1. Blood vessels = Tubes through which the heart pumps blood.
   a. 3 major types: arteries, capillaries, and veins.
2. Arteries = Take blood away from the heart.
   a. Branch repeatedly, forming smaller and smaller arteries and eventually the arterioles.
   b. Typically carry oxygenated blood (exception – pulmonary arteries, umbilical arteries).
3. Capillaries = Smallest and most numerous vessel type.
   a. Sites of exchange btwn blood & ISF (facilitated by their thinness & vast number (10 billion)).
4. Veins = Take blood toward the heart.
   a. Converge and join, forming larger and larger vessels.
   b. Smallest veins are the venules, which receive blood from capillaries.
   c. Typically carry deoxygenated blood (exception – pulmonary veins, umbilical veins).
5. Tunics = 3 basic tissue layers surrounding the lumen of an artery or vein
   a. Tunica interna, tunica media, and tunica externa.
6. Tunica interna (intima)
   a. Lines the lumen and consists primarily of endothelium (simple squamous epithelium underlain by areolar connective tissue) that allows for smooth fluid flow.
   b. Continuous with the endocardium.
   c. Only layer found in capillaries.
7. Tunica media
   a. Consists of circularly arranged smooth muscle cells and elastic fibers. Prominent in arteries.
8. Tunica externa (adventitia)
   a. Consists of mostly collagen fibers that protect, reinforce, and support the vessel.
   b. Most prominent layer in veins.
10. Elastic arteries (a.k.a. conducting arteries)
    a. Closest to the heart, e.g., aorta and its major branches (common iliacs, common carotids).
    b. 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.k.a. distributing arteries)
    a. Involved in regional distribution, i.e., delivery of blood to organs (e.g., splenic artery).
    b. Contain a very thick tunica media.
12. Arterioles = Smallest vessels of the arterial tree.
    a. Large arterioles have all 3 tunics. Small ones may only have a tunica media and interna.
       i. Usually in a state of partial contraction – vasomotor tone.
       ii. Regulated by vasomotor fibers of the SNS, hormones, and local chemicals.
       iii. Increase in tone leads to vasoconstriction – a decrease in vessel diameter.
       iv. Decrease in tone leads to vasodilation – an increase in vessel diameter.
    b. Very important in regulation of blood pressure and flow.
    c. Heavily innervated by sympathetic vasomotor fibers.
13. Capillaries = Smallest vessels.
    a. Contain only a tunica interna. Thinness facilitates exchange btwn plasma and ISF.
    b. Billions of capillaries in the human body. This presents a huge surface area for exchange.
    c. Arranged in networks (beds).
    d. Rich in metabolically active tissues, e.g., lungs, liver, kidneys, skeletal and cardiac muscle.
    e. Absent in epithelia, cartilage, and the corneas and lenses of the eyes.
14. Types of capillaries: = Continuous, fenestrated, and sinusoidal.
15. Continuous capillaries = Most common type and are abundant in skin, lungs, CNS, and muscle.
    a. “Continuous” in terms of each cell (i.e., no holes w/i the cell membrane).
    b. Contain intercellular clefts (spaces btwn endothelial cells).
    c. Found in areas where exchange of large items is unnecessary.
16. Fenestrated capillaries = Similar to continuous except the endothelium is riddled with pores.
    a. Pores plus larger intercellular clefts yield much greater permeability than continuous cap.
b. Found in sites of active fluid movement (e.g., small intestine, kidneys, choroid plexuses).

17. Sinusoids = Least common but very permeable. (a.k.a. discontinuous capillaries)
   a. Found in liver, bone marrow, and lymphoid tissues, and some endocrine organs.
   b. Fenestrated and have big intercellular clefts. Large molecules and blood cells can exit/enter.
   c. Twisty, which slows down blood flow.
   d. Macrophages can form portions of the interna in the liver (monitor blood for bacteria, etc.).

18. Capillary beds = Interconnected networks of capillaries
   a. Fed by metarterioles (arteriole branches) and empty into postcapillary venules (small veins).
   b. Consists of a thoroughfare channel (that directly connects the metarteriole to the postcapillary venule) and the true capillaries (the actual exchange vessels).
   c. Smooth muscle rings (precapillary sphincters) surround the entry to each true capillary.
      i. If open (relaxed), blood flows thru the true capillaries.
      ii. If closed (contracted), blood flows thru the vascular shunt from arteriole to venule.
      iii. Sphincter contraction level is determined by the metabolic needs of the tissue.
      iv. Precapillary sphincters relax in response to low O\textsubscript{2} and high CO\textsubscript{2}.

