Cardiovascular System: The Heart

I. Anatomy of the Heart (See lab handout for terms list)
   A. Describe the size, shape and location of the heart
   B. Describe the structure and function of the pericardium
   C. Describe the histology of the three major layers of the heart
   D. Describe the external and internal anatomy of the heart
   E. Describe the route of Blood flow through the heart.

II. Histology
   A. Cardiac muscle:
      1. Elongated branching with one and sometimes two centrally located nuclei,
      2. Striated muscle
         a. Contain actin and myosin myofilaments
      3. Smooth sarcoplasmic reticulum
         a. Not as regularly arranged or as abundant as skeletal muscle
         (1) partly responsible for the slow onset and prolonged contraction phase in cardiac muscle.
      4. ATP is the energy source for contraction
         a. depends on oxygen availability
         b. can’t develop a large oxygen debt like skeletal
         c. Cardiac muscle contains large amounts of mitochondria.
         d. Extensive capillary beds provide adequate oxygen for production of ATP.
      5. Cells bound at ends by intercalated disks
         a. desmosome - Hold cells tightly together
         b. Gap junction - allows flow of ions between cells (electrical current)
            (1) allows heart muscle to function as a single unit.
            (2) highly coordinated muscular contractions.
   6. Conducting system of the heart. (Brief review)
      a. Nodes
         (1) SA node
            (a) medial to the opening of the superior vena cava
            (b) action potentials originate in the SA node and travel across the atrium
            (c) considered to be the pacemaker of the heart.
               i) muscle cells have an intrinsic ability to contract but the SA node contracts a
t                  greater frequency.
         (2) AV node
            (a) medial to the right AV valve
            (b) receives action potentials from the atrium
            (c) passes them to the interventricular septum to the bundle of His after a brief delay
               i) delay allows for complete contraction of atrium and filling of the ventricle.
      b. Bundle
         (1) AV bundle (Bundle of His)
         (2) bundle branches
            (a) rapid transmission of signal to apex
            (b) result in apex contracting first -
      c. purkinje fibers
         (1) large diameter cardiac muscle fibers
         (2) don’t contain as much actin and myosin
            (a) don’t contract as forcefully
         (3) well developed intercalated disks and gap junctions.
            (a) action potentials travel quickly through these fibers.
      d. wringing action -
         (1) due to spiral arrangement of cardiac muscle and
B. Electrical properties

1. Action potentials
   a. Last longer in Cardiac muscle than in skeletal muscle
      (1) Action potential last 200-500 ms in cardiac compared to 2 ms in skeletal muscle.
   b. Contain different membrane channels than skeletal.
   c. Different Phases of contraction:
      (1) depolarization phase
      (2) partial repolarization
      (3) plateau phase (not found in skeletal)
      (4) repolarization phase.
   d. Cardiac muscle contains voltage gated Ca++ slow channels which account for the plateau phase.
   e. Action potentials are transmitted from fiber to fiber unlike skeletal which depolarizes along the length of only one fiber.
   f. Rate of action potential propagation is slower in cardiac fibers.

2. Autorhythmicity of Cardiac muscle
   a. If heart is removed from the body it will continue to beat for some time if maintained under physiological conditions.
   b. Spontaneous action potentials are generated in cardiac muscle.
      (1) more rapid in SA node.
         (a) SA node contains Ca++ channels that open spontaneously
         (b) SA frequency = 70 - 80 bpm
      (2) AV node also contains leaky Ca++ channels.
         (a) AV frequency = 40-60 bpm
      (3) Bundle of His frequency = 30 bpm
   c. If any of these structures become blocked the others take over the autorythmicity of the heart.
   d. Ectopic foci - in unusual circumstances can become the pacemaker of the heart.
      (1) Appear when the rate of contraction is enhanced in another part of the heart
         (a) - injured cells usually have and increased rate of depolarization.
      (2) Also appear when the rythmicity at the SA node is reduced or blocked
C. Major Cardiac Arrhythmias

1. **Tachycardia** - excess of 100 bpm
   a. Cause: elevated body temp; excessive sympathetic stimulation

2. **Atrial flutter** - 2-3 contractions of the atria before a contraction of the ventricle
   a. Cause: ectopic action potentials in atria

3. **Atrial fibrillation** - irregular timing of atrial contraction causing ventricle to be constantly stimulated
   a. Cause: ectopic action potentials in atria

4. **Ventricular fibrillation** - many patches of asynchronous contracting ventricular muscles
   a. Cause: ectopic action potentials in ventricle

5. **Bradycardia** - Heart rate less than 60 bpm
   a. Cause: elevated stroke volume in athletes; excessive vagal stimulation;

6. **SA Node block** - cessation of SA node action resulting in low heart rate
   a. lower heart rate due to AV node taking over as pacemaker
   b. Cause: tissue damage due to infarction

7. **AV Node block** - high atrial rhythm with low ventricular rhythm
   a. Cause: Inflammation or compression of AV bundle

8. **Premature Atrial contraction** - shortened intervals between contractions
   a. Cause: Excessive; smoking, caffeine, alcohol, Not enough sleep.

