Blood Vessels

I. Blood Vessel Structure and Function-

A. Overview- Great arteries leave the heart, branch to smaller and smaller arteries which lead to capillaries. Capillaries allow exchange of materials at tissues. Capillaries merge and lead to tiny venules, which merge to larger and larger veins until they finally dump back into the heart, via the huge inferior and superior vena cava.

B. Structure of vessel walls- All but the tiniest of vessels have walls that are composed of three "tunics" (layers):

1. Tunica interna/intima- innermost: Endothelium (simple squamous epithelium) of connected cells; forms a smooth, flat, low friction surface. All vessels have this layer, and all but the teeny-tiniest have a basement membrane associated with the endothelium.

2. Tunica media-smooth muscle and elastic connective tissue surrounding the interna. Responsible for vasoconstriction and vasodilation..

3. Tunica Adventitia/Externa- connective tissue, surrounds entire vessel. Lots of collagen, some elastin.

C. Arterial System- arteries carry blood away from the heart.

1. Elastic Arteries- thick-walled, near the heart. Includes the aorta and its major branches, and the pulmonary trunk/arteries.

Largest and most elastic of all arteries. They absorb much of the pressure from ventricular contraction by stretching to accommodate blood. Elasticity damps pressure leaving the heart, but activity does not play a large role in minute-by-minute blood pressure adjustment.
2. Muscular Arteries- Elastic arteries branch into smaller muscular arteries. These bring blood to specific ORGANS. Proportionally, thickest tunica media of all vessels. Each side of the media is lined by elastic fibers. The muscular arteries play a major role in adjusting/controlling blood pressure by vasodilation & constriction. General vasoconstriction of body vessels will increase whole body pressure, and blood flow can be directed to certain areas of the body by constricting some muscular arteries and dilating others.

3. Arterioles- Muscular arteries branch into arterioles. The larger arterioles have all 3 tunics, but the smaller ones that give way to capillaries are just composed of endothelium with smooth muscle cells encircling it. These control blood flow to specific TISSUES. They can constrict and cut off blood flow to capillary beds, and vice versa.

D. Capillaries- Smallest vessels. One layer of endothelium. Capillaries service cells throughout the body, exchanging gases, nutrients, and wastes with those cells. On average, every cell of the body is no more than 3 cell diameters’ distance from a capillary!

1. Types of capillaries- categorized based on the type/sizes of “holes” in the capillary. These are holes that certain substances can pass across, to get into the blood from the interstitium or out of the blood to the interstitium.

However, in addition to these “holes,” the endothelial cells constantly engage in pinocytosis: sampling the blood plasma by endocytosis, and sending the random sample of plasma into the interstitium by exocytosis. The reverse happens as well, interstitial fluid is randomly taken in and sent to the plasma. It’s a veritable lava-lamp in there!

a. Continuous- most common. Endothelial cells connected by tight junctions, without large pores. Small spaces between tight junctions (intercellular
clefts) allow fluid and small solutes to pass into and out of blood. Proteins and large peptides are too big! (the "holes" are called intercellular clefts)

b. Fenestrated- located in areas where lots of exchange of relatively large particles take place, like endocrine glands. Large pores in cells. Fenestrations are large enough to allow polypeptides (less than \( \sim 200 \) amino acids long) like hormones through, but are not large enough to allow many proteins through (more than \( \sim 200 \) amino acids long). (the "holes" are called fenestrations, though clefts still exist)

c. Sinusoidal- leaky. Large spaces between endothelial cells allow very large particles, including proteins and RBC, to pass. We will see sinusoidal capillaries in the next chapter, when we talk about the spleen. (the "holes" could, I suppose, be called sinusoids, but often the capillaries themselves are simply called sinusoids... they're just SO HOLEY!)

2. Capillary beds- networks of capillaries serving the cells of a tissue. The capillary beds branch off of a Metarteriole, which is a tiny arteriole that connects a terminal arteriole with a venule. The venous end of the metarteriole is called a Thoroughfare Channel.

The capillaries branch off of the arterial end of the metarteriole, then remerge into the thoroughfare channel, to enter the venule.

At the metarteriole end, there are sphineters (muscular valves) leading to each capillary. If these sphineters are closed, much blood will bypass the capillary bed and go straight to the venule.

