

1. Blood vessels
 - a. Tubes through which the heart pumps blood.
 - b. 3 major types of blood vessels: arteries, capillaries, and veins.
2. Arteries
 - a. Take blood away from the heart.
 - b. Branch repeatedly, forming smaller and smaller arteries and eventually the smallest arteries – the arterioles.
 - c. Typically carry oxygenated blood (exception – pulmonary arteries).
3. Capillaries
 - a. Smallest and most numerous vessel type.
 - b. Sites of exchange between blood and tissue fluid.
 - c. Exchange is facilitated by their thinness and vast number (≈ 10 billion).
 - d. “Connect” arteries and veins.
4. Veins
 - a. Take blood toward the heart.
 - b. Converge and join, forming larger and larger vessels.
 - c. Smallest veins are the venules, which receive blood from capillaries.
 - d. Typically carry deoxygenated blood (exception – pulmonary veins).
5. Tunics
 - a. Arteries and veins have 3 basic layers or tunics surrounding their lumen:
 - i. Tunica interna, tunica media, and tunica externa.
 - b. Capillaries contain only the tunica interna.
6. Tunica interna
 - a. A.k.a. the tunica intima.
 - b. Lines the lumen and consists primarily of endothelium, a simple squamous epithelium underlain by loose connective tissue.
 - c. Provides a smooth surface ideal for fluid flow.
7. Tunica media
 - a. Consists of circularly arranged smooth muscle cells and sheets of the protein elastin.
 - i. Smooth muscle tone is regulated by vasomotor fibers of the sympathetic nervous system, hormones, and local chemicals.
 - ii. Increase in tone leads to vasoconstriction – a decrease in vessel diameter.
 - iii. Decrease in tone leads to vasodilation – an increase in vessel diameter.
 - iv. There is a tonic release of NE onto vascular smooth muscle by vasomotor neurons.
 - v. Increasing NE release causes smooth muscle contraction (vasoconstriction).
 - vi. Decreasing NE release causes smooth muscle relaxation (vasodilation).
 - b. Most prominent layer in arteries.
8. Tunica externa
 - a. A.k.a. tunica adventitia.
 - b. Consists of mostly collagen fibers that protect, reinforce, and support the vessel.
 - c. Most prominent layer in veins.
9. Basic types of arteries:
 - a. Elastic arteries, muscular arteries, and arterioles.
10. Elastic arteries
 - a. A.k.a. conducting arteries.
 - b. Closest to the heart, e.g., the aorta and its major branches (e.g., common iliacs, common carotids).
 - c. Contain a great deal of elastic tissue in all 3 layers.
 - i. Allows them to absorb the pressure associated with each ventricular contraction.
 - ii. Helps produce continuous blood flow even while the heart is in diastole.
11. Muscular arteries
 - a. A.k.a. distributing arteries.
 - b. Primarily involved in regional distribution of blood, i.e., delivery of blood to specific organs (e.g., splenic artery, renal artery).
 - c. Contain a very thick tunica media.
12. Arterioles

- a. Smallest vessels of the arterial tree.
 - b. Large arterioles have all 3 tunics. Small ones may only have a tunica media and interna.
 - c. Very important in regulation of blood pressure and flow.
 - d. Innervated to the greatest extent by sympathetic vasomotor fibers.
 - e. Their level of muscle tone is the most adjustable and the most often adjusted.
13. Capillaries
- a. Smallest vessels.
 - b. Contain only a tunica interna.
 - c. Billions of capillaries in the human body. This presents a huge surface area for exchange.
 - d. Arranged in networks (beds)
 - e. Rich in metabolically active tissues, e.g., lungs, liver, kidneys, skeletal and cardiac muscle.
 - f. Absent in epithelia, cartilage, and the corneas and lenses of the eyes.
 - g. Thin walls facilitate exchange between blood and ISF.
14. Types of capillaries:
- a. Continuous, fenestrated, and sinusoidal.
15. Continuous capillaries
- a. Most common type and are abundant in skin and muscle.
 - b. “Continuous” in terms of each cell (i.e., no holes w/i the cell membrane).
