BE 3600 BIOMEDICAL INSTRUMENTATION (LAB) -

Experiment 8: Implantable Devices: Cardiac Pacemakers

OBJECTIVE: Learn the basic principles of an implantable therapeutic system

BACKGROUND CARDIOVASCULAR SYSTEM

The most common medical condition requiring a cardiac pacemaker is called "bradycardia," meaning an abnormal heart rate that is less than 60 beats per minute. People with bradycardia have a heartbeat that is too slow or irregular to meet their body's metabolic demands. Symptoms of bradycardia may include dizziness, extreme fatigue, shortness of breath, or fainting spells. By restoring a heart rate to its appropriate rate, a pacemaker can relieve these symptoms.

The function of the human heart is to pump blood carrying oxygen and nutrients to the organs of the body. When the heart fails to pump enough blood either due to slowing down of its rate, or due to reduction in stroke volume, organs suffocate and tissue damage rapidly starts to occur. Therefore, it is vital to maintain the pumping action of the heart without any interruptions. The figure 2 below shows a simplified block diagram of the electrical conduction system of the human heart.

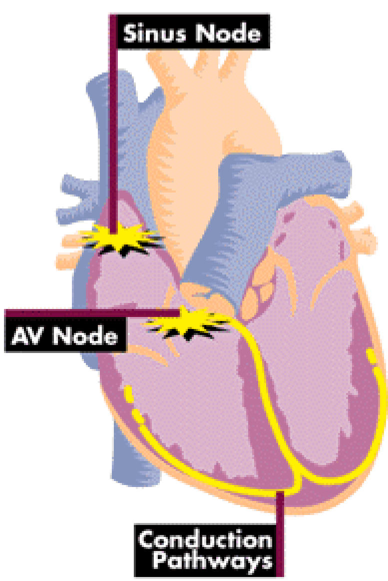

Figure 1. Electrical Conduction System of the Heart

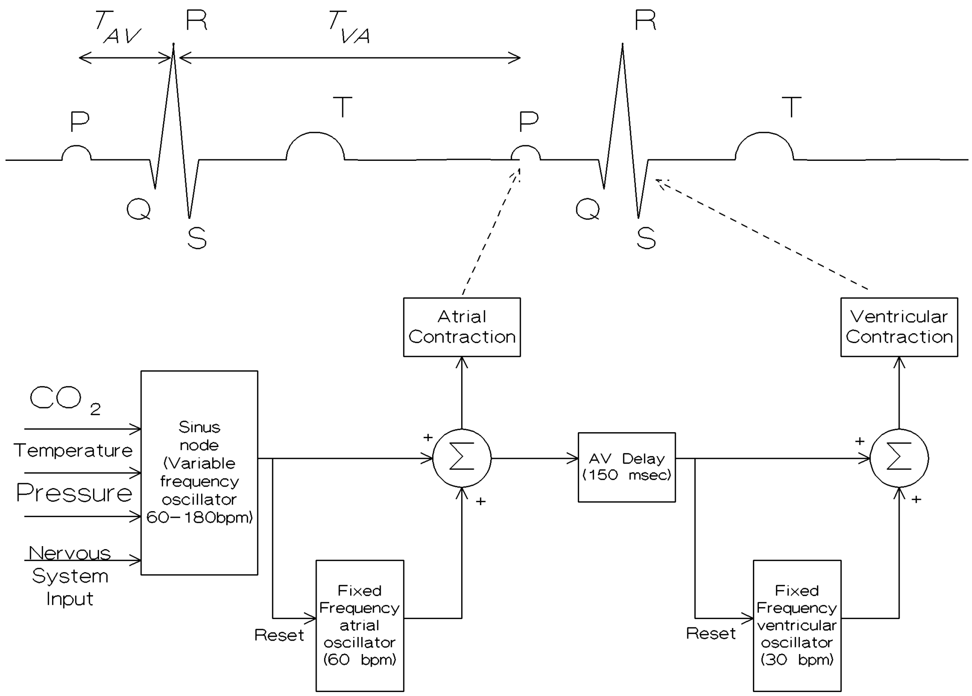

Figure 2. Engineering Model of the Conduction System of the Heart

The sinus node is a natural variable-frequency oscillator that initiates each beat. The sinus frequency depends on the CO_2 concentration, temperature, and pressure of the blood. For example, when the CO_2 concentration increases, perhaps from vigorous exercise, the sinus frequency increases. Each cycle of oscillation initiates a contraction of the atria. Ventricles contract after an atrial-to-ventricular (AV) delay of approximately 150 milli-seconds.

