1. **Heart Functions**
   a. Generates pressure that propels blood thru blood vessels. (Tissue perfusion.)
   b. Separates oxygenated and deoxygenated blood.

2. **Basic Blood Vessel Types**
   a. Arteries = carry blood away from the heart
   b. Veins = carry blood towards the heart
   c. Capillaries = link arteries and veins. Sites of exchange btw blood and tissues.
   d. Blood vessels directly leading into/out of the heart are known as the great vessels.

3. **Heart position** = w/i the mediastinum, the medial cavity of the thorax.
   a. Apex rests on the superior diaphragmatic surface and points toward the left hip.
   b. Base points towards the right shoulder.
   c. Medial to the lungs. Anterior to the esophagus and vertebrae. Posterior to the sternum.

4. **Pericardium** = Encloses the heart.
   a. Outermost layer is the fibrous pericardium – a collagenous sac that protects and anchors
      the heart and prevents it from distending.
   b. Deeper is the serous pericardium, a 2 layered serous membrane.
   c. Parietal serous pericardium is the outer of the 2 and abuts the fibrous pericardium.
   d. Visceral serous pericardium is the inner of the 2 and is the external covering of the heart
      and is a.k.a. the epicardium.
   e. Parietal and visceral layers are continuous where the great vessels leave the heart.
   f. Pericardial cavity is the space btw the parietal and visceral layers and contains serous
      fluid, which reduces friction.

5. **Heart wall** = Divided into 3 layers.
   a. Epicardium = Most superficial and is a.k.a. visceral serous pericardium.
      i. Composed of simple squamous epithelium overlying adipose & areolar CT.
   b. Myocardium = Middle layer
      i. Primarily cardiac muscle, but also contains blood vessels, nerves, and CT.
      ii. Myocardial CT forms a dense network (fibrous skeleton), which supports the
          heart valves, acts as origin/insertion for the cardiac muscle cells, and helps direct
          the spread of electrical activity within the heart along defined pathways.
   c. Endocardium = Inner layer
      i. Consists of endothelium (simple squamous epithelium) resting on thin CT.
      ii. Lines the heart chambers and its folds create the heart valves.

6. **Heart Chambers** = 2 sup. atria (thin receiving chambers) and 2 inf. ventricles (muscular pumping
   chambers)
   a. Thin interatrial septum divides atria. Thick interventricular septum divides ventricles.

7. **Heart consists** of 2 pumps connected in series.
   a. Each ventricle sends blood to a different circuit. Pulmonary circuit runs btw the heart
      and the lungs. Systemic circuit runs btw the heart and the rest of the body tissues.
   b. R. side receives deO₂ blood from systemic circuit and pumps it thru pulmonary circuit.
   c. L. side receives O₂ blood from pulmonary circuit and pumps it thru systemic circuit.
   d. The 2 ventricles MUST pump an equivalent volume of blood. This is ventricular balance.
      i. If RV>LV → Pulmonary edema. If RV<LV → Systemic edema

8. **Right atrium** = Receives deO₂ blood from the systemic circuit via 3 vessels:
   a. Superior vena cava carries blood from arms, head, and upper torso.
   b. Inferior vena cava carries blood from the legs, abdomen, and pelvis.
   c. Coronary sinus carries blood from the coronary circulation (nourishing the heart wall).
   d. Sends blood to right ventricle thru tricuspid valve.

9. **Left atrium** = Receives O₂ blood from the pulmonary circuit via the 4 pulmonary veins.
   a. Sends blood to left ventricle thru mitral (bicuspid) valve.

10. **Fossa ovalis** = Remnant of the foramen ovale, a hole in the fetal atrial septum.
    a. Fetal blood flowed through the hole from RA to LA thus bypassing the pulmonary circuit
      (since the fetal lungs are neither developed nor oxygenated).
11. **Ventricles** = Large, muscular chambers. The actual pumps.
   a. Contain muscular ridges (trabeculae carneae) and muscular bulges (papillary muscles).

12. **Right ventricle** = Discharges blood into pulmonary trunk, the first vessel of the pulmonary circuit.
   a. Separated from the pulmonary trunk by the pulmonary semilunar valve

13. **Left ventricle** = Discharges blood into the aorta, the first vessel of the systemic circuit.
   a. Separated from the aorta by the aortic semilunar valve.
   b. More muscular than the RV. Necessary because the LV pumps blood a farther distance and against greater pressure (note: RV and LV pump the same volume of blood per beat).