19. Venules = Formed when capillaries unite and coalesce to form small veins.

20. Veins = Contain all 3 tunics, but in different proportions than arteries.
   a. Most prominent layer is the tunica externa.
   b. Walls are thin and their lumens are large. This results in low resistance and high compliance.
   c. Typically contain 55% of the BV (and are thus called blood reservoirs).
   d. Venous muscle tone (the contraction of the tunica media as controlled by the SNS) prevents the veins from being distended too much.
   e. Venous blood pressure is quite low b/c they are so far from the pumping action of the heart.
   f. Low BP necessitates venous valves. (More valves in the lower than upper extremities.)

   a. Nutrients, wastes, signaling molecules, and gases are exchanged primarily by diffusion (movement of solutes from areas of high concentration to areas of low concentration).
   b. Exchange of fluid btwn plasma and ISF depends on 4 forces: capillary BP, capillary colloid osmotic pressure, interstitial fluid pressure, and interstitial fluid osmotic pressure.

22. Capillary BP = a.k.a. capillary hydrostatic pressure
   a. Forces fluid out of the capillary and into the ISF. This is known as capillary filtration.
   b. 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.

23. Capillary colloid osmotic pressure
   a. Tendency of fluid to be drawn into the capillary from the ISF by plasma proteins (albumin).
   b. This is known as capillary reabsorption.

24. Interstitial fluid hydrostatic pressure
   a. It would promote fluid movement into the capillary from ISF. However, it’s normally too low...

25. Interstitial fluid osmotic pressure
   a. If substantial enough, would promote fluid movement into the tissue space from the capillary (filtration). However, it’s normally inconsequential due to the low protein content of ISF.

26. Net filtration pressure = Balance of the aforementioned 4 forces. NFP= (CHP + IOP) – (COP + IHP)
   a. Determines how much interstitial fluid is created as blood passes thru a capillary.
   b. Pressure of 10 mmHg causes capillary filtration forming 1.5mL of ISF per minute.

27. Lymphatic vessels - Function to remove the majority of this fluid (as well as any “accidentally” leaked proteins) and send it back to the vascular system.
   a. Excess ISF due to excess formation or failure of the drainage system is known as edema.

28. Tissue perfusion - Adequate flow to provide tissue cells w/ O\textsubscript{2} and nutrients and get rid of wastes.
   a. Necessary for proper gas exchange in the lungs, nutrient absorption in the small intestine, and urine formation in the kidneys.
   b. Blood flow to a tissue depends on:
      i. Degree of vascularization
29. Degree of Vascularization
   a. Varies directly with metabolic activity. Highly active tissues (skeletal muscle, cardiac muscle, and the liver) are very vascular. Inactive tissues (tendons and ligaments) are not vascular.
   b. Increases in metabolic activity can prompt new blood vessel growth (angiogenesis). This occurs in skeletal muscle as a result of training and in adipose tissue as a result of weight gain.
   c. Decreases in activity cause regression of vessels.
30. Local Regulatory Chemicals - Primary determinant of local blood flow.
   a. Vasoactive chemicals can be vasoconstrictors or vasodilators.
   b. ↓ in O₂, ↓ in nutrients, ↑ in CO₂, ↑ in lactate, ↑ in H⁺, and ↑ in K⁺ all cause vasodilation.
   c. Increase in local blood flow occurs during inflammation. Vasodilators (e.g. histamine, bradykinin, nitric oxide) are released by damaged cells and WBCs.
31. Blood pressure = Force per unit area exerted on the vessel wall by the contained blood.
   a. Expressed in millimeters of mercury (mmHg).
   b. All vessels have pressure; however “blood pressure” typically refers to arterial pressure.
   c. Differences in blood pressure (i.e., pressure gradients) drive blood flow.
   d. Vessel with the highest BP is the aorta (b/c of its proximity to the heart)
   e. Vessels with the lowest BP are the venae cavae. (BP drops to 0 within the right atrium.)
   f. Most significant drop in BP occurs in the arterioles (where resistance is the highest).
   g. BP directly varies with cardiac output, blood volume, and vascular resistance.
32. Arterial BP
   a. 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 (systolic BP, e.g., 120 mmHg) the inflow and runoff are equal.
   b. During ventricular diastole:
      i. Pressure declines b/c runoff to the periphery exceeds the inflow from the heart.
      ii. The lowest pressure (diastolic BP, e.g., 80 mmHg) in the arterial system occurs just prior to the next ventricular contraction.
   c. 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.
   d. As blood flows farther and farther from the heart, the difference b/w the systolic and diastolic pressure decreases b/c the vessels contain less and less elastic tissue.
33. Pulse = Difference b/w the expanded, stretched artery and the recoiling artery.
   a. Felt at any palpable artery
   b. Each pulse is caused by a single ventricular contraction. Thus, pulse rate equals heart rate.
34. Pulse pressure = Difference b/w the systolic BP and diastolic BP. PP = SBP – DBP.
   a. Varies directly with stroke volume.
35. Mean arterial pressure = Weighted average of the pressure driving blood flow.
   a. Expressed as the sum of ⅔ of the diastolic pressure and ⅓ of the systolic pressure.
   b. MAP = ⅔DBP + ⅓SBP.
   c. Can be algebraically rearranged to MAP = DBP + ⅓PP.
   d. MAP depends more on diastolic BP b/c the greater amount of time spent in diastole.
36. Capillary BP = No longer fluctuates w/ each heartbeat.
   a. Lower than it was in the arteries. This is b/c capillaries are fragile and high BP could cause them to burst; and capillaries are quite permeable and high BP could cause excess fluid loss.
   b. Declines from 40 mmHg at the arterial end to 20 mmHg at the venous end.
37. Venous BP = Steady and lower than that of the arteries and capillaries.
   a. Low pressure allows veins to be in superficial locations, whereas arteries are usually deeper.
   b. Gradient of about 20 mmHg b/w the venules and the venae cavae.
      i. Not enough by itself to drive blood flow back to the heart.
c. Several other factors enhance venous return to the right atrium.
d. Gravity returns blood from the head and neck when upright but opposes return from the legs.
e. Skeletal muscle pump = squeezing of veins by leg muscles that forces blood upwards.
f. Respiratory pump = 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.
g. Sympathetic activation can cause an increase in venous motor 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.
h. B/c of the intermittent nature of all these subsidiary venous pumps, valves are quite necessary.