E. Venous System
1. Postcapillary venules receive blood from capillary bed or thoroughfare channel. These will merge into larger venules.

2. Larger venules join to form **veins**

Three distinct tunics, tunica externa is the most substantial and the media is much thinner than arteries. The walls in general are thinner than artery walls.

Veins hold a substantial amount of blood at any given time, up to 65%. They are considered blood reservoirs.

Pressure in veins is very low. No pumping action returns blood. Muscle action squeezes blood in the veins, and valves prevent that blood from moving backward. Also, inhalation creates a suction that pulls blood toward the thoracic cavity.

**II. Physiology of Circulation**

A. Blood Flow, Pressure, Resistance

1. Definitions-

   a. **Blood flow**- volume of blood flowing through a vessel, organ or entire body in a given period of time.

   b. **Pressure**- Force per unit area exerted on the wall of a blood vessel by blood. Expressed in mm Hg.

   c. **Resistance/Peripheral Resistance**- Opposition to flow caused by friction. Three sources:

      i. **Viscosity**- Resistance related to thickness of a fluid. High viscosity means molecules have a harder time slipping past each other. RBC have the greatest effect on viscosity, but other formed elements and blood proteins affect viscosity as well.
ii. Total Vessel Length- More resistance is encountered in long vessels than short.

iii. Turbulence- Occurs in the great arteries, and can occur around plaques in muscular arteries. Turbulence increases resistance.

iv. Vessel Diameter- Has the largest and fastest effect on resistance. Smaller diameter leads to increased resistance.

2. Relationship between Flow, Pressure, and Resistance

Flow is directly proportional to the difference in pressure between two points, and is inversely proportional to resistance.

That is, the greater the **decrease in pressure between two points** along an artery, the greater the flow; and, the greater the resistance, the lower the flow.

\[ F = \text{change in } P/R \]

3. Blood pressure is lower in smaller vessels because the total cross sectional diameter exceeds the total cross sectional diameter of larger vessels.

B. Systemic Blood Pressure-

1. Arterial Blood Pressure- blood pressure in elastic and muscular arteries needs to exceed that in arterioles and capillaries to keep blood moving in the right direction. Arterial pressure is pulsatile and corresponds with ventricular systole and diastole. The pressure peak is called systolic pressure, and the dip is called diastolic pressure.

   a. Pulse pressure- difference between systolic and diastolic pressure.
b. Mean Arterial Pressure (MAP)- "overall" pressure; if
diastole and systole lasted for the same period of time,
MAP would be diastolic + systolic. But, diastole lasts
longer than systole, so

\[
\text{MAP} = \frac{\text{diastolic pressure} + (\text{systolic-diastolic pressure})}{3}
\]

MAP and pulse pressure decline from larger arteries to smaller
arteries.

2. Capillary blood Pressure- by the time blood reaches
capillaries, the pressure is low (~40 mmHg) and not as
pulsatile. By the end of the capillaries, it is very low (~20
mmHg). Low pressure is required in the capillaries. If pressure
were too high, they would lose too many fluids and solutes, and
could even rupture.

3. Venous Blood Pressure- non-pulsatile and low, ~20 mmHg.
Blood in veins below the heart need some help getting back to
the heart (what about blood in veins above the heart?):

-Factors that affect venous return:

a. Respiratory pump- as we breath, pressure differentials
in the thoracic cavity and abdominal cavity "suck" blood
up through the veins like a straw.

b. Muscular pump- contraction of muscles squeeze veins
like a tube of toothpaste, and valves in veins make sure
that blood that gets squeezed forward doesn't backflow
when the muscles relax.

c. Valves- prevent backflow

C. Blood Flow Through Tissues- "tissue perfusion"; capillaries are
responsible for this.
* Please read text re: diffusion, filtration, and reabsorption. Focus on how specific types of solutes get into and out of capillaries.

1. Functions- delivery of gases and nutrients and removal of wastes; gas exchange in the lungs; absorption of nutrients from the digestive tract; urine formation by the kidneys.

