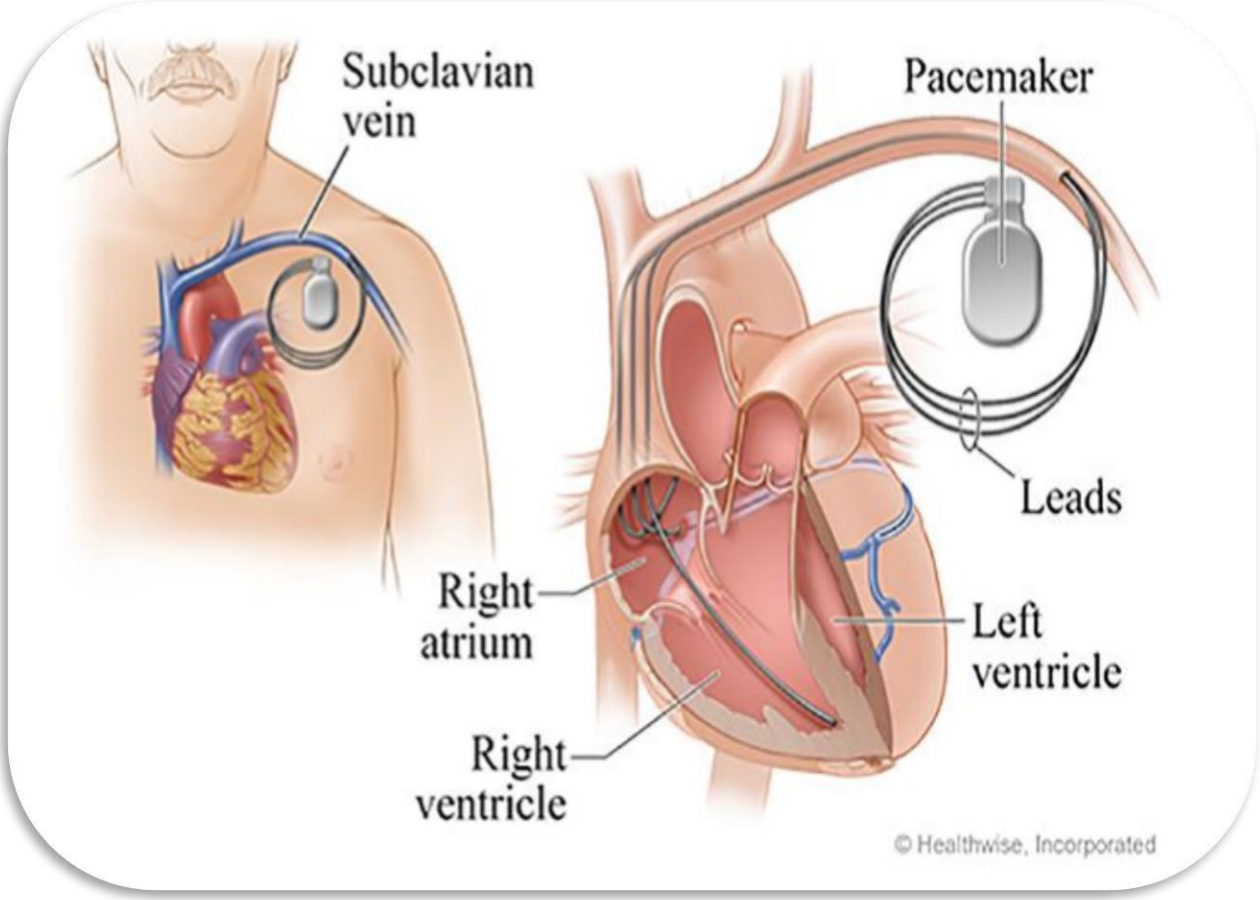
Artificial organs – internal & external (PACEMAKER)



Cardiac pacemakers

- **Introduction:**
- Electrical stimulators are widely used: physiotherapists use them in order to exercise muscles; anesthetists test for muscular relaxation during surgery by observing the response to stimulation of a peripheral nerve.
- A growing use of peripheral nerve stimulators is for the relief of pain. Cardiac pacemakers and defibrillators are used to stimulate cardiac muscle directly .