 - c. Contain intercellular clefts (spaces btwn endothelial cells).
 - d. Found in areas where exchange of large items is unnecessary.
16. Fenestrated capillaries
- a. Similar to continuous except the endothelial membranes are riddled with pores (fenestrations).
 - b. Contain intercellular clefts.
 - c. Much more permeable than continuous capillaries.
 - d. Found in sites of active absorption (e.g., intestines) or filtrate formation (e.g., kidneys).
17. Sinusoidal capillaries
- a. Least common but very permeable capillaries found in liver, bone marrow, lymphoid tissues, and some endocrine organs.
 - b. Fenestrated and contain huge intercellular clefts. Large molecules and even blood cells can exit/enter.
 - c. Twisty, which slows down blood flow.
 - d. Macrophages can form portions of the interna in the liver (monitor the blood for bacteria, etc.)
18. Capillary beds
- a. Interconnected networks of capillaries.
 - b. Bounded by an arteriole and venule.
 - c. Consists of a vascular shunt (a channel that directly connects the arteriole to the venule) and the true capillaries (the actual exchange vessels).
 - d. Smooth muscle rings (precapillary sphincters) surround the entry to each true capillary.
 - i. If open (relaxed), blood will flow through the true capillaries.
 - ii. If closed (contracted), blood will flow through the vascular shunt from arteriole to venule.
 - iii. Whether the sphincters are open or closed is determined primarily by the metabolic needs of the tissue.
 - iv. Precapillary sphincters relax in response to low O₂, high CO₂, as well as the accumulation of the byproducts of metabolism.
19. Venules
- a. Formed when capillaries unite.
 - b. Coalesce to form small veins.
20. Veins
- a. Contain all 3 tunics, but in different proportions than arteries.
 - b. Most prominent layer is the tunica externa.
 - c. Walls are thin and their lumens are large.
 - d. Low resistance and are extremely compliant.
 - e. B/c of this compliance they typically contain 65% of the body’s blood volume and are known as capacitance vessels or blood reservoirs.

- f. Venous muscle tone (the contraction of the tunica media as controlled by the SNS) prevents the veins from being distended too much.
 - g. Venous blood pressure is quite low b/c they are so far from the pumping action of the heart.
 - h. Low BP necessitates venous valves (extensions of endothelium reminiscent of the cardiac semilunar valves) to prevent backflow.
 - i. Far more valves in the lower extremities than compared to the upper extremities.
 - i. Venous sinuses (e.g. coronary sinus, dural sinuses) are flattened veins whose walls are composed only of endothelium.
21. Blood flow
- a. Volume flowing thru a vessel, organ, or the entire circulation per unit time (e.g., ml/min).
 - b. Under resting conditions, blood flow thru the entire vascular system is equal to cardiac output and is relatively constant.
 - c. Blood flow to individual organs varies greatly.
22. Blood pressure
- a. Force per unit area exerted on the vessel wall by the contained blood.
 - b. Expressed in millimeters of mercury (mmHg).
 - c. All vessels have pressure; however “blood pressure” typically refers to arterial pressure.
 - d. Differences in blood pressure (i.e., pressure gradients) that drive blood flow.
 - e. Vessel with the highest BP is the aorta (b/c of its proximity to the heart)
 - f. Vessels with the lowest BP are the venae cavae.
 - g. BP drops to 0 within the right atrium.
 - h. Most significant drop in BP occurs in the arterioles (where resistance is the highest)
23. Resistance
- a. Opposition to flow and a measure of the friction blood encounters as it passes thru vessels.
 - b. B/c most friction is encountered in the peripheral blood vessels, resistance is often termed peripheral resistance.
 - c. Altering vessel resistance is one way to direct blood flow.
 - d. 3 main sources are: blood viscosity, total blood vessel length, and blood vessel radius.
24. Blood viscosity
- a. Thickness or stickiness of the blood.
 - b. Directly proportional to resistance.
 - c. Relatively constant in a normal, healthy individual.
 - d. An increase in RBC count (due to a rise in EPO levels for example) would increase viscosity.
25. Total blood vessel length
- a. Directly proportional to resistance.
 - b. The longer the vessel, the more friction blood will encounter.
