LAB

17

The Heart

How amazing is the heart! In the embryo it begins as a simple tube with two veins dumping into it and two arterial vessels leading out. Blood is being pumped by the human heart at three weeks after fertilization. Watch the YouTube 1951 film “Normal Development of the Heart” by Dr. Richard Blandau, University of Washington. The reality is more amazing than words can describe.

The heart, about the size of your fist, is located pretty much in the center of the chest (between the lungs) with a slight pointing to the left which makes it feel like it is on the left side. The “lub-dub” sound we hear when listening to the beat is the result of heart valves closing. It is an incredible pump. It can pump 35 million gallons of blood (3 supertankers) in a lifetime. Furthermore, the heart is capable of varying its output between 50ml and 250ml per beat and its contraction rate from 40 to 200 beats per minute (bpm). As a child your resting heartbeat was about 100 bpm, and as an adult the normal is near 70. When you are resting, the heart pumps about 5 liters of blood per minute. This is about the same rate as a slow flow of water from the bathroom faucet when you brush your teeth. During strenuous exercise your heart can pump 30 liters of blood per minute. An elite-trained heart can pump 40 liters per minute. This is about equal to the water flow when you fast-fill the bathtub.

The strength of your heartbeat is equal to a “hard squeeze” of a tennis ball. It beats 100,000 times in a day and about 2.5 billion times before it is completely worn out. Although a woman’s heart beats 10% faster than a man’s which would predict 10% fewer years, she outlives him by 10%. The heart defies simple description. You will refer to it as the center of your love for others – the seat of your character. It started you going at three weeks after conception and will provide life until your last breath. Now it’s time to learn how the heart accomplishes these feats.

Exercise #1 The Heart as a Pump
Exercise #2 The Heart Cycle
Exercise #3 Heart Sounds
Exercise #4 Heart Rate and Stroke Volume
Exercise #5 Clinical Treatments for Heart Disorders

Exercise #1
The Heart as a Pump

Two Pumps in One

The heart must control two separate circuits – pulmonary and systemic.

The heart is actually two pumps—a ***right pump*** and a ***left pump***. The right pump delivers blood to the lungs; this route is called the ***pulmonary circuit***. The left pump pushes blood to the rest of the body; this route is called the ***systemic circuit***.

Notice that Figure 17.1 is drawn as if the heart is facing you. This means that the right side of the heart is on the left side of the drawing. All anatomy diagrams are drawn in this view. Remember this whenever you look at a medical picture.

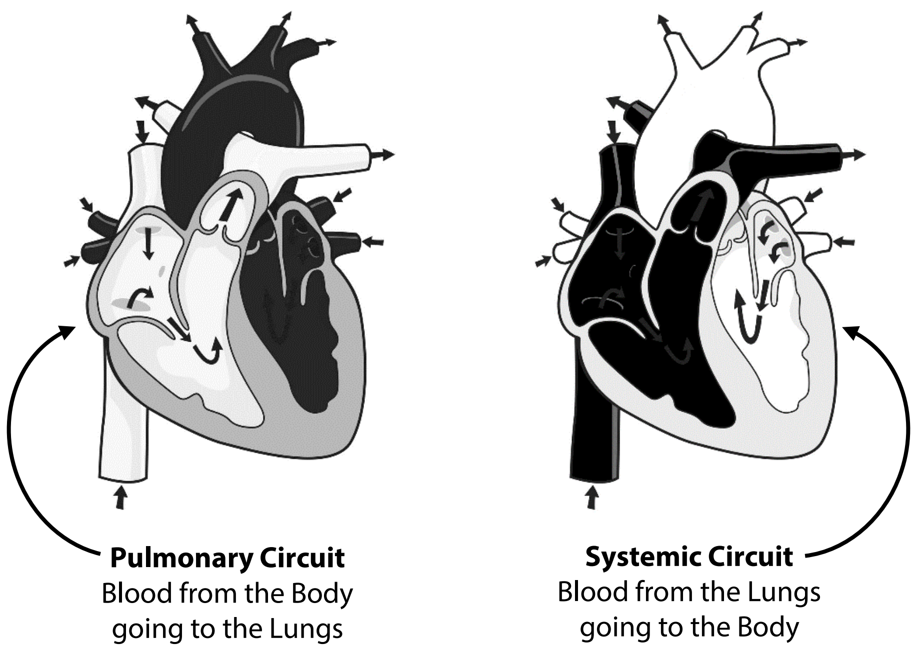


Figure 17.1. Diagram of the heart showing blood flow in the Pulmonary and Systemic Circuits.

Two Chambers per Pump

There are *two* chambers in each of the two heart pumps. The top one is a temporary storage chamber called the ***atrium***, and the bottom one is a pumping chamber called the ***ventricle***. Blood from the body tissues flows into the atrium of the right heart pump. This blood is then pushed through a valve and enters the right ventricle. The ventricle does the hard work of

Atria are storage chambers; Ventricles are pumping chambers.

pumping blood out of the heart. The right ventricle pumps blood to the lungs where it is ***oxygenated***. While the ventricle is pumping blood out of the heart, the atrium fills with blood entering the heart. This efficient design allows the atrium to quickly refill the emptied ventricle, resulting in a fast-pumping heart.

Oxygenated blood from the lungs enters the atrium of the left heart pump. This blood is then moved into the left ventricle which pumps the blood to all of the body tissues (except the lungs). The left pump has to work harder than the right pump.

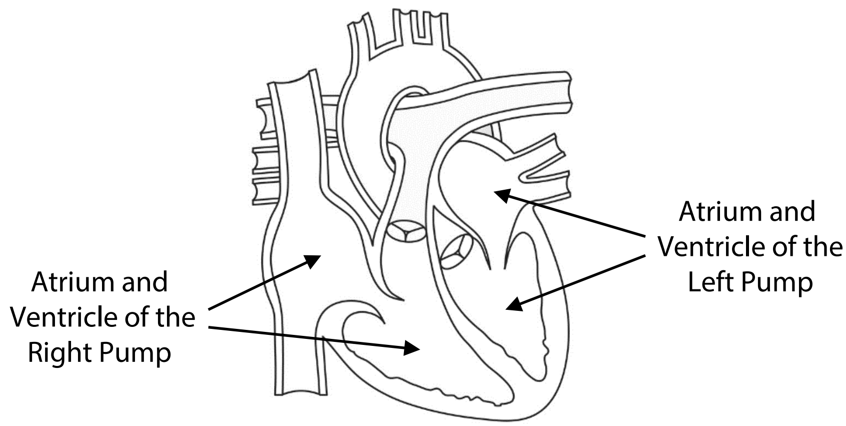


Figure 17.2. Diagram of the heart showing the Right Pump (Pulmonary) and the Left Pump (Systemic). Each pump has a storage chamber (atrium) and a pumping chamber (ventricle).