The pacemaker corrects for abnormalities in heart rate, whereas cardiac defibrillators are used to restore a fibrillating heart to normal sinus rhythm

- Rhythmic contraction of the heart is maintained by action potentials which originate at a natural cardiac pacemaker.
- There are actually two pacemaker areas in the heart, the sinoatrial (SA) node and the atrioventricular (AV) node, but the SA node normally dominates because it has the higher natural frequency.
- The normal course of events is that an impulse from the SA node is propagated through the myocardium, spreading over the atria to the AV node where there is a small delay before the impulse is conducted over the ventricles causing depolarization of the musculature.
- The normal cardiac rhythm is called sinus rhythm.Any defects in conduction of the cardiac impulse can cause a change in the normal sinus rhythm and this is called an arrhythmia.
- Heart block occurs when the conduction system between atria and ventricles fails.

- This will not usually stop the heart because other pacemaking areas of the ventricles will take over or, if the blockage is not complete, some impulses may get through from the atria, but the heart rate will fall.
- This is called bradycardia (slow heart rate) and it may mean that the heart cannot supply the body's demands and so dizziness or loss of consciousness may occur.

There are three types of heart block:

- In first-degree block the delay at the AV junction is increased from the normal 0.1 to 0.2 s.
- In second-degree block some impulses fail to pass at all but a few get through to the ventricles.
- In complete block no impulses get through and so the ventricles pace themselves, but at a very much reduced heart rate of typically 40 beats per minute.

In all these cases an artificial pacemaker can be used to increase the heart rate to a level where the cardiac output is adequate to meet the body's needs.

Types of pacemaker:

- The classification of pacemakers into different types is based on the mode of application of the stimulating pulses to the heart.
- External pacemakers are used when the heart block presents as an emergency and when it is expected to be present for a short time.

- Internal pacemakers are used in cases requiring long-term pacing because of permanent damage that prevents normal self-triggering of the heart.
- In the latter case, the pacemaker itself may be implanted in the body. The patient is able to move about freely and is not tied to any external apparatus.

External Pacemaker:

- External pacemaker are employed to restart the normal rhythm of the heart in cases of cardiac standstill, in situations where short-term pacing is considered adequate, while the patient is in the intensive care unit or is awaiting implantation of a permanent pacemaker.
- Frequently, External pacemakers are used for patients recovering from cardiac surgery to correct temporary conduction disturbances result in for the surgery.
- As the patient recovers, normal conduction returns, and the use of pacemakers are discontinued. The pacing impulse is applied through metal electrodes placed on the surface of the body.
- Electrode jelly is used for better contact and to avoid burning of the skin underneath. An external pacemaker may apply up to 80 mA pulses through 50cm2 electrode on the chest.
- This procedure is painful and therefore is used only in an emergency of a temporary situation.

The pulses may be delivered:

1. Continuously: when it is felt that the heart rate is below the pre-set value. The impulses frequency is independent of the electrical activity of the heart.
2. On demand R-wave synchronous pacing: normally the pacemaker is inoperative but is activated when the heart rate falls below the normal or pr-set value. In such a situation, beat to beat examination of the time interval between two R-waves is done. When this interval exceeds the pre-set value, the pacemaker comes into operation. This technique eliminate any competition between the heart's own pacemaker and externally applied pacemaker pulses. In the R-wave synchronous mode of the operation, the

external pacemaker can be used to support an implanted unit shortly before re-implantation or shortly after initial impanation to secure pacing.

- Pacing with external pacemakers through the chest requires a maximum of 150V pulses across an impedance of the order1kΩ.
- However, external pacing has the disadvantage that the electrodes tend to burn the skin and the electrical pulses become painful. Also, each impulse causes an uncomfortable contraction of the thoracic muscles around the area of the electrodes.
- The stimulation pulses can be applied to a heart through pacing catheter passing through a vein and connected to the heart.
- This is called internal pacing. The current pacing required is much less than when is applied through the chest.
- The voltage output of internal pacemakers is about 0-15 V and the available output current ranges form 1-20 mA, and the pulse width is around 2ms with a rate of 30-180 pulse per minute.
- The electronic circuit of a pacemaker consists of two parts, namely the impulse-generating circuit and the output circuit.
- The impulse-forming circuit determines the frequency and duration of the impulses. This is usually a multi-vibrator circuit with adjustable rate and fixed pulse width.
- The output circuit determines the shape and amplitude of the impulse.

Implantable Pacemaker:

- The implantable pacemaker, along with its electrodes, is designed to be entirely implanted beneath the skin. Their output leads are connected directly to the heart muscle.
- The PM is a miniaturized pulse generator and is powered by small batteries. The circuit is so designed that the batteries supply sufficient power for a long period.
- Since the PM is located just beneath the skin, the replacement of the pacemaker unit involving relatively minor surgery.