 - c. Relatively constant in a normal, healthy individual.
 - d. Growth of adipose tissue results in new blood vessel formation and ↑ in total vessel length.
26. Blood vessel radius
- a. Most important of the 3 factors for two reasons.
 - b. Quite variable.
 - c. Resistance is inversely proportional to *radius to the 4th power*.
 - i. Thus small changes in vessel radius will result in large changes in resistance.
 - d. As vessel radius increases (vasodilation), resistance decreases.
 - e. As vessel radius decreases (vasoconstriction), resistance increases.
27. Blood flow btwn 2 points
- a. Directly proportional to the pressure gradient btwn those 2 points
 - b. Inversely proportional to the resistance of the vessel connecting those 2 points.
28. Arterial BP
- a. Directly proportional to cardiac output.
 - b. Directly proportional to the peripheral resistance.
 - c. Directly proportional to blood volume. (Controlled by kidneys via regulation of urine output.)
 - d. During ventricular systole:
 - i. Arterial BP rises b/c the quantity of blood entering the arterial system exceeds the run off to the periphery.

- ii. At the peak pressure (the systolic blood pressure, e.g., 120mmHg) the inflow and run off are equal.
 - e. During ventricular diastole:
 - i. Pressure declines b/c run off to the periphery exceeds the inflow from the heart.
 - ii. The lowest pressure (the diastolic blood pressure, e.g., 80mmHg) in the arterial system occurs just prior to the next ventricular contraction.
 - f. Recoil of the elastic arteries helps propel blood onward through the system as the heart relaxes. In other words, the elastic arteries act as auxiliary pumps.
 - g. As blood flows farther and farther from the heart, the difference btwn the systolic and diastolic pressure decreases – b/c the vessels contain less and less elastic tissue.
 - h. By the capillaries, the pressure is relatively constant.
- 29. Pulse
 - a. Felt at any palpable artery
 - b. Difference btwn the expanded, stretched artery and the recoiling artery. Each pulse is caused by a single ventricular contraction.
 - c. Pulse rate is equivalent to heart rate.
- 30. Pulse pressure
 - a. Difference btwn the systolic BP and diastolic BP $PP = SBP - DBP$.
 - b. Varies directly with stroke volume and indirectly with arterial compliance.
- 31. Mean arterial pressure
 - a. Weighted average of the pressure driving blood flow.
 - b. Expressed as the sum of $\frac{2}{3}$ of the diastolic pressure and $\frac{1}{3}$ of the systolic pressure.
 - c. $MAP = \frac{2}{3}DBP + \frac{1}{3}SBP$.
 - d. Rearranged to $MAP = DBP + \frac{1}{3}PP$.
 - e. MAP depends more on diastolic BP b/c of the greater amt of time spent in diastole.
- 32. Capillary BP
 - a. No longer fluctuates w/ each heartbeat.
 - b. Lower than it was in the arteries.
 - i. Capillaries are fragile and high BP could cause them to burst;
 - ii. Capillaries are quite permeable and high BP could cause excess fluid loss.
- 33. Venous BP
 - a. Steady and lower than that of the arteries and capillaries.
 - b. Low pressure allows veins to be in superficial locations, whereas arteries are usually deeper.
 - c. Gradient of about 20mmHg btwn venules and the venae cavae.
 - i. Not enough by itself to drive blood flow back to the heart.
 - d. Several other factors enhance venous return to the right atrium.
 - i. Gravity helps return blood from the head and neck when upright but opposes return from the legs.
 - ii. Skeletal muscle pump is the term given to the squeezing of veins by leg muscles that forces blood upwards.
 - iii. Respiratory pump refers to the effect on venous blood flow created by the diaphragm and other inspiratory muscles. During inspiration, the downward motion of the diaphragm coupled with the outward motion of the ribs and sternum lowers the intra-thoracic pressure. This helps draw blood upwards from the lower limbs.
 - iv. Sympathetic activation can cause an increase in venomotor tone, i.e., an increase in smooth muscle tone of medium and large veins. This causes an increase in venous return – as would be helpful during the sympathetic response.