? Question

1. Which side of the heart is part of the pulmonary circuit?

2. Which side of the heart is part of the systemic circuit?

3. One congenital heart abnormality is a hole between the right and left ventricles. What two problems result?

4. Which chamber has to do the most work?
   Atrium or Ventricle

5. Which chamber has a thicker muscle wall?
   Atrium or Ventricle

6. Which pump has to do the most work?
   Right Ventricle or Left Ventricle

7. Which pump has a thicker muscle wall?
   Right Ventricle or Left Ventricle

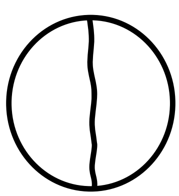
8. The right heart pump moves blood to the _____________.

9. The left heart pump moves blood to the _________.

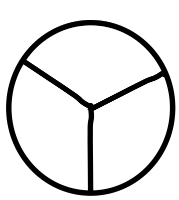
Heart Valves

A heart valve is designed to prevent blood from moving in the wrong direction.

Four heart valves are strategically located to prevent backflow as blood moves through the heart. These valves are like one-way doors—they only open in one direction. There is a chamber valve between each atrium and ventricle. These are called ***atrio-ventricular valves***, and they ensure that blood will not flow back into the atria when the ventricles contract. The medical name of the left atrio-ventricular valve is the ***mitral*** valve. The medical name of the right atrio-ventricular valve is ***tricuspid*** valve. To help you remember these names, think of the letter "l" and "m" as being next to each other in the alphabet. That means mitral = left side. Tricuspid is closer to the letter "r" (right side). Tricuspid = right side.



Bicuspid Valve (semi-lunar)



Tricuspid Valve

Blood is pushed out of the ventricles and into the two big arteries leaving the heart. The ***aorta*** receives blood from the left ventricle and directs it to the body. The ***pulmonary artery*** receives blood from the right ventricle and directs it to the lungs. There is a valve at the beginning of each of these arteries. They have a half-moon shape and are sometimes called ***semi-lunar valves***. Otherwise, the medical term refers to the vessel name (i.e. aortic valve for the aorta valve, and pulmonary valve for the pulmonary artery). The artery valves prevent backflow into the heart once blood has been pumped into the arteries. Together the four heart valves ensure that blood moves in only one direction through the heart circuit.

A heart valve is designed to plug an opening when blood moves in the wrong direction. Think of a valve as being something like a parachute that is attached to the wall of the heart or artery. If blood moves in the wrong direction, the "parachute" (valve) fills with blood and expands to plug the opening. When the blood moves in the correct direction, the valve collapses like an upside-down parachute. This allows the blood to easily pass through the valve.

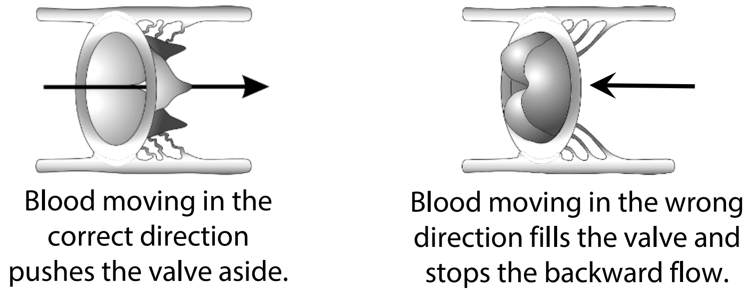


Figure 17.3. Structure of a heart or vessel valve. Valves are somewhat like a parachute that fills with blood when the blood moves in the wrong direction.

The heart valves are very flexible so that they can easily fill with blood. Special cords, called ***chordea tendineae***, attach the valve to the heart wall. These cords operate similar to the ropes of a parachute, and poets refer to them as our "heart strings".

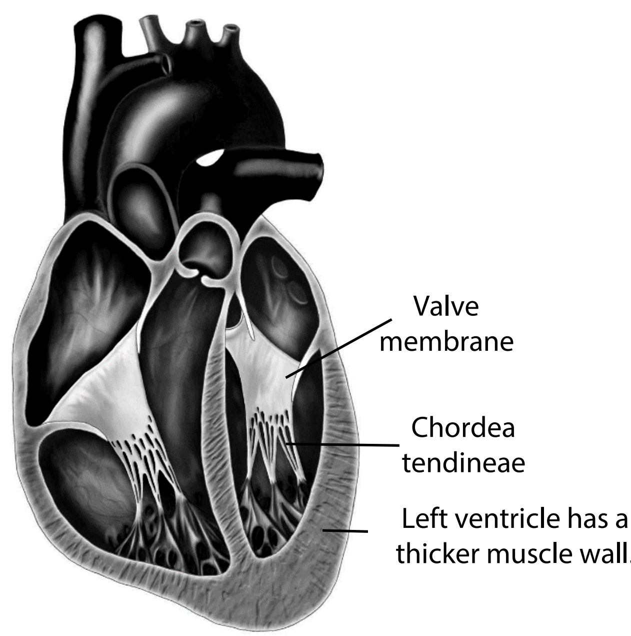


Figure 17.4. Section of the heart showing the membrane structure of valves and string-like anchors for them.

? Question

1. The atrio-ventricular valves are between the ___________ and the __________.

2. Is the mitral valve on the right or left side of the heart?

3. There are two other valves in the heart. Where are they located?

4. What would happen to blood flow if one of the valve "cords" broke? Be specific.

5. What happens to blood flow if a valve opening is narrowed by disease scarring?

6. If there is a moderate heart valve problem, what would the heart do to compensate?

7. What would you then expect to happen to the size (thickness) of the muscle on the affected side?

8. On which side of the heart would a moderate heart valve problem have more consequence to your health? Explain your answer.

Examination of the Sheep Heart

Procedure

- Go to the dissection table and observe the sheep heart.
- See if you can identify the four chambers of the heart. Remember: one of the ventricles should have a thicker muscle wall. Which one? Find it to get oriented.
- Find a heart valve, and feel the valve to determine its flexibility. Can you find the valve "cords"?
- Show your instructor when you can identify all of these structures.
- Draw a simple sketch of the dissected heart. This will remind you of what you saw in case you are tested on it later.