For any implantable circuit, the basic requirements are:

- The components used in the circuit should be highly reliable.
- The power source should be in a position to supply sufficient power to the circuit over prolonged periods of time.

- The circuit should be covered with a biological inert material so that the implant is not rejected by the body.
- The unit should be covered in such a way that body fluids do not find a way inside the circuit and thus short- circuit the batteries or result in other malfunctioning of the circuit.
- Internal pacemakers are implanted, with the pulse generator put in a surgical pouch often below the left or right clavicle (figure 1). The internal leads may then pass into the heart through the cephalic vein.

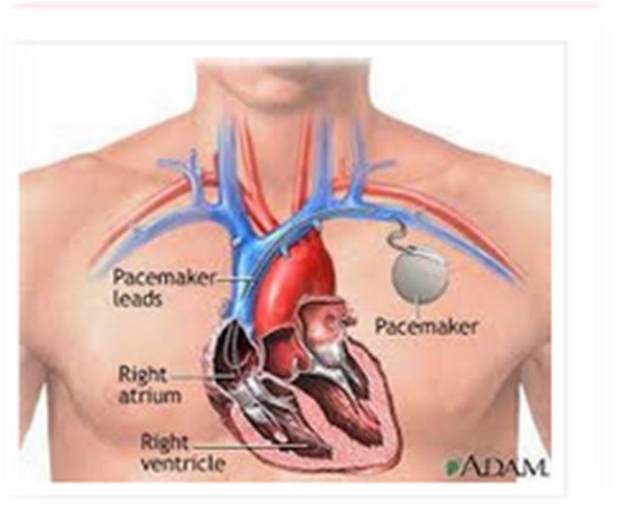


Figure 1. The transvenous lead from the pacemaker enters the subclavian vein and is guided under x-ray control into the heart. The pacemaker is installed in a subcutaneous pouch.

- The simplest type of pacemaker produces a continuous stream of output pulses at about 60-70 bpm like circuit in figure 2.
- The circuit is self-starting, and its output wave shape (pulse width and interval between pulses) remains almost constant despite drops in battery voltage.
- The circuit consumes almost no power between pulses. The output was a 2-ms pulse of about 5 V in amplitude every 1 s. This early circuit powered from a single 2.8-V cell.
- In the circuit, the output of the oscillator drives a voltage doubler, making the pacing pulses delivered to the heart achieve sufficiently high amplitudes

(approximately 5V) for the pacing electrodes of the time to "capture" the heart.

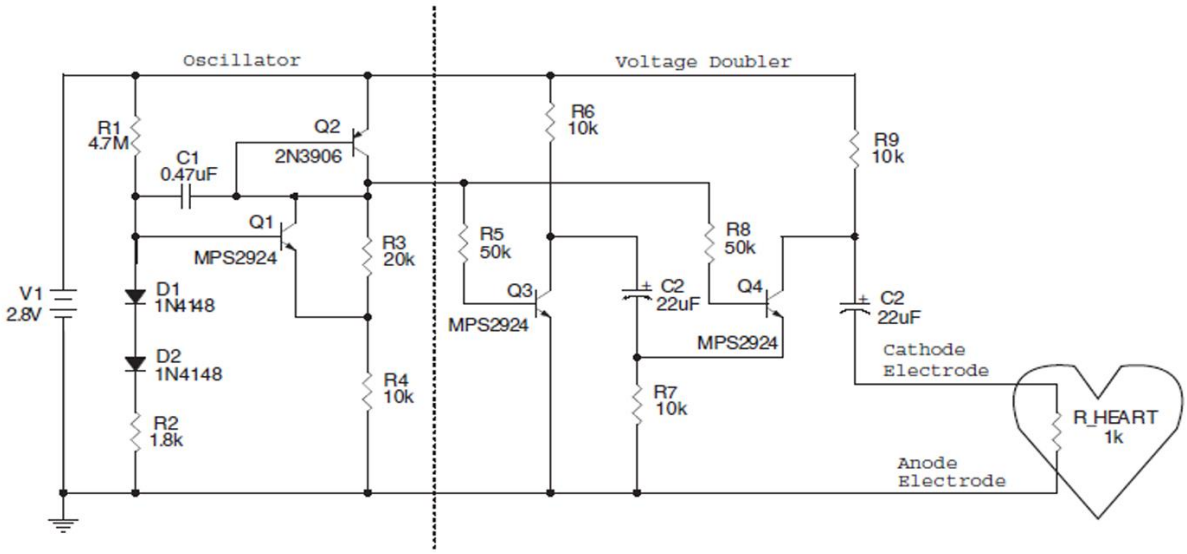


Figure 2. Early pacemakers had a period and pacing pulse characteristics (amplitude, wave shape, and duration) that were solely a function of their circuit.

