The Circulatory System

- **Arterial side:**
  - Venticle → Great arteries (2) → large arteries (10-20) → arterioles (10^7) → capillaries (10^{10}).

- **Venous side:**
  - Capillaries (10^{10}) → venules (10^7) → large veins (20 – 40) → great veins (2) → right atrium.

- All the functional work of the cardiovascular system occurs in the capillaries.

Anatomy of Blood Vessels

- Endothelial layer (1-cell layer) separates blood from vessel wall.
- 3 main layers within blood vessel wall:
  - Intima, media, adventitia.
Arteries

- Three types of arteries:
  - Elastic arteries
    - Aorta, pulmonary arteries (diameters: 1.0 – 2.0 cm).
    - Primarily elastic fibers within media.
    - Acts as an energy “reservoir” (spring, capacitor).
  - Muscular arteries
    - Smaller than the elastic arteries (diameters: 0.4 – 0.8 cm).
    - Contains more smooth muscle in medial layer.
    - Part of the resistance portion of the cardiovascular system.
  - Arterioles (diameters: 30 – 100 microns)
    - Predominantly smooth muscle.
    - Vasoconstriction occurs at arteriolar level via constriction of smooth muscles.

Capillaries

- Smallest blood vessels (diameters: 6 – 10 microns).
- Consist of endothelial wall + basement membrane.
- High degree of branching and parallel networks (allows minimum diffusion distances).
- Autoregulation occurs to direct blood flow to regions that need it most.
Veins

- Similar in structural classification to arteries, ie, 3 main types:
  - Venules (diameters: 20 – 50 microns)
    - Smallest veins with endothelial layer, some intima, no media, and supporting adventitia.
  - Medium sized veins (diameters: 2 – 5 mm).
    - Smooth muscle bands within medial layer.
    - Supporting collagen and elastic fibers within adventitia.
  - Large veins (diameters: 1 – 2 cm).
    - Mainly elastic supporting fibers.
- Veins have much thinner walls than arteries (why?).
- Veins also contain valves that maintain unidirectional flow and oppose gravitational gradients.

Circulatory Physiology

- Control mechanisms act to maintain cardiac output.
- Typical arterial pressures
  - Average normal arterial systolic pressure is 120 mm Hg
  - Average normal arterial diastolic pressure is 80 mm Hg.
  - Pulse pressure = systolic pressure – diastolic pressure.
- Pressure gradient within cardiovascular system provides driving forces for flow.
- Pressure gradient needs to overcome fluid resistance within the cardiovascular system for flow to occur.
- Resistance over a unit length of vessel occurs due to:
  - Size of blood vessel (diameter).
  - Viscosity of blood.
  - Fluid nature of the flow (laminar — vs — turbulent).
Pressures in the Cardiovascular System

Type of blood vessel

Capillary Pressure

BP = Capillary blood pressure
COP = Capillary osmotic pressure

Lymphatic vessel

3.6 l/day reabsorbed into lymphatic vessels

24 l/day moves out of capillaries
20.4 l/day reabsorbed

Arteriole

Venule

BP > COP Fluid moves out of capillary
BP = COP No net movement
COP > BP Fluid moves into capillary

Anatomy and Physiology for Engineers

Slide 9.7

Slide 9.8
Measurement of Blood Pressure

Cardiovascular Regulation

- Regulation of hemodynamics occurs via local autoregulation, neural control and hormones.
**Autoregulation of Blood Flow**

- Local regulation of blood flow occurs by vasoconstriction and vasodilation.
- Both occur at the site of arteriolar branches, usually into capillary beds (precapillary sphincters).
- Smooth muscle contraction closes lumen of the blood vessel.
- Response is a direct effect of conditions within local environment.
  - Local vasodilation can be caused by:
    - Uptake of O₂ (local decrease) by local cells and release of CO₂ (local increase).
    - Fall in pH.
    - Injury / inflammation.
  - Local vasoconstriction can be caused by:
    - Decrease in temperature.
    - Release of various chemicals in response to trauma (shock).
    - Response to certain localized activities (digestion –vs- exercise, etc).