 - e. B/c of the intermittent nature of all these subsidiary venous pumps, valves are quite necessary to prevent backflow.
- 34. Controlling mean arterial blood pressure
 - a. It must be high enough to adequately drive blood flow but not so high that it causes damage to fragile organs.
 - b. Short-term MAP control is performed primarily by altering cardiac output and peripheral resistance. This is accomplished both neurally and hormonally.
 - c. Long-term control is achieved primarily by altering blood volume. The kidneys do this.
- 35. Short term control of MAP

- a. Altering peripheral resistance counteracts most moment-to-moment fluctuations of MAP.
 - b. In addition to its cardioacceleratory and cardioinhibitory centers, the cardiovascular center in the medulla oblongata also contains a cluster of neurons known as the vasomotor center.
 - i. It works toward short-term MAP control as well as altering blood distribution during special situations (e.g., exercise).
 - ii. Increased vasomotor activity leads to increased sympathetic NE release on arterioles and an increase in vasomotor tone and thus peripheral resistance.
 - iii. Decreased vasomotor activity yields a decrease in peripheral resistance.
 - iv. Vasomotor activity is affected by baroreceptors, chemoreceptors, and higher brain centers.
 - c. Most short-term alterations in MAP are countered via the baroreceptor reflex.
36. Baroreceptors
- a. Specialized neurons that can measure arterial BP.
 - b. Found primarily in the aortic arch and carotid sinuses (dilations in the internal carotid arteries), but also in most large arteries of the neck and thorax.
 - c. Continually send impulses to the medulla via branches of the glossopharyngeal and vagus nerves (cranial nerves IX and X).
 - d. Impulse frequency varies directly with the BP.
 - e. Increased BP causes increased baroreceptor activity, which causes:
 - i. An increase in the activity of the parasympathetic cardioinhibitory center and thus, an increase in vagal tone (i.e., an increase in ACh release on the SA and AV nodes by the vagus nerve). This results in a decrease in HR and thus CO and thus BP.
 - ii. A decrease in the activity of the sympathetic cardioacceleratory center and thus, a decrease in the activity of the sympathetic cardiac nerves (i.e., a decrease in NE release on the SA and AV nodes and the ventricular myocardium). This results in a decrease in HR, contractility, and SV and thus CO and thus BP.
 - iii. A decrease in activity of the vasomotor center and a decrease in vasomotor tone - a decrease in NE release onto arteriolar smooth muscle. This results in an increase in arterial diameter and thus a decrease in TPR and thus a decrease in BP. There is also an increase in venous diameter which allows blood to pool in the veins, thus decreasing venous return and therefore decreasing CO and BP.
 - f. Unfortunately baroreceptors are ineffective at dealing with sustained changes in BP – as occurs in hypertensive individuals.
37. Adrenal medullary mechanism
- a. The adrenal glands sit atop the kidneys and their medullae secrete epinephrine (and a small amt of NE) in response to large decreases in BP, sudden/substantial increases in physical activity, or stressful conditions.
 - b. Epinephrine increases HR, SV, and TPR. Thus it causes BP to increase.
38. Cerebral cortex and hypothalamus
- a. Exert effects on MAP during emotional situations, stress, and sexual activity.
 - b. Usually via increases in the activity of the vasomotor and cardioacceleratory centers.
39. Long term MAP regulation
- a. Achieved by the kidneys by altering blood volume.
 - b. Occurs when a major increase in MAP causes an increase in urine formation. This reduces MAP by decreasing blood volume.
 - c. Likewise, a major decrease in MAP causes a decrease in urine output and resists further decreases in BV and MAP.
40. Renin-angiotensin-aldosterone system
- a. Kidneys affect MAP having a tonic release of the enzyme renin, which can raise MAP.
 - b. In response to a drop in MAP, the kidney increases its release of renin.
 - c. Increased renin leads to increased plasma levels of angiotensin II.
 - d. Angiotensin II
 - i. Is a potent vasoconstrictor and therefore causes increased TPR and thus increased MAP.
 - ii. Causes the adrenal cortex to release aldosterone, a hormone that promotes water retention. The resulting increased BV increases MAP.

