Cardiac Pacemakers

Cardiac pacing

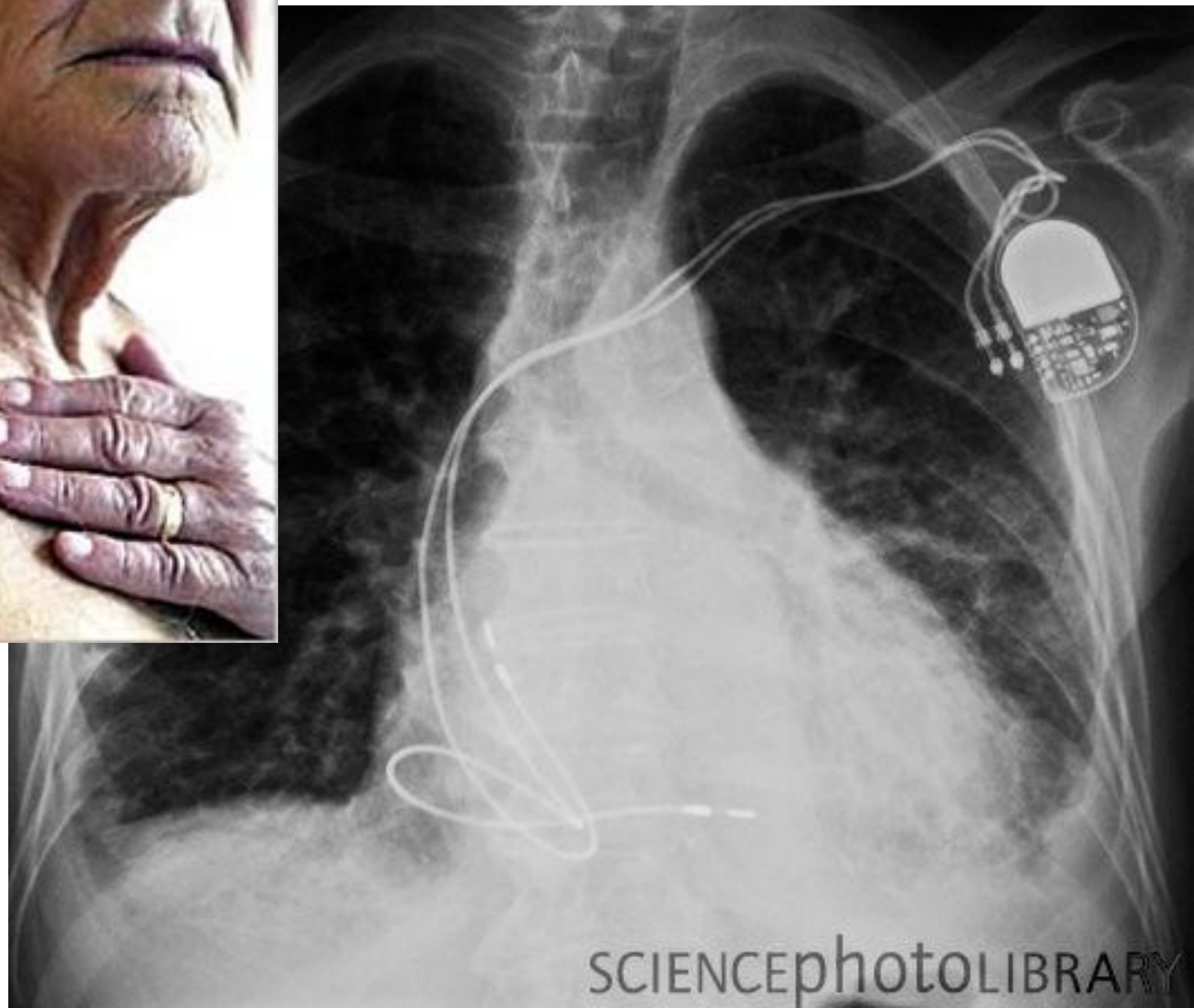
By Dr. Muhammad Riaz

Objectives of the topic

By the end of this lecture you will be able to understand:

- Heart and its conduction system
- Define cardiac pacemaker
- Design of pacemaker
- Clinical indications of pacemaker
- Types of pacemakers
- List functions of pacemakers
- Implementation procedure
- Patient preparation
- Risk factors and complications