2. Autoregulation- local regulation of tissue perfusion. This is a mechanism that allows each tissue to have some control over how much blood is delivered to it. (We will see later that the nervous and endocrine systems exert larger-scale control over how much blood goes to different areas, and over general blood pressure).

   a. In autoregulation, tissue perfusion is adjusted by altering the diameter (via constriction/dilation) of terminal arterioles and precapillary sphincters, thus adjusting the amount of blood allowed to flow through the capillary bed. Each capillary bed can be affected separately.

   b. Factors that cause dilation or constriction of terminal arterioles/precapillary sphincters are chemicals that are biproducts of metabolism, or are released by cells (recall the process of hemostasis, many of the chemicals are the same).

      i. Chemicals that cause dilation: CO₂, organic acids, low O₂, inflammatory chemicals from cells (NO, histamine), elevated local temperature

      ii. Chemicals that cause constriction: primarily chemicals involved with hemostasis, ex. prostaglandins

3. Capillary Dynamics- movement of fluid and solutes through capillaries, into capillaries and out of capillaries
a. Exchange of solutes- see pg.735, "diffusion." I'd like you to generally know what types of solutes can pass at specific types of capillaries, but for the remainder of the discussion on capillaries, you need to know: Other than at sinusoidal capillaries, whole proteins are too large to pass across capillary walls, so they are generally stuck "in" or "out" of capillaries. Proteins attract water.

b. Movement of materials (fluids and "hitching" solutes)- the movement of fluids into and out of capillaries is driven by pressure gradients. When fluids move, solutes that can move across the capillary walls move with the fluids. Two types of pressure gradients affect fluid movement:

i. Capillary Hydrostatic Pressure (CHP)- This is the force of the fluid against the capillary walls. It is highest at the beginning (arterial end) of a capillary bed, and lowest at the end (venous end) of a capillary bed.

The CHP generally pushes fluid out of capillaries (filtration), because it is greater than the hydrostatic pressure of interstitial fluid (which varies, but we can consider ~ 0 mmHg) The Net Hydrostatic Pressure (NHP) takes into account the opposing action of interstitial fluid: NHP = CHP- Interstitial Hydrostatic Pressure

ii. Blood Colloid Osmotic Pressure (BCOP)- Osmotic Pressure, in general, describes the tendency of water to move from hypotonic to hypertonic solutions. The greater the difference in solute concentration, the greater the osmotic pressure.

Plasma proteins are the most important factors influencing BCOP. There are tons of proteins in blood plasma (way more than in interstitium), so BCOP generally pulls fluid into capillaries.
(reabsorption). The Net Osmotic Pressure takes into account the opposing action of interstitial fluid: NCOP = BCOP - Interstitial OP.

iii. The movement of fluids across capillaries is determined by an interplay of CHP and BCOP. The Net Filtration Pressure (NFP) describes the total pressure that will affect how much fluid leaves and returns to a capillary bed. NFP = NHP - NCOP (Net hydrostatic - Net Osmotic Pressures). Since the hydrostatic and osmotic pressures of the interstitium average around 0, I will just use the terms CHP and BCOP.

The point is. Hydrostatic pressure tends to push fluid out of capillaries. Osmotic pressure tends to pull fluid into capillaries. The total amount of fluid lost at capillaries depends on the strength of hydrostatic vs osmotic pressures, both in the capillaries and in the interstitium.

At the arterial end of a capillary bed, the NFP is positive; that is, CHP > BCOP. So, fluid is pushed out of the capillary and into the tissue. At the venous end, the NFP is negative; that is, CHP < BCOP, so plasma proteins pull fluid back into the capillary.

More fluid leaves the capillary bed (filtration) than is pulled back in (reabsorption) because the degree of pressure is greater at the arterial end than at the venous end (see fig. 21-13 pg. 738 for numbers). This excess fluid is absorbed by lymphatic capillaries, which are a whole 'nother set of vessels that run alongside blood vessels. They will return the lost fluid to the blood.

4. Edema and recall of fluids- see text

D. Larger Scale Maintenance of Blood Pressure/Flow- Neural and endocrine control. The main factors influencing pressure are Cardiac Output, Peripheral Resistance, and Blood Volume.
1. Neural Controls- two primary mechanisms: Alter blood distribution (where blood goes) to meet specific demands; and Alter total body blood vessel diameter to maintain an adequate MAP (enough pressure to move blood to tissues, and to ensure that fluid/solutes leave capillaries)

   a. Remember that the sympathetic division influences the diameter of arteries; parasympathetic fibers do not innervate the smooth muscle of vessels. Vasomotor tone refers to the fact that sympathetic fibers are always "active" at vessels. Under "normal" conditions, the diameter of a vessel is about half its total possible diameter, because of input by sympathetic fibers.