- iii. Prompts antidiuretic hormone release by the posterior pituitary. ADH causes vasoconstriction and decreased urine output, which increases MAP by increasing TPR and blood volume.
 - iv. Activates the body's thirst center. This increases BV and MAP.
 - e. In response to a rise in MAP, the kidneys release of renin declines and as a result AgII, ADH, aldosterone, thirstiness, and MAP all decline.
41. Tissue perfusion
- a. Adequate blood flow to provide tissue cells w/ O₂ and nutrients and get rid of wastes.
 - b. Necessary for proper gas exchange in the lungs, nutrient absorption in the small intestine, and urine formation in the kidneys.
42. Rate of blood flow
- a. Varies in different parts of the vascular system.
 - b. Rapid in large vessels and slow in small vessels.
 - c. Blood flow velocity varies inversely w/ total cross-sectional area of a class of vessel.
 - d. Total cross sectional area can be determined by multiplying the cross sectional area of a single vessel by the total # of those vessels.
 - e. As you go from the aorta to the arteries to the capillaries, total cross-sectional area increases dramatically. (This is b/c of the incredibly large # of capillaries.) Thus the velocity of flow will decrease. The low velocity w/i capillaries allows for easy exchange btwn blood and interstitial fluid.
 - f. As you go from capillaries to veins to the venae cavae, cross-sectional area decreases. As a result, blood flow increases in the venous system; although it does not achieve the speeds found in the arterial tree b/c of the lack of a pump.
43. Autoregulation of blood flow
- a. Volume of blood delivered to specific organs depends on the needs of those organs. Such local allotment of blood flow is known as autoregulation.
 - b. Depends on the automatic adjustment of blood flow to each tissue in proportion to the tissue's requirements at any instant.
 - c. Blood flow is adjusted by altering the diameters of the local arterioles feeding the capillaries.
 - d. Factors associated with increased tissue metabolism (such as ↓O₂ levels and ↑CO₂, K⁺, H⁺, and lactate) cause local arterioles to vasodilate. This reduces the local resistance and increases blood flow to the tissue that needs it.
 - e. Most metabolites directly cause the relaxation of vascular smooth muscle while some prompt endothelial cells to release nitric oxide, which is a powerful vasodilator.
44. Capillary exchange
- a. Btwn blood and tissue fluid.
 - b. Nutrients, wastes, signaling molecules, and gases are exchanged primarily by diffusion (movement of solutes from areas of high concentration to areas of low concentration).
 - c. Exchange of fluid btwn plasma and ISF depends on 4 forces: capillary hydrostatic pressure, capillary osmotic pressure, interstitial fluid hydrostatic pressure, and interstitial fluid osmotic pressure.
45. Capillary hydrostatic pressure
- a. A.k.a. capillary BP
 - b. Forces fluid out of the capillary and into the interstitial space. This bulk flow of fluid is known as capillary filtration.
 - c. Declines by 50% from the arterial end of the capillary to the venous end of the capillary – b/c of the increased distance from the heart.
46. Capillary osmotic pressure
- a. Tendency of fluid to be drawn into the capillary from the ISF by plasma proteins (mainly albumin).
 - b. This bulk flow of fluid is known as capillary reabsorption.
47. Interstitial fluid hydrostatic pressure
- a. If substantial enough, would promote fluid movement into the capillary from interstitial space (reabsorption). However, it's normally inconsequential.
48. Interstitial fluid osmotic pressure

- a. If substantial enough, would promote fluid movement into the interstitial space from the capillary (filtration). However, it's normally inconsequential due to the low protein content of interstitial fluid.
49. Net filtration pressure.
- a. Balance of the aforementioned 4 forces.
 - b. $(CHP + IOP) - (COP + IHP)$
 - c. Determines how much interstitial fluid is created as blood passes thru a capillary.
 - d. Pressure of 10mmHg causes capillary filtration forming of 1.5mL of ISF per minute.
50. Lymphatic vessels
- a. Functions to remove the majority of this fluid (as well as any "accidentally" leaked proteins) and send it back to the vascular system.
 - b. Excess ISF due to excess formation or failure of the drainage system is known as edema.