9. **Premature Ventricular contraction** - ectopic foci in ventricle, only one ventricle may contract
   a. Cause: ectopic foci, lack of sleep, irritability, coronary thrombus, too much caffeine.

III. Cardiac Cycle

A. Cardiac cycle is the repetitive pumping cycle of the heart

1. Begins with contraction and ends with the beginning of the next contraction
   a. Resulting changes in pressure cause movement of the blood (high pressure to low)

2. Systole and Diastole
   a. Systole - to contract
   b. Diastole - to dilate
   c. Atrial vs Ventricular Systole and Diastole
      (1) When we mention Systole and diastole we are generally talking about ventricular S & D.
   d. Atrial S&D
      (1) Ventricular filling
         (a) 2/3 of filling takes place during the first 1/3 of ventricular diastole
         (b) middle 1/3 little filling takes place
         (c) last third of ventricular diastole SA node depolarizes, Atria contract to finish filling of ventricle
      (2) Atria only important for increased blood flow during exercise (3-400% increase in flow needed)
      (3) Changes in left atrial pressure curve
         (a) a wave -
            i) atrial contraction,
            ii) increase of 7-8 mm Hg.
         (b) c wave -
            i) beginning of ventricular systole. 
            ii) AV valves close
            iii) slight increase in atrial pressure
         (c) v wave -
            i) end of ventricular systole
            ii) increased pressure due to flow of blood into atria from vena cava
      (4) Ventricular S & D
         (a) isometric contraction
            i) AV valves close as contraction starts
            ii) no changes in blood flow until pressure is high enough to open semilunar valves.
(aortic~80 mmHg; ~25 mmHg in pulmonary)

(b) Ejection
i) Pressure climbs to approximately 120 mmHg in left ventricle
ii) Climbs to 33 mmHg in the right ventricle.
iii) Amount of blood pumped by either side is about the same.
iv) Ventricular pressure decreases during contraction as blood flows out.
v) Arterial walls are stretched to accommodate new blood.

(c) Ventricular Relaxation
i) blood pressure falls rapidly
ii) stretched vessel walls force blood back into ventricle causing the aortic and pulmonary semilunar valves to close at approx. 95 mmHg

(d) Isometric relaxation
i) no blood flows from atria to ventricle.

(e) Pressure in ventricle falls below that of atria and filling begins.

B. Stroke volume
1. Volume of blood pumped during each cardiac cycle
   a. at rest ~70 ml
   b. can increase to ~200 ml during exercise

C. Heart Rate
1. ~72 BPM
2. Increase to over 120 bpm in exercise.

D. Cardiac Output
1. = stroke volume x heart rate
2. Resting: 72 beats/min x 70 ml/beat = 5040 ml/min
3. Exercise: 120 beats/min x 200 ml/beat = 24,000 ml/min.
4. Cardiac reserve
   a. max cardiac output - resting cardiac output
   b. = 24,000-5040 ml/min = 18960 ml
5. C.O. is the major factor in determining blood pressure.

E. Blood pressure
1. Blood pressure reflects pressure changes in the aorta not the ventricle
2. Normal BP 120 systolic / 80 diastolic

F. Heart Sounds:
1. Lub: closing of AV valves (QRS wave)
2. Dub: closing of Semilunar valves (T wave)
3. Systole occurs between the 1st and 2nd heart sound
4. Diastole occurs between 2nd heart sound and the 1st.
5. Clinical:
   a. Murmurs: abnormal heart sounds
   b. Incompetent valve - leaks excessively (gurgling, swishing)
   c. Stenosis: abnormally small valve openings (rushing sound before valve closes.
   d. Causes: genetic or due to rheumatic fever scaring or myocardial infarction affecting the papillary muscles.
IV. Regulation of the heart