14. Systemic and pulmonary circuits

   **Systemic circuit:**
   - L ventricle
   - Aorta
   - Systemic arteries
   - Syst. capillaries
   - Syst. veins
   - Venae cavae
   - R atrium

   **Pulmonary circuit:**
   - R ventricle
   - Pulmonary trunk
   - Pulm. arteries
   - Pulm. capillaries
   - Pulm. veins
   - L atrium

15. Ways in which the systemic circuit differs from the pulmonary circuit
   a. Longer
   c. Its blood is under far greater pressure.
   d. Resistance to blood movement is also far greater.
   e. Systemic arteries are O₂ rich & CO₂ poor. Pulmonary arteries are O₂ poor & CO₂ rich.
      Systemic veins are O₂ poor and CO₂ rich. Pulmonary veins are O₂ rich and CO₂ poor.

   a. Needed b/c the heart requires a prodigious amount of O₂ and nutrients, and little O₂ or nutrients can diffuse thru the thick myocardium.
   b. Basic pathway of blood in the coronary circuit is:

17. 4 Heart valves = Ensure 1-way flow within the heart.
   a. 2 atrioventricular valves separating the atria from the ventricles
   b. 2 semilunar valves separating the ventricles from their great vessels.

18. AV valves
   a. Tricuspid valve has 3 flaps and prevents backflow of blood from the RV to the RA.
   b. Mitral (bicuspid) valve prevents backflow from the LV to the LA
   c. AV valve flaps are attached to strings of collagen called chordae tendineae.
   d. Chordae tendineae attach to papillary muscles in the ventricle wall.
   e. Blood goes thru an AV valve from atria to the ventricle when atrial BP > ventricular BP.
      At this time the chordae tendineae are slack, and papillary muscles are relaxed.
   f. When the ventricle contracts:
      i. Ventricular BP > atrial BP. Blood will attempt to flow down its pressure gradient back into the atria. This pushes the valve flaps towards the atria (closing them). Chordae tendineae tighten as papillary muscles contract thus preventing the valve flaps from flipping up (prolapsing) into the atrium.
      g. Note that the chordae tendineae and papillary muscles do NOT close the AV valves themselves. Blood’s attempt to backflow is what pushes the valves shut.

19. Aortic semilunar valve = Prevents backflow from the aorta into the LV.
   a. It opens when LV BP > aortic BP. It shuts when aortic BP > LV BP.

20. Pulmonary semilunar valve = Prevents backflow from the pulmonary trunk into the LV.
   a. It opens when RV BP > pulmonary trunk BP. It shuts when PT BP > RV BP.
b. Note that b/c the semilunar valves are “pocket valves” they have no need for associated chordae tendineae or papillary muscles.

21. Cardiac muscle = involuntary muscle that comprises the bulk of the heart wall.
   a. 2 types of cardiac muscle cells – contractile cells and autorhythmic cells.
   b. Contractile cells: 99%. Generate the pumping force. Striated, short, and branched.
   c. Autorhythmic cells: 1%. Spontaneously depolarize to set the rate of contraction.

22. Intercalated discs = Link cardiac muscle cells together mechanically and electrically.
   a. Contain 2 separate structures: gap junctions and desmosomes.
   b. Gap junctions = Protein channels that allow ions to flow btwn adjacent cells.
      i. Create an electrical connection btwn cardiac muscle cells.
      ii. Allow the depolarization wave initiated by autorhythmic cells to spread through
          the cardiac musculature.
      iii. Electrical excitation of cardiac muscle cells causes contraction.
      iv. Allows the heart to function as a single coordinated unit (functional syncytium),
          which helps maximize its efficiency.
   c. Desmosomes = Protein filaments that physically connect adjacent cardiac muscle cells
      i. Prevent cells from separating during contraction.

23. Fibrous skeleton of the heart = Dense irregular CT w/i the heart.
   a. Provides origins and insertion points for cardiac contractile cells.
   b. Supports heart valves and separates the atria from ventricles physically and electrically

24. Intrinsic control of heart rate = Performed by the autorhythmic cardiac muscle cells.
   a. 5 main groups of autorhythmic cells:
      i. Sinoatrial node – group of autorhythmic cells near opening of the SVC.
      ii. Atrioventricular node – group in the inferior IA septum near tricuspid orifice.
      iii. Atrioventricular bundle – group of ACs in the superior IV septum.
      iv. Right and left bundle branches – group of ACs in middle & inferior IV septum.
      v. Purkinje fibers – separate autorhythmic cells that wind through the ventricles.
   b. The above list also gives the path of the electrical conduction system within the heart.
   c. All autorhythmic cells have the ability to rhythmically and spontaneously depolarize.
   d. SA node cells have the fastest rate of depolarization and are the pacemaker of the heart.
   e. Spread of depolarization:

<table>
<thead>
<tr>
<th>Depolarization wave travels to atrial contractile cells.</th>
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<tbody>
<tr>
<td>Atrial contractile cells contract. Note that the right atrium begins to contract before the left.</td>
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   | Depolarization wave travels to AV node. Depolarization wave is briefly delayed, allowing atria to complete contracting before the ventricles begin. |

   | Depolarization wave travels down AV bundle & bundle branches. (Fibrous skeleton prevents it from traveling directly from atria to ventricles) |

   | Depolarization wave travels thru the ventricles via Purkinje fibers. |

   | Ventricular contractile cells depolarize and then contract. |

   f. W/o any input (neural or hormonal), the inherent rate of SA node depolarization determines heart rate. Normal rate is roughly 100 depolarizations per minute.
   g. Fibrous skeleton of the heart electrically isolates the atria and the ventricles. The AV bundle is the only electrical connection btwn them.
   h. Ventricular depolarization and contraction begin at the apex of the heart and proceed upward. This allows blood to be propelled up out of the ventricles into the great vessels.

25. Extrinsic control of heart rate = Refers to factors outside of cardiac tissue that affect heart rate.
   a. Most extrinsic control is nervous or endocrine in nature.

26. Medulla oblongata contains 2 cardiac centers that can alter the heart’s activity.
a. Cardioacceleratory center = Projects to heart via cardiac sympathetic nerves
   i. Releases NE upon SA node, AV node, and ventricular myocardium.
   ii. Increases contraction rate and force.

b. Cardioinhibitory center = projects to heart via parasympathetic neurons in CN X
   i. Releases ACh upon the SA node and AV nodes.
   ii. Decreases heart rate but causes no change in the heart’s contractile strength.

c. At rest, both parasympathetic and sympathetic neurons are releasing neurotransmitters onto the heart, but the parasympathetic branch releases more.

d. During stress, exercise, and excessive heat the sympathetic influence dominates.

27. Heart sounds = 2 associated with each heartbeat.
   a. 1st heart sound (LUB) = Caused by the shutting of the atrioventricular valves
      i. Occurs at the onset of ventricular contraction (i.e. end of ventricular relaxation).
   b. 2nd heart sound (DUP) = Caused by the shutting of the semilunar valves
      i. Occurs at the end of ventricular contraction (i.e. end of ventricular relaxation).

28. Cardiac cycle = Refers to all events associated with blood flow thru the heart during one heartbeat.
   a. Includes the contraction (systole) and relaxation (diastole) of all 4 chambers.
   b. Divided into 4 parts: ventricular filling, isovolumetric contraction, ventricular ejection, and isovolumetric relaxation.
   c. We’ll discuss it in terms of the LV and LA. Same events are occurring on the right side.

29. Ventricular filling
   a. LA BP is lower than the BP of the pulmonary vasculature, so blood enters the left atrium.
   b. LA BP is greater than LV BP. Thus the mitral valve is open and blood enters the LV.
   c. LV BP is less than aortic BP. As a result, blood tries to back flow from the aorta into the LV and this forces the aortic semilunar valve closed.
   d. Neither atrial nor ventricular muscle is contracting. Both are in diastole.
   e. About 80% of the ultimate ventricular volume will enter in this passive manner.
   f. Near the end of filling, while the LV is still relaxing, the LA depolarizes and contracts. This pushes roughly the final 20% of blood into the LV.
   g. LV now has the max volume it will contain during this cycle. This is the end diastolic volume (EDV). (= 130mL). For the rest of the cycle, the LA will be in diastole.

30. Isovolumetric contraction
   a. LV depolarizes, contracts, and LV BP rises and almost immediately exceeds LA BP.
   b. Blood is pushed upward shutting the mitral valve- creating the 1st heart sound (LUB).
   c. However, the opening of the aortic semilunar valve requires much more pressure than was necessary to close the mitral valve.
   d. So after the mitral valve is shut, the LV continues to contract and its BP rises, but until LV BP exceeds aortic BP the aortic semilunar valve remains shut.
   e. Thus, during this period the AV and semilunar valves are shut and the volume within the LV is not changing. Hence this phase is known as “isovolumetric” contraction.

31. Ventricular ejection
   a. LV BP now exceeds aortic BP (80 mmHg), the semilunar valve is forced open, and blood is ejected from the LV into the ascending aorta.
   b. Not all of the blood in the LV is ejected. The amount remaining after ventricular contraction is known as the end systolic volume (ESV). A typical value is 70mL. This gives a reserve that could also be ejected if needed (e.g., during exercise).
   c. Amount of blood ejected during this phase is known as the stroke volume. Stroke volume is the difference between end diastolic and end systolic volumes: SV=EDV-ESV.