Sheep Heart

Exercise #2
The Heart Cycle

Conduction of the Heart Impulse

Heart muscle exhibits an ***intrinsic rhythmic contraction***. This means that a piece of it will contract on its own. Different parts of the heart muscle have different rates of contraction. In general, all parts of the heart are relatively slow in contraction rate compared to that of the pacemaker of the heart, and because they are slower they are controlled by it. The pacemaker is the ***sino-atrial node*** located in the upper part of the right atrium where the superior vena cava brings blood into the heart from the arms and head.

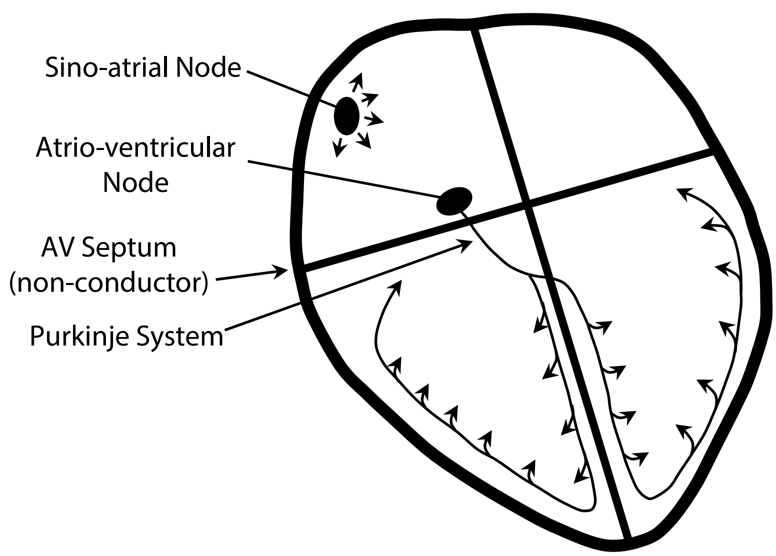


Figure 17.5. The Conduction System for the heart impulse.

A period of time after a muscle has contracted and during which it is impossible to stimulate that muscle to contract again is called the ***refractory period***. Think of it being something like "firing" a gun, and then "cocking" it to fire again. You can't fire the gun until it has been re-cocked. All muscle, including heart muscle, has a recovery time during which the contractile mechanism is returning to a "ready to go again" condition.

The normal refractory period in human heart muscle is about 0.3 seconds. ***Normal conduction time*** for the heart impulse to travel throughout the entire heart during a heartbeat is about 0.06 seconds. If the heart impulse starts at the SA node (which it normally does), it will travel throughout the heart and then stop because the heart muscle is still in refractory period. Normally, conduction time is much shorter than refractory period, and heartbeats are separated by a short resting period. Medical problems arise when anything slows conduction time.

The ***AV septum*** is connective tissue and does not conduct the heart impulse. It would stop the impulse with the contraction of the atria, but there is a special "delay center" called the ***atrio-ventricular node*** that carries the signal into the ventricles. This cluster of specialized muscle cells has a very slow transmission rate (about 10X slower than normal heart cells). This is a "delay" in the transmission of the heart impulse. Once the impulse leaves the AV node, it enters the ***Purkinje System*** (another specialized set of muscle cells). Purkinje fibers conduct the impulse very rapidly (almost 10X faster than normal heart muscle). The heart impulse conduction system operates to create two separate contractions in a single heartbeat – first, contraction of the atria, followed by a delay, and then contraction of the ventricles.

The normal ***cardiac cycle*** can be summarized as:

1. Initiation of heart impulse in the SA node.
2. Spread of impulse through atria.
3. Both atria contract together.
4. Heart impulse is stopped by the AV septum (non-conductor).
5. AV node has been activated, but the spread is very slow which delays the heart impulse before it enters the ventricles.
6. Heart impulse enters the Purkinje System which then conducts very fast throughout both ventricles.
7. Both ventricles contract together.
8. Heart impulse stops because of the refractory period.
9. The next heartbeat is again initiated by the SA node about 1 second after the previous impulse.

Heart rate and strength of contraction are controlled by the autonomic nervous system – ***sympathetic*** increases heart output, and ***parasympathetic*** decreases heart output. There are important medical implications of this control process discussed later.

Electrocardiogram (EKG)

The ***electrocardiogram*** (called ***EKG*** or ECG) is a recording of the small electrical currents produced by the traveling heart impulse and the contracting and relaxing heart muscle. These electrical patterns indicate whether there is a normal or abnormal functioning of the heart. A normal EKG is shown in Figure 17.6.

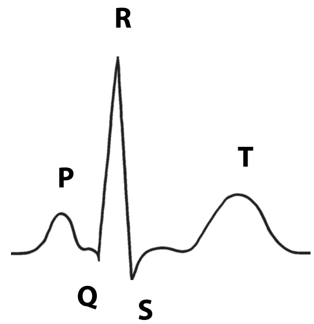
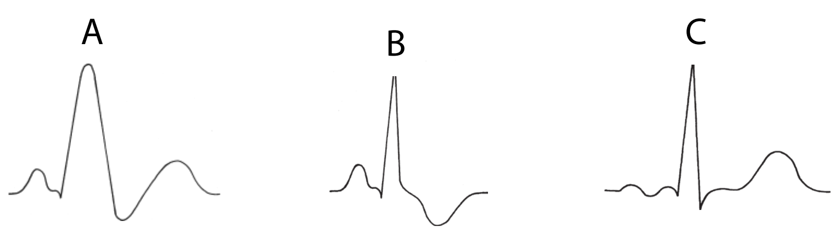


Figure 17.6. Normal EKG. The P wave is the pacemaker; QRS wave is conduction through the ventricles; and T wave is recovery of the ventricles.

The ***P wave*** is a recording of the electrical activity in the atria, and it is especially important in diagnosing problems in the heart's natural pacemaker.

The ***QRS wave*** is a recording of the conducting current in the ventricles. This current travels very rapidly along the Purkinje System. The result is that all muscle cells in both ventricles are stimulated at the same time, causing these chambers to contract quickly and strongly.

The ***T wave*** occurs just after the ventricles contract, and it is a recording of the normal recovery phase of the ventricles. This is a period when the muscle cells perform various biochemical reactions that prepare them for the next contraction.



? Question

1. A person who drinks a lot of coffee complains that he has irregular heart rate. Which one of the above EKG waves could reflect this problem? Explain your answer.

2. A person has a greatly enlarged heart from the overwork created by years of high blood pressure. Which abnormal EKG wave could reflect this problem? ______________ Explain your answer.

3. A person with poor coronary circulation to the heart muscle has some heart injury. Which abnormal EKG wave could reflect this problem? ______ Explain your answer.