   - Most sympathetic postganglionic fibers secrete NE.

   Most blood vessels' smooth muscle contain alpha-1 adrenergic receptors, which respond to NE and E by constricting.

   Some blood vessels serving skeletal muscle contain beta-2 adrenergic receptors, which respond to NE and E by relaxing.

   - Some sympathetic postganglionic fibers secrete Ach (specifically serving skeletal muscle, brain and sweat glands).

   Blood vessels containing cholinergic receptors respond by relaxing.

   - So, since most sympathetic fibers only release NE, and most blood vessels respond to NE by constricting, general vasodilation reflects a decrease in sympathetic activity while general vasoconstriction reflects an increase. However, since vessels that service the brain and skeletal muscle are served by populations of sympathetic fibers that release Ach, and since some
vessels in these areas respond to NE by relaxing, vasodilation in these areas reflects an increase in sympathetic activity.

b. The control of sympathetic activity, as it relates to vessel diameter, involves communication between the hypothalamus, the cardiovascular centers of the medulla, and two types of sensory neurons (baroreceptors and chemoreceptors). We’ll just focus on the sensory neurons and the medulla.

i. The cardiovascular (CV) centers are a cluster of neurons in the medulla that include the cardiac centers and the vasomotor centers. The cardiac centers control ANS preganglionic fibers to the heart. The **vasomotor centers** control ANS preganglionic fibers to blood vessels.

ii. Baroreceptors involved in blood pressure regulation are located in the Carotid Sinuses (expansions of the carotid arteries to the brain), the Aortic Sinuses (expansions in the aortic arch), and the right atrium. Recall that baroreceptors monitor degree of stretch.

- When blood pressure rises in the **aortic and carotid sinuses** (the walls of the vessels are stretched), the vasomotor centers are alerted and sympathetic activity is tuned down, allowing vessels to dilate and pressure to decline. In addition, parasympathetic activity to the HEART increases, reducing Heart Rate and Cardiac Output.
The reverse is true as well; when pressure declines, sympathetic activity steps up (vessels constrict), and HR/CO increase.

-When blood pressure rises in the **right atrium**, vasodilation occurs as usual, but CO is actually increased. Why is that? What else happens when the right atrium is stretched?

   ii. Chemoreceptors involved in blood flow regulation are located in the carotid bodies (near carotid sinuses) and aortic bodies (near aortic arch). When O2 drops or CO2 rises, general sympathetic activity is initiated, increasing HR and CO, constriction of vessels, and an increase in respiratory rate.

Another population of chemoreceptors is located in the medulla at the 4\(^{th}\) ventricle. These guys monitor pH of the CSF and have a particularly strong effect on breathing rate. We will consider the role of those chemoreceptors in more detail when we get to Respiration.

2. Endocrine Controls-

   a. NE and E from the Adrenal Medulla- released in response to a stressor; generally cause vasoconstriction (E may cause vasodilation in vessels serving skeletal and cardiac muscle, where there are beta-2 receptors).

   b. Atrial Natriuretic Peptide from the right atrium of the heart- released in response to excess stretching; causes blood volume and pressure to decline by encouraging Na\(^+\) and H\(_2\)O excretion at the kidneys, causing vasodilation, and blocking the release of hormones with opposing actions.
c. Angiotensin II from capillaries in the lungs- released indirectly in response to a decline in renal blood pressure. Renin is an enzyme released from the kidneys. It converts the blood protein Angiotensinogen to Angiotensin I. Angiotensin I is then converted to Angiotensin II in the lungs. Phew. AngioII causes intense vasoconstriction (rapid increase in blood pressure), and stimulates the release of hormones with supporting actions (ADH & Aldosterone).

d. AntiDiuretic Hormone (ADH) from the neurohypophysis (posterior pituitary)- released in response to decrease in blood pressure, increase in plasma osmotic pressure, and circulating Angiotensin II. Causes peripheral vasoconstriction and water conservation at the kidneys (thereby increasing blood volume)

e. ErythroPOietin (EPO) from the kidneys- released in response to low blood pressure or O2. Causes the production of erythrocytes.