32. Isovolumetric relaxation
   a. LV stops contracting, its BP falls and quickly becomes less than aortic BP and blood tries to back flow, which shuts the semilunar valve- creating the 2nd heart sound (DUP).
   b. It takes more time for LV BP to drop below LA BP – and cause the mitral valve to open.
   c. During this time, as LV BP is falling, the AV and semilunar valves are shut and LV volume is not changing.
d. Once LV BP falls below LA BP (which is rising as blood returns to the heart), the mitral valve will open and the cycle will begin anew with another round of ventricular filling.

33. LV vs. RV
   a. Events on the left side of the heart are mirrored by the events on the right side.
   b. Both the right and the left side of the heart contract at the same rate.
   c. They have identical stroke volumes on average.
   d. The only difference is the pressure involved. LV pressure is greater than RV pressure.
   e. LV and RV need identical stroke volumes. If LV SV > RV SV, then blood backs up in the systemic circuit. If LV SV < RV SV, then blood backs up in the pulmonary circuit.

34. Cardiac output = Amount of blood pumped by each ventricle in one minute.
   a. Product of heart rate and stroke volume: \( CO(\text{mL/min}) = HR(\text{beats/min}) \times SV(\text{mL/beat}) \).
   b. Changes in either stroke volume or heart rate can alter cardiac output.
   c. During exercise, cardiac output can \( \uparrow \) dramatically.

35. \( \uparrow \) in heart rate are achieved by:
   a. \( \uparrow \) in cardioacceleratory center activity. This \( \uparrow \) sympathetic nerve activity and \( \uparrow \) NE release on the heart.
   b. Decrease in cardioinhibitory center activity. This decreases parasympathetic nerve activity and \( \uparrow \) Ach release on the heart.

36. Decreases in heart rate are achieved by:
   a. Decreased CAC activity. This decreases sympathetic activity and NE release on heart.
   b. \( \uparrow \) in cardioinhibitory activity. This \( \uparrow \) parasympathetic nerve activity and \( \uparrow \) vagus nerve activity (a.k.a. vagal tone), and \( \uparrow \) ACH release on the heart.

37. Relationship btwn heart rate and stroke volume
   a. If heart rate changes without a change in contractility (the strength of the contraction), stroke volume will change also. This is because changing the heart rate alters the filling time (i.e., the time btwn beats during which the heart fills up with blood).

38. Hormonal influences on heart rate.
   a. Epinephrine, released by the adrenal gland (located superior to the kidney), \( \uparrow \) HR.
   b. Thyroxine, released by the thyroid gland (located in the anterior neck), \( \uparrow \) HR.

39. Other factors that raise heart rate = \( \uparrow \) body temp, caffeine, nicotine, and ephedrine.

40. Other factors that decrease heart rate = Decreased body temp and drugs such as beta blockers.

41. Regulation of stroke volume = Depends on 3 main variables: preload, contractility, and afterload.

42. Preload = Refers to the degree of ventricular stretch during filling.
   a. \( \uparrow \) stretch causes more optimum cross-bridge formation btwn actin and myosin and a stronger contraction, thus ejecting a larger volume.
   b. Frank-Starling law states: "What returns to the heart will get pumped out of the heart."
   c. As venous return (blood volume entering RA per min) \( \uparrow \), EDV \( \uparrow \), and stroke volume \( \uparrow \).
   d. A decrease in HR will increase the filling time and thus increase EDV (and preload).
   e. An \( \uparrow \) in venous pressure will also increase EDV (and preload).
   f. The stroke volume is greatly influenced by changes in preload.

43. Contractility = Strength of the heart’s contraction independent of its degree of stretch.
   a. Increase in contractility will increase stroke volume and decrease end systolic volume.
   b. Contractility is \( \uparrow \) by: \( \uparrow \) cardioacceleratory activity; epinephrine and thyroxine.

44. Afterload = Pressure that must be overcome to open the semilunar valve and eject blood.
   a. Equivalent to arterial blood pressure.
   b. \( \uparrow \) in arterial BP will increase afterload. This makes the heart expend more time/energy on opening the semilunar valve and less on ejecting blood.
   c. It takes a significant \( \uparrow \) in afterload to decrease the pumping output of the heart.
   d. Increased afterload decreases stroke volume and \( \uparrow \) end systolic volume.

45. Effects of cardiovascular training:
   a. Increased LV contractility
   b. Increased size of the LV chamber
   c. Increased branching of coronary blood vessels.