4. What is the name of the pacemaker of the heart?

5. Where is the pacemaker located?

6. What is the refractory period?

7. In a normal beating heart the impulse conduction time is longer than the refractory period? (yes or no)

8. What is the general function of the atrio-ventricular node?

9. Where are the Purkinje fibers?

Circulation to the Heart Muscle

Heart muscle works very hard, and it must be supplied with oxygen and nutrients just like any other part of the body. The vessels that supply blood to the heart muscle are called ***coronary arteries***. Two important circulation patterns can be seen in Figure 17.7. The right atrium is fed only by the right coronary artery, and the left atrium is supplied only by the left coronary artery. However, each coronary artery supplies blood to parts of both ventricles. Partial blockage to one of the coronary vessels could affect the atrium on one side of the heart more than the ventricle on that side. However, the ventricles do more work than the atria and must be supplied with more blood. This makes each clinical case a bit different.

Another important aspect of coronary arteries is the connection between arteries. Connections between arteries are called ***collateral circulation***. These connections are alternate routes of blood flow to tissue if one path is blocked. Some parts of the heart have no collateral circulation. Other parts have only very small-diameter collateral vessels because they are mostly unused. Also, there are different amounts of collateral vessels among people. Can you find a large collateral vessel in Figure 17.7? Color that vessel. Hint: It is called the ***posterior circumflex***.

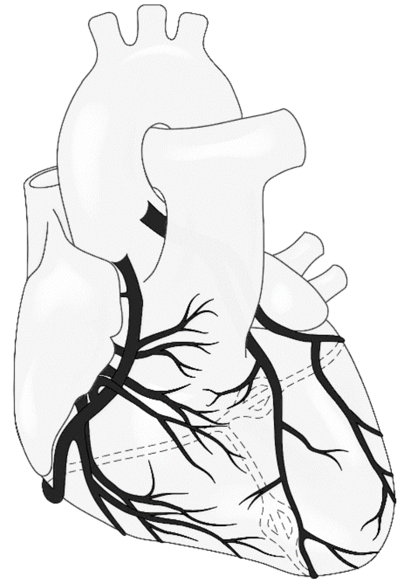


Figure 17.7. Collateral circulation in the coronary arteries.

One of the medical paradoxes happens when a healthy person dies suddenly with the first heart attack. Another less healthy person has a series of small heart attacks over many years and lives a long life. Some of this is explained by differences in collateral circulation. After the first small heart attack, a collateral vessel can be slowly stretched by more blood flowing through it. This can provide a degree of protection from a large heart attack in the future.

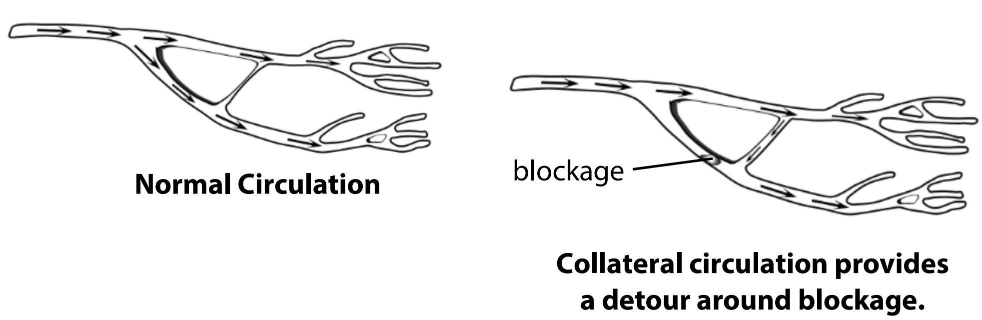


Figure 17.8. Collateral circulation. A collateral vessel may be unused until there is a blockage that forces blood to flow through it.

Use of Stints in Coronary Vessels

Stints are medical devices that are used to open partially blocked arteries. Once positioned in an area of blockage, the stint is expanded by an inflatable bladder which is then removed leaving the stint in place.

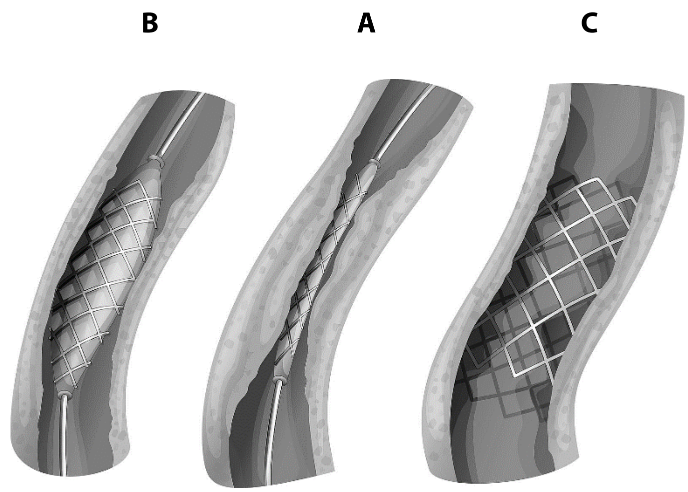


Figure 17.9. Arterial stints. In (A) the stint is positioned; (B) bladder is inflated; and (C) bladder is removed leaving the expanded stint in place.

? Question

1. A patient is told that she has a narrowing of the right coronary artery. Which chamber of her heart is going to be affected the most by this disorder?

2. Which chamber would also be somewhat affected?

3. A group of patients were told that they had plugged arteries in their hearts. In addition, they had all suffered a similar size of heart attack. All of these patients survived. Some of them had parts of their injured hearts return to normal after several months. The other patients had no such luck. Explain these differences in terms of coronary circulation.

4. A heart attack on which side of the heart would probably cause the most serious immediate risk to the person?

Abnormal Holes in the Heart

The heart in a normal fetus has a hole between the right and left atria. This opening allows fetal blood to partially bypass the lung circuit since the lungs aren't used to supply oxygen during life in the womb. Usually, the atrial hole closes shortly after birth. A birth defect results if this hole does not grow closed. Another birth defect occurs when there is an abnormal opening between the right and left ventricles. Both of these abnormalities in heart development are called ***septal defects***. Septal defects allow mixing of oxygenated and deoxygenated blood. This reduces the efficiency of the heart. Also, an opening between ventricles means that the left side can not pump at the needed high pressure. The right and left ventricles will have the same pressure. Septal defects can have serious health implications if left uncorrected.