In the event that the sinus oscillator fails, a fixed-frequency (approximately 60 beats per minute) atrial oscillator takes over. In normal operation, each cycle of the sinus oscillator resets this fixed-frequency oscillator so that it does not try to initiate contractions. Similarly, if pulses fail to arrive through the AV-delay, another natural fixed-frequency oscillator (approximately 30 beats per minute) maintains ventricular contractions, but does not provide a quality of life that an individual expects to have.

BACKGROUND ON CARDIAC PACING

Many different types of failures can occur in the natural operation of the heart. For example, the sinus node may stop functioning. Then the heart beats at a low rate (60 beats per minute) due to the fixed atrial oscillator, which does not respond to temperature, pressure, or CO_2 concentration. Generally, the patient is very weak and cannot perform many normal daily activities. In these cases, electronic pacemakers can be used to stimulate the atria at the appropriate rate. A microprocessor chip in the pacemaker determines the appropriate rate by using data from an accelerometer, which gives an indication of physical activity, such as walking or climbing stairs. Thus, a properly designed electronic pacemaker can replace the defective sinoatrial node of the natural heart.

Electronic pacemakers can also help cardiac patients when there is a failure of the natural conduction system of the heart, such as in the *AV* delay. When that happens, the sinus node responds to the physiological needs of the patient, but its signal never reaches the ventricles, which are the main pumping chambers of the heart. In these cases, an electronic pacemaker can sense the onset of contraction from the natural electrical signals in the atria and stimulate the ventricular muscle in synchrony. Hence, a second type of pacemaker can replace the defective *AV* delay of the heart. Frequently, these malfunctions of the heart are intermittent, and the pacemaker must be able to sense natural contractions to avoid issuing competing, wasteful and potentially harmful pacing pulses.

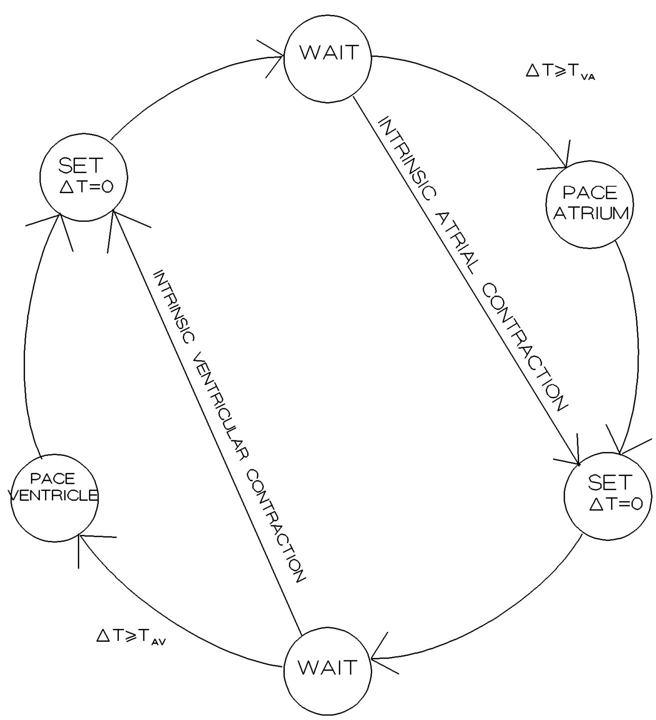

Figure 3. Flow diagram of a cardiac pacemaker.

BACKGROUND ON PACING MODES

Pacemakers can operate on very many different modes. A standard code was developed to identify the mode of operation of the device. It consists of a three of four letter codes as shown in the Table 1 below.

Position of the letter	Designation
1st letter	Chamber being paced (A=atrium, V=ventricle, 0=none)
2nd letter	Chamber being sensed (A=atrium, V=ventricle, 0=none)
3rd letter	Pacing Mode (O=none, I=inhibited, T=triggered, D=dual)
4th letter	Rate Response (R=rate response is on)

Table 1. Pacemaker modes.

For example, a mode code of VVI would indicate that device is pacing the ventricle of the heart, sensing the ventricle, and inhibiting the delivery of pacing pulse when an intrinsic beat in the ventricle is detected. Since there is no R at the fourth position, device has no rate response.

When the pacing mode is set to inhibit, the delivery of pacing pulse is inhibited if a beat is detected from that chamber. If no intrinsic beat is detected within a predetermined time period, pacemaker goes ahead and paces.

