distensible

### B. Resistance: low

### C. Functions

1. Return blood to the heart
2. Act as volume reservoir
  - a. normally contain about 55% of body's total blood
  - b. can expel blood to the remaining circulation by venoconstriction (controlled by the sympathetic system)
3. Can aid in return of blood to the heart (venous return) by rhythmic skeletal muscle contraction (muscle pump) and respiratory movements (respiratory pump)
4. Some veins are valved; this helps prevent pooling of blood in the veins due to gravity

Pathophysiology note: loss or incompetence of the venous valves can result in enlargement (varicosity)