A. Amount of blood pumped by heart to maintain homeostasis must change dramatically ie. Rest vs exercise

B. Two forms of regulation (Intrinsic and extrinsic regulation)

1. **Intrinsic regulation**
   a. relies only upon the heart itself and not on neural or hormones control.
   b. **Starling's law of the heart**
      1. Increased venous return causes stretching of the heart
      2. The greater the stretch the greater the stretch of contraction.
      3. The greater the preload / stretch the more forcefully the heart contracts.
   c. **Stretching the SA node**
      1. causes an increased permeability to Ca++ and therefore increased rate of action potential generation.
   d. During **exercise**
      1. Muscle contraction compresses veins forcing blood out of muscle and back to heart
      2. increasing venous return subsequently increases: heart rate, stroke volume and force of contraction
      3. End result increase in cardiac output and blood flow to exercising muscle.
      4. Return to rest decrease blood flow back to heart.
         a) decrease preload, heart rate, stroke volume and blood flow.

2. **Extrinsic regulation**
   a. Heart is innervated by both parasympathetic and sympathetic nerve fibers.
      1. Affect heart rate and stroke volume
      2. Sympathetic effect can increase cardiac output by 50-100% above resting
      3. Parasympathetic effect is small
         a) can lower cardiac output 10-20%.
   b. Function: to maintain blood pressure, oxygen levels, CO₂ levels, and pH.
   c. **Parasympathetic control**
      1. Supplied by the vagus nerve
      2. decreases heart rate
      3. postganglionic neurons secrete acetylcholine which increase membrane permeability to K+ ions producing hyperpolarization of membrane
   d. **Sympathetic control**
      1. supplied by cardiac nerves via sympathetic chain ganglia
      2. increase heart rate and force of contraction
      3. Postganglionic neurons secrete norepinephrine which increase membrane permeability to Na and Ca++ ions producing depolarization of membrane
      4. Epinephrine and NE are released into the blood from the adrenal medulla as a result of sympathetic stimulation.
         a) Epi and NE have long lasting effects on the heart compared to neural control’
         b) Epi and NE increase rate and force of heart contraction

V. Heart and Homeostatis

A. Effect of Blood Pressure on the heart

1. Baroreceptors in carotid sinus and aortic arch monitor blood pressure
   a. Increase in BP (above 80/120)
      1. causes walls of carotid and aorta to stretch
      2. increased frequency of signals to medulla
         a) vasomotor control center (vasoconstriction / dilatation)
         b) cardiac control center (heart rate)
      3. Result:
         a) decrease sympathetic stimulation and
         b) increase parasympathetic stimulation of heart.
(4) results is decreased heart rate and cardiac output and vasodilation to decrease peripheral resistance in arteries.

b. Decrease in BP (below 80/120)

2. Stretching of the right atrial wall
   a. Stretch of atria causes an increase in the depolarization of the SA node due to increased Ca++ permeability.
   b. Result: increase in the heart rate

B. Effect of pH, Carbon Dioxide and Oxygen on the heart
   1. Chemoreceptors monitor pH, Carbon Dioxide and Oxygen levels
      a. Chemoreceptors in carotid sinus and aortic bodies monitor blood $O_2$, $CO_2$, and pH.
      b. Chemoreceptors in the medulla oblongata monitor $CO_2$, and pH.
   2. Increased $CO_2$ and decreased pH
      a. Medullary chemoreceptors increase sympathetic stimulation and decrease parasympathetic stimulation to heart.
      b. Result:
         (1) increased heart rate,
         (2) increased stroke volume and
         (3) vasoconstriction
      c. Increased mean arterial pressure increases flow to lungs
         (1) helps eliminate excess $CO_2$ and $H+$ ions and
         (2) increases $O_2$ uptake.
   3. Low oxygen levels
      a. Stimulate Carotid and aortic body chemoreceptors
      b. Result:
         (1) decreased heart rate and vasoconstriction.
            (a) Vasoconstriction increase blood pressure even with drop in heart rate.
            (b) Carotid chemoreceptors normally function with other systems to increase heart rate.
         (2) Carotid body chemoreceptors are more heavily involved in control of respiratory center
            (a) - increase rate of respiration with low Oxygen levels.
   4. Chemoreceptor systems only engage in emergency conditions and do not normally regulate the cardiovascular system.

C. Effect of Extracellular Ion concentration on the heart
   1. Excess K+ ions cause heart rate and stroke volume to decrease
      a. Two fold increase results in heart block.
   2. Increased extracellular Ca++ ions increases the force of contraction and decreases heart rate
   3. Decreased Ca++ decreases force of contraction and increases H.R.

D. Effect of Body Temperature on the heart
   1. H.R. increase when body temp increase and decreases with decrease in temp.