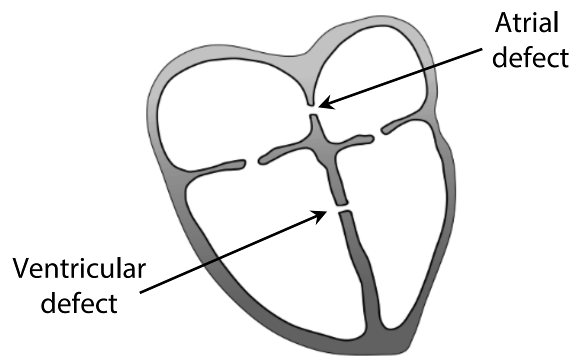


Figure 17.10. Septal defects of the heart.

? Question

1. What important molecule is carried by blood entering the left heart pump and is not in the blood entering the right heart pump?

2. If the fetal hole between the right and left atria does not close, what happens to the blood in these two chambers?

3. Which ventricle operates under the most pressure (does the most work)?

4. What would happen to the pressure in the two ventricles if there was a hole between them?

5. What would the heart do to compensate for the pressure problem created by a ventricle hole? Hint : People with this abnormal hole must have it repaired while they are young, or they won't live long.

Exercise #3
Heart Sounds

The heart sound is often described as "**lub-dub**." You might think that the two parts of this sound come from the actual contractions of the upper and lower chambers of the heart. That is not correct. These sounds are more closely associated with the closing of the heart valves. The first sound, ***lub***, happens when the blood vibrates just after the ***chamber valves close*** between the atria and ventricles. Heart sounds are created by fluid vibration waves rather than a physical closing sound of the valves. The second sound, ***dub***, occurs just after the heart ***artery valves close***. With the aid of a stethoscope, a physician can hear these heart sounds and determine if there has been damage to any of the valves.

Heart Sounds on the Internet

Procedure

- Go on the Internet and listen to examples of heart sounds. A good start is to search for "Demonstration: Heart Sounds & Murmurs" offered by the Department of Medicine at University of Washington.
  http://depts.washington.edu/physdx/heart/demo.html

Listen to the following heart sounds:

What you hear depends on where you place the stethoscope.

- **Normal**
  Can you hear two distinct sounds? _____ The first sound happens when the valves between the atria and ventricles close. The second sound happens with the closing of the artery valves after blood leaves the ventricles.

- **Mitral Regurgitation**
  What is the main difference in this sound?

  This is a mitral valve defect, so the sound should be heard during the lub or the dub? _____

- **Benign Murmur**
  How is this benign murmur different from the sound of the mitral valve defect?

- **Pericardial Rub**
  Can you hear the difference between a murmur and a rub?
  Describe the difference.

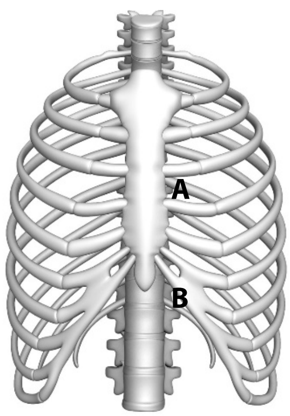
- **Extra Heart Sounds**
  When does the extra sound happen in this example? (circle your choice)

  During lub sound (S_1)
  During dub sound (S_2)
  After dub sound (S_2)

Listening to Your Own Heart Beat

Procedure

- Get a stethoscope.
- Clean the earpieces of the stethoscope with a cotton ball soaked in alcohol. Always repeat this procedure whenever another person uses the stethoscope.
- Carefully fit the stethoscope earpieces in your ears so that they are comfortable and point slightly forward in the ear passage. (Your ear passage points forward before it turns inwards to the ear drum.)
- Move the diaphragm of the stethoscope around the left side of your chest starting at the lower center notch of your rib cage.



As the stethoscope is moved around the heart area, you will hear the "lub" sound better at some places and the "dub" sound better at other places. An experienced physician or nurse can position the stethoscope to hear each heart valve and determine whether there is an abnormal sound. Abnormal sounds indicate possible valve damage or other circulation problems.

The "lub" sound of the heartbeat resonates downward from the chamber valves, so you hear it best at the bottom of the heart. In which position of the stethoscope (A or B) do you hear mainly a "lub" sound?______ This would indicate that you are located nearer the bottom of the heart where the sound of chamber valves is loudest.

Most people expect that the two big heart arteries would exit from the bottom of the ventricles, but they don't. These arteries come out of the top of the ventricles and arch upwards above the heart. Refer to the previous diagrams of the heart, and notice the location of the two heart arteries (Figures 17.1 and 17.2). The "dub" sound of the heartbeat resonates upward, which is the direction that the heart arteries leave the heart. In which position of the stethoscope (A or B) do you hear primarily a "dub" sound?_____ This would indicate that you are located near the top of the heart where the heart artery valves make their sounds.

There are other clinical procedures for listening to patient heart sounds. Some of these procedures include positioning the patient onto their left side or right side, or having the patient try to push out air while the throat is closed, or squatting, or quickly standing, or clenching fists. These are methods for changing specific chamber pressures during the cardiac cycle, and they can help with specific diagnoses of heart problems by listening to heart sounds.

Exercise #4
Heart Rate and Stroke Volume

There are two ways of increasing heart output. The first is to pump faster (heart rate), and the second is to pump more blood per beat (***stroke volume***). Both methods allow us to recover from an accumulating oxygen debt during exercise. Heart output usually shows an emphasis on one or the other method depending on the nature of that particular heart. For example, people with a larger than average heart have a greater range in stroke volume possible per heartbeat. The smaller heart does not have this same range in stroke volume, and it must adapt to the output demand by increasing the heart rate. Your heart will favor either stroke volume or heart rate, and this can be determined by results from the Step Test recovery data that you will collect in the Blood Pressure and Conditioning Lab. If your heart quickly returns to the resting heart rate but your blood pressure remains above normal for a longer time after exercise, then your heart probably favors stroke volume. If your heart rate is fast during exercise and the blood pressure is about normal when heart rate recovers, then your heart may favor heart rate as the method of recovery after exercise.

Cardiac Output = Stroke Volume X Heart Rate

Greater Stroke Volume → Heart Rate can be slower

Smaller Stroke Volume → Heart Rate must be faster

Daily training will increase the size and strength of the heart. Consider the following differences in stroke volumes.

Table 17.1. Comparison of Stroke Volumes in Conditioned and Unconditioned Subjects.

Degree of Conditioning in the Subject	Representative Stroke Volumes (ml)	
	While Resting	During Exercise
Unconditioned	60	120
Conditioned	80	150
Elite-Conditioned	100	200+

? Question

1. Define stroke volume.

2. Compare stroke volumes of the unconditioned with the elite conditioned (Table 17.1). About what % more cardiac output is occurring in the elite conditioned?