38. Resistance = Opposition to flow. A measure of the friction blood encounters as it passes thru vessels.
   a. Since friction occurs in peripheral vessels, resistance is often termed peripheral resistance.
   b. Altering vessel resistance is one way to direct blood flow.
   c. 3 main sources are: blood viscosity, total blood vessel length, and blood vessel radius.

39. Blood viscosity = Thickness or stickiness of blood
   a. Directly proportional to resistance and relatively constant in a normal, healthy individual.
   b. An increase in RBC count (due to a rise in EPO levels for example) would increase viscosity.

40. Total blood vessel length = The longer the vessel, the more friction blood will encounter.
   a. Directly proportional to resistance and relatively constant in a normal, healthy individual.
   b. Growth of adipose tissue results in new blood vessel formation and ↑ in total vessel length.

41. Blood vessel radius = Most important of the 3 factors for two reasons.
   a. Quite variable.
   b. Resistance is inversely proportional to radius to the 4th power.
      i. Thus small changes in vessel radius will result in large changes in resistance.
   c. As vessel radius increases (vasodilation), resistance decreases.
   d. As vessel radius decreases (vasoconstriction), resistance increases.

42. Blood flow btwn 2 points = Directly proportional to the pressure gradient btwn those 2 points and inversely proportional to the resistance of the vessel connecting those 2 points.

43. Controlling BP - High enough to drive blood flow but not so high that it damages organs.
   a. Short-term BP control is performed primarily by altering cardiac output and peripheral resistance. This is accomplished both neurally and hormonally.

44. Short term control of BP
   a. Altering peripheral resistance counteracts most moment-to-moment fluctuations of BP.
   b. Medulla oblongata also contains a cluster of neurons known as the vasomotor center. (VMC)
      i. It works toward short-term BP control as well as altering blood distribution during special situations (e.g., exercise).
      ii. Increased VM activity leads to increased sympathetic NE release on arterioles and an increase in vasomotor tone and thus peripheral resistance.
      iii. Decreased VM activity yields a decrease in peripheral resistance.
      iv. VM activity is affected by baroreceptors, chemoreceptors, and higher brain centers.
   c. Most short-term alterations in BP are countered via the baroreceptor reflex.

45. Baroreceptors = Specialized neurons that can measure arterial BP.
   a. Found primarily in the aortic arch and carotid sinuses but also in most large arteries of the neck and thorax.
   b. Continually send impulses to the medulla via branches of the glossopharyngeal and vagus nerves (cranial nerves IX and X).
   c. Impulse frequency varies directly with the BP.
   d. 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.

e. Unfortunately baroreceptors are ineffective at dealing with sustained changes in BP – as occurs in hypertensive individuals.

46. Adrenal medullary mechanism
   a. The adrenal glands 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.

47. Cerebral cortex and hypothalamus = Affect BP during emotional situations, stress, and sex.
   a. Usually via increases in the activity of the vasomotor and cardioacceleratory centers.

48. Renin-angiotensin-aldosterone system
   a. Kidneys exhibit 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 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.

49. Atrial Natriuretic Peptide = Hormone released by atria in response to increased stretch (which is indicative of increased blood volume).
   a. ANP is a vasodilator and thus decreases TPR.
   b. ANP also increases sodium excretion in the urine and thus increases urine volume. Increased urine volume decreases blood volume.
   c. The decreases in blood volume and TPR decrease BP.

50. Rate of blood flow = Varies in different parts of the vascular system.
   a. Rapid in large vessels and slow in small vessels.
   b. Blood flow velocity varies inversely w/ total cross-sectional area of a class of vessel.
   c. Total cross sectional area can be determined by multiplying the cross sectional area of a single vessel by the total # of those vessels.
   d. As you go from the aorta to the arteries to the capillaries, total cross-sectional area increases dramatically (b/c of the incredibly large # of capillaries.) Thus the velocity of flow decreases. The low velocity w/i capillaries allows for easy exchange btwn blood and ISF.
   e. 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.

51. Distribution of blood flow during exercise
   a. During exercise blood flow increases to:
      i. Coronary blood vessels 3-fold
      ii. Skeletal muscles 11-fold
      iii. Skin 5-fold.