When the pacing mode is set to triggered, a redundant pacing pulse is sent soon after the detection of an intrinsic beat. If no intrinsic beat is detected within a predetermined time period, pacemaker goes ahead and paces. This mode comes in handy when the cardiologist is trying to determine the sensitivity of the pacemaker circuitry to detect the intrinsic beats. If the device is set too sensitive, it will sense noise and will pace very frequently, asynchronous to the intrinsic beats. If the device is set too insensitive, it will never sense, and pace with a fixed rate, again asynchronously. Only when the sensitivity is set correctly, there will be a pace after soon after an intrinsic beat. Therefore, triggered mode used by physicians for device setting and troubleshooting.

When the pacing mode is set to dual, pacemaker works in both inhibited and triggered mode. Operation would be very similar to the one shown in Figure 3.

BACKGROUND ON RATE RESPONSE OF A PACEMAKER

The pacemaker can improve a patient's lifestyle by appropriately changing the delays T_{AV} and T_{VA}, thereby adjusting the heart rate. When the patient is not very active, the heart must pump modest amounts of blood. But when the patient is exercising or involved in an activity requiring increased cardiac output, such as climbing stairs, the heart rate must be increased to meet the increasing metabolic demand for oxygen. Therefore, the pacemaker must be able to sense the patient's physical activity. In most modern pacemakers, this is accomplished by using sensors built into the pacemaker such as an accelerometer, which is also known as the activity sensor. The accelerometer consists of a mass suspended at the end of a cantilever beam formed from a piezoelectric material. As the patient's activity levels increase, the amplitude and the frequency of the signal coming from the accelerometer increase. The job of interpreting this signal to determine the most appropriate heart rate is one of the tasks performed by the microprocessor.

The rate response of some pacemakers uses integrated sensor therapy. Activity sensor responds quickly -- important for activities of daily living where short, transient activities are frequent. Minute ventilation (MV) sensor is more sensitive to respiratory demands associated with exertion or difficult breathing. Most minute ventilation sensors uses the principle of impedance plethysmography where the electrical impedance of the lung tissue is monitored and the changes in electrical impedance are interpreted as changes in the volume of air in the lungs. Higher impedance would result from more air and less blood in the lung following inhalation, where the lower impedance would result from less air and more blood in the lung, as a result of expiration. Each pulse in the impedance waveform would correspond to a breath, and higher the respiratory rate, higher the heart rate would be.

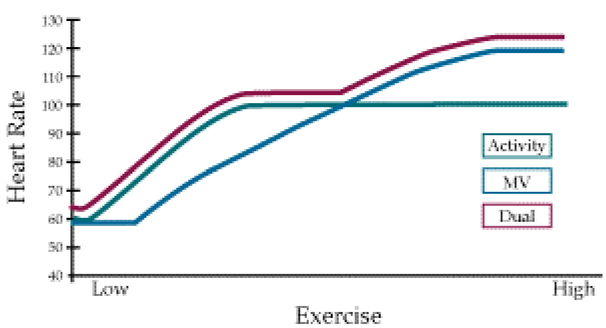

Figure 4. Rate response from individual sensors as well as combined sensory systems.

EXPERIMENT:

PART A

You will be provided with a pacemaker already programmed at VVIR mode.

1. Record the output settings of the pacemaker by filling in the table below:

Rulse rate (bpm)	
Pulse width	
Pulse amplitude	
Polarity (wrt to case)	

2. Attach ECG electrodes and measure your heart rate.

3. While keeping the pacemaker in your hand, walk around the lab to raise your heart rate. Repeat steps 1 and 2.

PART B

1. Place the pacemaker in the fish tank containing saline solution.

2. Using your oscilloscope, map the stimulation amplitude around the tank. Be careful not to get the scope probes into the saline solution since it is corrosive to metals. Fill the table below. Draw an overlay of the pacemaker as well as the lead and its tip location.

Y=5											
Y=4											
Y=3											
Y=2											
Y=1											
Y=0											
	X=0	X=1	X=2	X=3	X=4	X=5	X=6	X=7	X=8	X=9	X=10

REPORT:

a. Fill the table below:

	Before Exercise	After Exercise
Your Heart Rate(bpm)		
Pacemaker Rulse rate (bpm)		
Pacemaker Pulse width		
Pacemaker Pulse amplitude		
Pacemaker Polarity (wrt to case)		

b. Which parameters of the pacemaker did change when you exercised? Why?

c. How do the changes in the pacing parameters correlate with the changes in your heart rate? Compare the absolute and percentage changes in your heart rate and the pacing rate.

d. Make a 3D surface plot of the pacing amplitude a function of the measurement location. Where is the peak voltage? Why?

e. Using colored markers, sketch the E-field lines and the equipotential lines. Explain the relationship between these two.