3. When the unconditioned runs 1 mile, how far has the elite conditioned person run with the same number of heartbeats?
_____ miles

4. If we assume that an average person needs to pump 5 liters of blood per minute during resting conditions, then how many heartbeats are needed by each of the subjects?

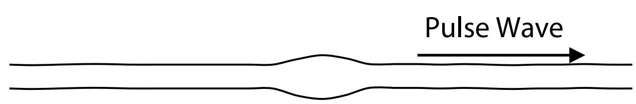
   Unconditioned person needs _____ heartbeats in a minute.
   Conditioned person needs _____ heartbeats in a minute.
   Elite Conditioned person needs _____ heartbeats in a minute.

5. (Note: When you finish the lab activity on "Heart Rate and Longevity", come back to this and the next question.) Based on the Internet Resting Heart Rate Longevity Calculator, how many extra years would you get by strengthening your heart from the unconditioned to the conditioned stroke volume? _____ years

6. How many more years by going from conditioned to elite conditioned? _____ years

The Pulse Wave

The ***aorta*** is the large artery leaving the heart and supplying blood to all other arteries. Each heart contraction forces a volume of blood (50–200 ml) into the aorta. The aorta is "ballooned" out by that blood. The elastic artery wall snaps back an instant after it has been stretched. This recoil causes the next segment of the aorta to balloon out and snap back. The alternate expansion and recoil of the aorta wall "pulses" outward from the heart to the other arteries of the body. You can feel these waves passing by whenever you press a finger on an artery. The pulse wave is not moving blood but is something like ripples spreading from a rock thrown into a pond. Its strength is determined by the strength of the heartbeat and the elasticity of the artery wall. If the beat is strong and the artery walls are very stretchy (a healthy condition), then the pulse wave will be strong.



Radial Pulse

The resting heart rate of most people is somewhere between 60 and 80 beats per minute (bpm). These contractions can be counted by listening to the heart beat or by counting the number of pulse waves that pass by a spot on an artery. Counting these waves by touch is how you measure the ***pulse***. The ***carotid pulse*** is felt when you press your fingers against the side of your throat. The ***radial pulse*** is felt when you press your fingers on the thumb side of your upward-turned wrist.

Procedure

- Use the stethoscope to count your heartbeats for 30 seconds.

  Stethoscope Heart Rate = _____ beats per minute.

- Count both your radial pulse waves and carotid pulse waves for 30 seconds.

  Radial Pulse = _____ waves per minute.

  Carotid Pulse = _____ waves per minute.

? Question

1. Which had the stronger pulse waves? (circle your choice)

   Carotid or Radial

2. Which is closer to the heart?

   Carotid or Radial

3. Which would produce a stronger pulse wave?

   Smaller heart or Bigger heart

4. Arteriosclerosis hardens the artery walls with scar tissue. If arteries have been partially injured by arteriosclerosis and the arterial wall is less flexible than normal, would the pulse be stronger or weaker than normal?

5. If a person has arteriosclerosis, what happens to the blood pressure near the end of the arteries? Hint : Is some of the energy of the heart contraction "used up" by the pulse wave?

   It is the same as normal
   It is higher than normal
   It is lower than normal

6. What would happen to the health of those small arterioles and capillaries affected by the condition posed in question #5?

7. Half of the people have a smaller-than-average sized heart and half have a larger-than-average sized heart. In which group would you expect the heart rate to be faster? Explain your answer.

8. In general, females have a higher heart rate than males. What explanation can you give for this difference?

Calculating Maximum Heart Rate

Most interval exercise programs tell you to perform high-intensity movements in order to elevate your heart rate to 70-85 % of maximum heart rate. This requires us to know our own maximum heart rate. It is not healthy to push your heart to absolute maximum unless your survival is at stake. So, it is best to make a calculation. Use the following formula:

Maximum Heart Rate = the number 210 minus (½ your age, and 5% of your body weight, and another 4 if you are male)

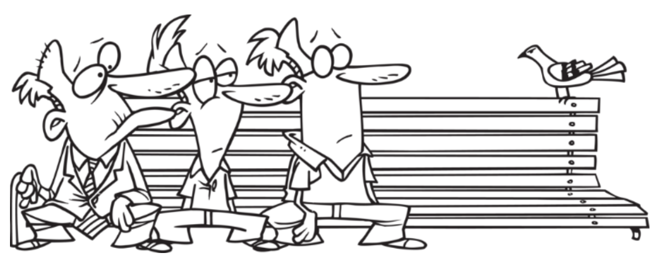
This formula tells us that a 20 year old male who weighs 150 lbs would have a calculated maximum heart rate of 210 minus 10, and then another minus 7, and finally another minus 4. His maximum heart rate is 189.

Calculate Your Maximum Heart Rate. ________

Now calculate 70% of Your Maximum Heart Rate. ________

Then Calculate 85% of Your Maximum Heart Rate. ________

Heart Rate and Longevity



Here comes the longevity judge.

Longevity means long life or "holding up" for a long time. It is very difficult to measure how well something is holding up, so scientists use life expectancy which is a statistical description of how many people live how many years. Modern longevity studies analyze data from large samples of people who have been evaluated on many aspects of their life – both medical and other. These people are followed through time until they get various illnesses or eventually die.

We know that there are serious problems with using correlations. Correlation is not causation. Causation is much more difficult to demonstrate. Correlated factors can overlap. For example, the type of diet may overlap physical activity. So, if you find that people with a certain diet live 5 years longer on average, and you discover that people with 30 minutes of strenuous daily exercise live 5 years longer, then you might assume that people with both habits would gain 10 years of life expectancy. It doesn't work out that way with correlations. The same generality applies to negative factors that take away from life expectancy.

When does running more shorten my life?

How reliable is the current use of resting heart rate to predict longevity, and what is this calculation based on? Research in comparative physiology has demonstrated that the average mammal heart beats about 1.5 billion times before it wears out. Although there are exceptions to this heart longevity rule, it seems to be generally true whether you're a mouse or an elephant. A mouse's heart beats about 10 times faster than an elephant's heart, and a mouse lives about one tenth as long. Modern humans score above most other species for longevity. This may be because we are smarter and can avoid more hardships than the average mammal. However, we also have a limit. The accepted estimate is somewhere around 2.5 billion beats—if we are lucky enough to survive disaster and illness. How you spend these heartbeats is determined by what you do.