**Neural Control of Blood Flow**

- Cardiac centers and the vasomotor centers within medulla oblongata are responsible for monitoring and regulating cardiovascular activities.
  - Carioacceleratory center (sympathetic excitation to increase cardiac output).
  - Cardioinhibitory center (parasympathetic inhibition of cardiac output).
  - Vasomotor centers cause vasodilation (inhibition) or vasoconstriction (excitation).
- Cardiovascular centers detect changes in pH, blood pressure and dissolved gas concentrations.
- Two types of “transducers” sense these parameters:
  - Baroreceptors (pressure sensors)
  - Chemoreceptors (chemical sensors).
The Baroreceptor Reflexes

- Autonomic reflexes that adjust cardiac output and peripheral resistance to regulate and maintain normal blood pressures.
- Baroreceptors are situated at:
  - Aortic sinuses (immediately distal to aortic valve).
  - Carotid sinuses (within carotid arteries of neck).
  - Right atrial walls.

Chemoreceptor Reflexes

- Found in aortic arch and carotid sinuses.
- Additional chemoreceptors in medulla oblongata monitor CSF composition.
- Activation occurs via a rise in CO₂ or drop in pH.
- Produces activation of cardioacceleratory and vasomotor centers.
- Increases cardiac output and vasoconstriction.
Hormones and Cardiovascular Function

- Endocrine system provides acute and chronic regulation.
- Short term:
  - Epinephrine released immediately upon activation of adrenal medulla.
- Long term:
  - Angiotensin II:
    - Produced via enzymatic reaction initially catalyzed by renin produced by kidneys in response to lower pressure.
    - Causes powerful vasoconstriction and elevation of blood pressure.
    - Activates other hormones that act to retain water.
  - Antidiuretic Hormone
    - Also responds to increase in plasma solute concentration.
    - Water retention at kidneys; Vasoconstriction.
  - Erythropoietin:
    - Released by kidneys in response to decreased O₂ or blood pressure.
    - Increases RBC production.
  - Atrial Natriuretic Peptide
    - Released by cells in RA in response to increased blood pressure.
    - Responds to increased venous filling by promoting loss of Na⁺ and water at kidneys, inhibiting sympathetic activation of adrenal medulla, and vasodilation.

Cardiovascular Response to Exercise

- Cardiac output at rest ranges from 4.5 – 6 L/min.
- Exercise produces substantial increase.
- Effects of exercise:
  - Vasodilation at skeletal muscle vasculature.
  - Increase in venous return.
  - Increase in cardiac output as a function of the Frank-Starling law and as a reflex response to atrial stretching.
  - Arterial pressure are therefore maintained despite decrease in downstream resistance.
  - Advanced stage of exercise produces sympathetic stimulation.
  - Produces vasoconstriction for non-essential vasculature.
  - Blood supply to brain remains unaffected.
  - Chronic exercise produces mild to moderate hypertrophy of cardiac muscle.
  - Significant chronic exertion coupled with genetic predisposition can cause hypertrophic cardiomyopathy.
Response to Hemorrhage

- Hemorrhage → significant loss of blood volume.
- Short term responses:
  - Baroreceptor reflexes stimulate cardiac output and initiate peripheral vasoconstriction.
  - Mobilization of the venous reserve.
  - Sympathetic stimulation of heart rate.
- Longer term responses:
  - Decline in capillary blood pressure reverses pressure gradient and moves interstitial fluid into capillaries.
  - Hormones (ADH, aldosterone) released to promote fluid retention at kidneys.
  - Erythropoietin released to stimulate RBC formation.
  - Thirst reflexes triggered.
- Significant blood loss (> 35%) leads to circulatory shock.

Anatomy of the Cardiovascular System

Pulmonary arteries.
Anatomy of the Cardiovascular System

- Larger arteries of the thorax.
- Aortic arch → Brachiocephalic; Left common carotid; Left subclavian.
- Descending aorta → Iliac; Femoral

Fetal Circulation

(a) Full-term fetus (before birth)

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