- There are many disadvantages to this simple approach, one being that the heart rate will not vary in response to what the patient is doing.
- Another disadvantage is that power may be wasted if heart block is not complete because some beats could occur naturally without the pacemaker.
- In addition, this competition between naturally occurring beats and the pacemaker output may not lead to the most effective cardiac performance.
- These disadvantages to fixed-rate pacing (often referred to as competitive or asynchronous pacing) have led to the development of a range of more complex devices. These are illustrated in figure 3.

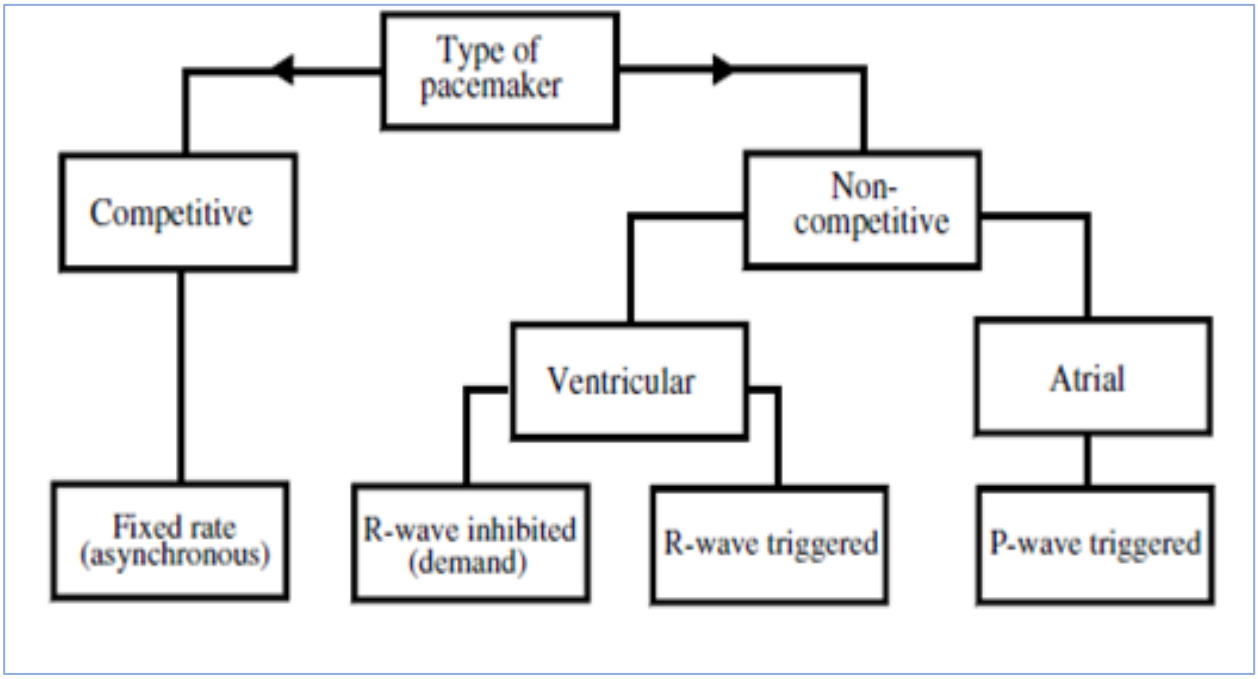


Figure 3 Categories of pacemaker.

- The alternative to fixed-rate or competitive pacing is non-competitive pacing. In this case the pacemaker records the ECG produced by the heart and produces an output in response to this signal. Non-competitive types can be subdivided into ventricular and atrial-triggered devices.
- Atrial-triggered devices produce an output triggered by the *P-wave* of the ECG which is generated by the atria and will not be affected by the heart block.
- Ventricular-triggered devices use the *R-wave* of the ECG in one of two ways. In a demand-type pacemaker an output pulse is only produced in the absence of a naturally occurring R-wave, i.e. the R-wave is used to inhibit the output of the pacemaker.

- If the pulse rate falls below the pre-set rate of the pacemaker then output pulses will again be produced. However, in a standby R-wave triggered device an output pulse is produced in response to every R-wave and if one does not occur when expected then the pacemaker will generate one.