Let's assume that the longevity rule (2.5 billion heart beats) is generally true for humans. The example we start with is a woman who already does enough daily activity to keep her heart healthy. She asks the question, "If I train in a very strenuous sport for 4 more hours a day beyond my normal activity, then how much might I shorten my life by doing this extra sport? " Assume that her normal heart rate of 70 is elevated to 120 during the heavy training.

? Question

1. If this athlete does an extra four hours of hard training beyond her normal active life, how many extra heartbeats has she used in that day? ____ extra heartbeats per day of training. (This is the difference between the heart beating at 70 and 120 for the four hours of training.)

2. If her normal heart rate is 70 and there are 1440 minutes in a day, then she normally uses _____________ heartbeats in a day. If an extra 100800 heartbeats represents one more lost day of longevity, then how many days of extra sport training does it take to shorten her life by one day? __________

3. How many years of this extra sport training would it take to shorten her life by one year? (You don't have to do a lot of multiplication here. It is the same ratio as the previous question.)

There were a number of assumptions in this example that we need to critique. First, we assumed that this person was already doing the perfect amount of exercise to keep her heart in prime condition. We assumed that additional sport training was not going to improve her heart, only use up more longevity heartbeats. That could be wrong. What if this extra training resulted in the heart getting even stronger so that her normal resting heart rate fell from 70 to 60 bpm? That slower heartbeat would mean that it is beating 14400 fewer beats per day than it was before the sport training program.

? Question

1. How many years of beating at this new improved and reduced rate of 60 bpm would add a year of longevity to her heart?

   Before we ascribe too much importance to a higher heart rate, remember that females generally live 10% longer than males even though females have a 10% higher resting heart rate. Obviously, other important factors affect longevity.

2. Smoking elevates the heart rate about 10% above normal; so does drinking 3-4 cups of coffee per day. If you were a smoker or a coffee drinker for 40 years, how many years of longevity might be lost due to the increased heart rate?

Could coffee shorten my life?

3. Negative stress can elevate the heart rate 10–20% above normal. How many lost years of longevity might result from a 20-year stress-filled job that elevated heart rate 20% above normal?

Resting heart rate is a useful predictor of live expectancy. There are longevity calculators on the Internet that will quickly predict how old a person is expected to live based only on the resting heart rate. The resting heart rate is measured in the morning before you get out of bed. This will be lower than what you would measure in lab today.

Longevity Calculator on the Internet

Procedure

- Go on the Internet and find a longevity calculator based on resting heart rate. Determine the calculated lifespan based on the following:

  50 bpm = ___ years old at death
  60 bpm = ___ years old at death
  70 bpm = ___ years old at death
  80 bpm = ___ years old at death
  90 bpm = ___ years old at death

- At the beginning of Exercise #4 (Question #4) you calculated the resting heart rate based on unconditioned, conditioned, and elite-conditioned. Use the Internet calculator to project the life expectancies of these three groups based on their resting heart rates.

  Conditioned _____
  Unconditioned _____
  Elite-Conditioned _____

- Answer Questions #5 and #6 in that same group of questions.

? Question

1. List two implications of using resting heart rates as a health tool in your chosen profession.

2. List two limitations of this approach.

Diving Reflex

Diving Reflex: Heart Rate slows when you put your face in cold water.

Popular magazines report that heart rate decreases when our face is submerged in cold water for 15 or more seconds. This reaction is called the ***diving reflex***. In diving mammals, like seals or dolphin, it is a major reaction with very dramatic changes in overall body physiology. The diving reflex is fun to investigate and is good practice with experimental design. Your job now is to design experiments that would test this idea. Also, test whether this reaction is caused by cold water only, or would it happen in normal temperature water? And, could it just be holding your breath that initiates the reflex?

There are plastic tubs in the lab that can be used for face immersion. Clean the container before you start, and use clean water for each subject.

Setup 1 (Testing whether temperature of the water is important.)

Description of experimental design:

Results:

Setup 2 (Testing whether it is holding your breath or face in the water that matters.)

Description of experimental design:

Results:

? Question

1. What do your results say about the stimulus for the diving reflex?

2. About how much change (from normal) in heart rate did you observe?

Exercise #5
Clinical Treatments for Heart Disorders

Coronary Heart Disease

Atherosclerosis is a build-up of cholesterol, fat, and other substances in the wall of an artery, eventually forming a plaque which can slow or block blood flow. ***Coronary Heart Disease*** is the development and progression of atherosclerotic plaque in the blood vessels supplying the myocardium. This gradually narrows these vessels and slows the blood flow to heart muscle, especially during exercise. If narrowing (***stenosis***) is greater than 80% in a localized blockage, the blood flow through that vessel won't increase during exercise even if other segments of the vessel dilate. Whichever parts of the heart are supplied by the partially blocked vessel will have inadequate oxygen during exercise, and this causes symptoms of chest pain (***angina***). This referred pain is often a squeezing or suffocating feeling centered in the chest that may radiate to jaw, neck, shoulder, and down the left arm.

Treatment of Angina

MONA for angina: Morphine, Oxygen, Nitrates, and Aspirin.

A clinical summary for the basic approach to treating angina are the letters MONA. This stands for Morphine, Oxygen, Nitrates, and Aspirin. Morphine relieves pain very rapidly. Oxygen helps relieve the oxygen debt in the heart muscle itself. Nitrates will temporarily help relieve some of the underlying problems with coronary circulation. Finally, aspirin is an agent for decreasing clotting. Clotting is a serious threat because it can increase the blockage already created by atherosclerosis.

Nitrates like nitroglycerin and related compounds (Nitrostat, etc.) dilate blood vessels throughout the body (both veins and arteries). This reduces peripheral resistance. Vasodilation decreases the workload on the heart, and it can improve circulation dramatically. Nitrates also dilate the coronary vessels opening a better blood flow to the heart muscle itself and are an immediate treatment for angina.

Part of the treatment for early heart problems is vasodilation of vessels and decrease in blood volume.

There are several categories of medications that are helpful in treating early heart problems including angina. They are some of the same drugs discussed under "Clinical Treatments for High Blood Pressure" in the Blood Pressure and Conditioning Lab. It is worth reading that exercise along with this exercise since most of the treatments are overlapping. Diuretics (like Lasix) lower blood volume and pressure and are very effective at reducing peripheral resistance. This helps reduce effects of heart failure.

Often a diuretic drug like Aldactone is used because it doesn't disturb the potassium level in the body. Potassium (K+) is necessary for conduction of the heart impulse.

Other drugs for treating heart patients include Direct Renin Blockers (DRBs), ACE inhibitors, and Angiotensin Receptor Blockers (ARBS). They are also discussed in the Blood Pressure and Conditioning Lab. These drugs lower blood pressure and peripheral resistance by causing vasodilation of veins and arteries.

Strength of Heart Contraction

A core problem of a weak heart is low stroke volume.

The two common causes of heart failure are long-term ***hypertension*** (high blood pressure) and ***myocardial infarction*** (damaged heart from atherosclerosis). Heart failure is characterized by ventricle dysfunction, poor cardiac output, and inadequate circulation to the body tissues. All of these problems must be addressed during the clinical management of heart failure. At the core of these problems is a low stroke volume. Stroke volume is affected by three factors: prefilling (***preload***), strength of ventricle contraction, and peripheral resistance (***afterload***). Clinical treatment of peripheral resistance has been discussed previously. Prefilling and strength of heart contraction are next.

By slowing the heart rate, you can increase the strength of contraction.

The diagnosis of heart failure must consider: (1) which side of the heart has been affected, (2) is there a valve problem, (3) how much muscle loss has occurred, and (4) is there an impulse conduction problem. The answers to these questions determine the clinical plan for treatment. Usually the first treatment for a weak heart contraction is a medication to slow the heart rate and impulse conduction so that there is more time for prefilling the ventricles. If prefilling time can be lengthened, the effectiveness of each beat is improved. The ventricle muscle contracts harder if it is stretched by more prefilling (Starling's Law of the Heart). Another factor related to the prefilling time is the flow of blood through the coronary vessels. The blood flow stops during the contraction of the ventricle wall. This is because those vessels are compressed by the heart contraction. Blood flows to the heart muscle only during the relaxation of the heart. Therefore, a long relaxing period (prefilling time) is necessary for adequate circulation to the heart muscle by the coronary vessels. Both slowing heart rate and increasing conducting time of the heart impulse through the heart conduction pathway are effective treatments for heart failure. This clinical approach assumes that there is a normal conduction in the patient (EKG analysis).

Medications that change heart rate or impulse conduction time include:

- **B-Blockers** (like Metaprolol, Atenolol, Propanolol and others).
  These drugs slow the activity of the pacemaker and thereby slow the heart rate. They also slow the conduction of the heart impulse

through the AV node which results in more separation of the atrial and ventricular contractions. Both of these effects create a more effective heart beat (greater stroke volume).

- **Calcium Channel Blockers** (like Verapamil, Diltazem, and others). These drugs block the movement of Ca++ into cells and thereby interfere with any reaction dependent on intracellular calcium. Contraction of the heart muscle and conduction of the heart impulse are two processes that are depressed by CCBs. Their effect is to slow heart rate and conduction time for a more effective beat.
- **Inotropic Drugs** (affect strength of contraction) include Digoxin and the catecholamines like adrenalin and its relatives. Digoxin mimics the effects of the parasympathetic system, and the catecholamines mimic the sympathetic system. The particular circumstances of a patient's heart can benefit from one or the other of these drugs. They affect heart rate and stroke volume.

Arrhythmias and Impulse Conduction Disorders

The cardiac output becomes inadequate when the heart rate is too slow or too fast.

The general definition of an ***arrhythmia*** is irregular heartbeat. It may be too fast (***tachycardia***) or too slow (***bradycardia***). Irregular beats can occur in either the atria or ventricles. They can originate from pathologies in the conduction pathway (SA node, AV node, or Purkinje System), or they can originate from any other part of the heart. All heart muscle is capable of contracting on its own and initiating an impulse, but this capacity is normally superseded by the activity of the pacemaker (SA node). When some part of the heart operates on its own, that event is called ***escape***, and the impulse resulting from it is called an ***ectopic*** event. Other arrhythmias are caused by a blocking of some part of the normal heart impulse. These are called ***blocks*** – SA block, AV block, left bundle block, etc.

The clinical plan for treatment of arrhythmias requires a careful analysis of several diagnostic procedures including:

- **Evaluation of Cardiac Output** and the particular dynamics of the patient's heart contractions.
- **Imagery of Coronary Circulation** to show if and where blockages occur.
- **EKG analysis** to show what dysfunctions are happening in the heart impulse conduction.

Clinical procedures and medications can help correct arrhythmias. Long term correction of a conduction problem may require a pacemaker or surgical intervention. But there are short-term and intermediate treatments that include:

- **Vagal Maneuvers** (including "bearing down" and coughing) simulate the parasympathetic nervous system and slow heart rate. This can be immediately effective for treating atrial tachycardia.
- **Electro-Cardio Therapy (ECT)** is very effective in stopping fibrillations in either the atria or ventricles. It is sometimes called cardioversion.
- **Na+ Channel Blockers** (like Lidocaine) suppress automaticity of heart muscle and slow conduction of the heart impulse. Targeting Na+ is an approach that reduces reactivity of heart muscle and transmission of impulses without directly reducing the strength of the contraction process (which involves Ca++ more than Na+).

The disadvantage of a Calcium Channel Blocker is weaker contraction. But the heart rate is slowed which improves stroke volume.

- **Ca++ Channel Blockers** (discussed previously) decrease contractility and slow impulse conduction. In addition they dilate coronary vessels.
- **Inotropic drugs** like Digoxin and catecholamines affect heart rate and the strength of heart muscle contraction.
- **K+ Channel Blockers** (like Cordarone, Tikosyn, and others) are used in treating severe arrhythmias by delaying repolarization (recovery) of contracted heart muscle cells. They can radically slow heart rate, but not without significant side effects.
- **A Pacemaker** may be required to over-ride the arrhythmia and conduction problems. Heart stimulation and rate is controlled by the implanted device.

? Question

1. Describe the anatomical changes that lead to coronary heart disease.

2. Define atherosclerosis and stenosis.

3. What amount of stenosis is the threshold for serious coronary circulation problems?

4. Describe the symptoms of angina, and explain what initiates it.

5. What does MONA stand for?

6. List two parts of the circulatory system that are dilated when nitrates are administered.

7. How do diuretics help in the treatment of heart failure?

8. Are other anti-hypertensive drugs used? What process do they activate?

9. Define myocardial infarction.

10. List three factors that affect stroke volume.

11. List four important clinical considerations of heart failure that indicate which specialized clinical plan should be used.

12. How would slowing the heart rate and conduction time help improve cardiac output?

13. Blood flow through the coronary vessels occurs only during ______________________________.

14. List three categories of drugs that change heart rate or impulse conduction time.

15. Define arrhythmia.

16. Define tachycardia.

17. Define bradycardia.

18. Define “escape”.

19. What is a vagal maneuver, and how does it work?

20. Why would a Na+ Channel Blocker be used to treat arrhythmias instead of a Ca++ Channel Blocker?