Cardiac Pacemakers



Normal conductive system of the heart

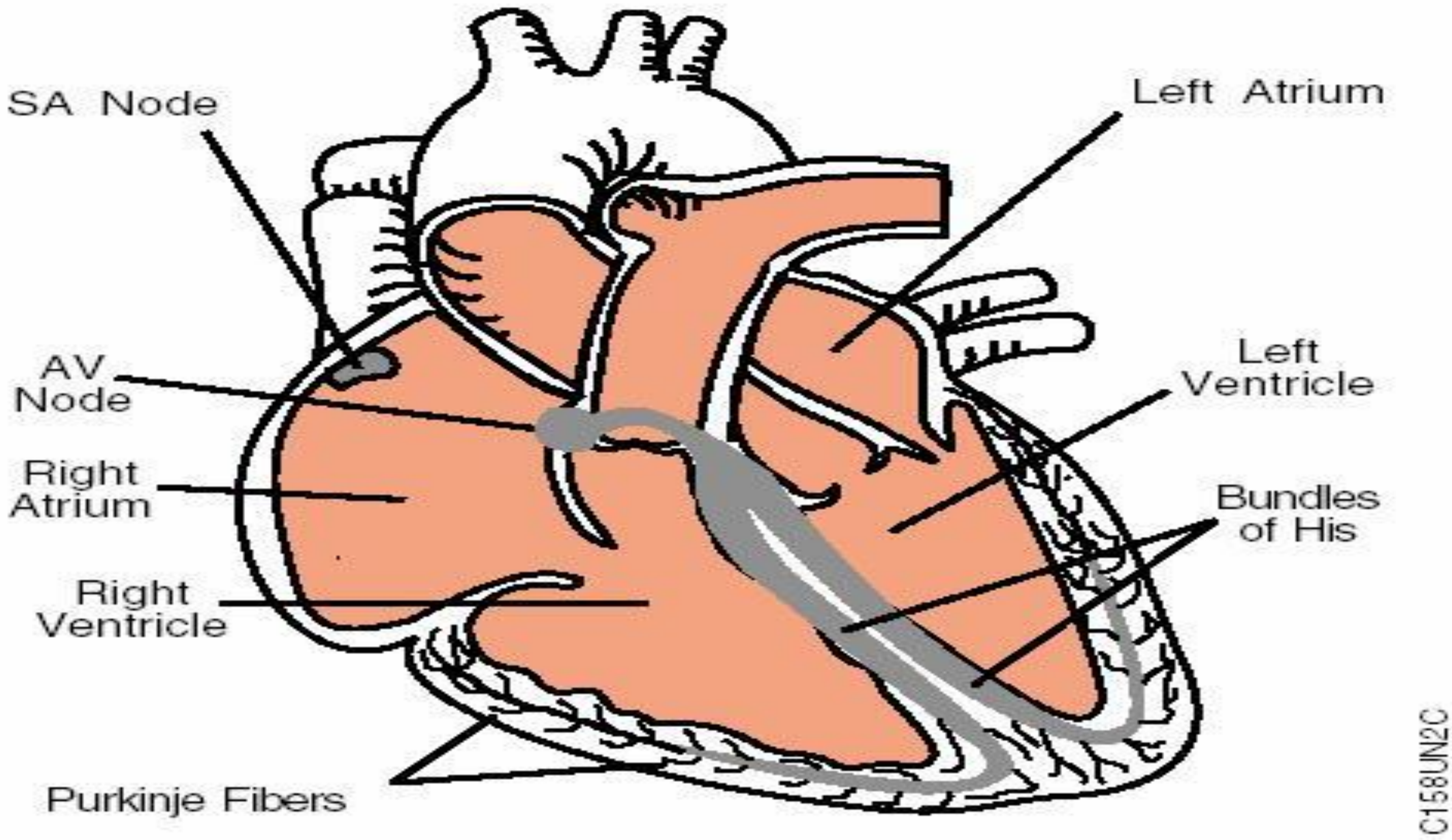


Figure 1. Structures involved in the conduction of electrical stimuli through the heart

Heart and its conduction

- Heart is a muscular organ
- provides a continuous blood circulation through the human’s body
- Normal heart beat **60 to 100** beats per minute
- Two upper chambers (left and right atria)
- two lower chambers (left and right ventricles)

Blood circulation in two loops

Pulmonary loop:

- The oxygen-poor blood enters the right atrium via superior and inferior vena cava.
- The right atrium pumps the blood into the right ventricle through a tricuspidal valve.
- The right ventricle contracts and pumps the blood through the right and left pulmonary arteries to the lungs for oxygenation

Systemic loop:

- The oxygen-rich blood from the lungs passes through the pulmonary veins and enters the left atrium.
- Left atrium pumps blood into left ventricle through a mitral valve.
- Left ventricle contracts & pumps oxygen-rich blood through aorta to the body.

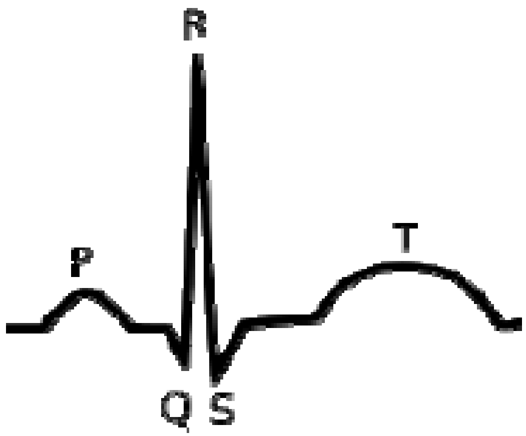
Regular contraction of heart

- managed by heart’s electrical system
- **Sinoatrial (SA) node** – heart’s natural pacemaker. In healthy heart it leads the heart rhythm.
- **Atrioventricular (AV) node** – bridge between the atria and ventricles. Passes electrical signals from atria to the ventricles.
- **His-Purkinje system** – it carries electrical signals throughout the ventricles and includes His bundle, Right bundle branch, Left bundle branch and Purkinje fibers

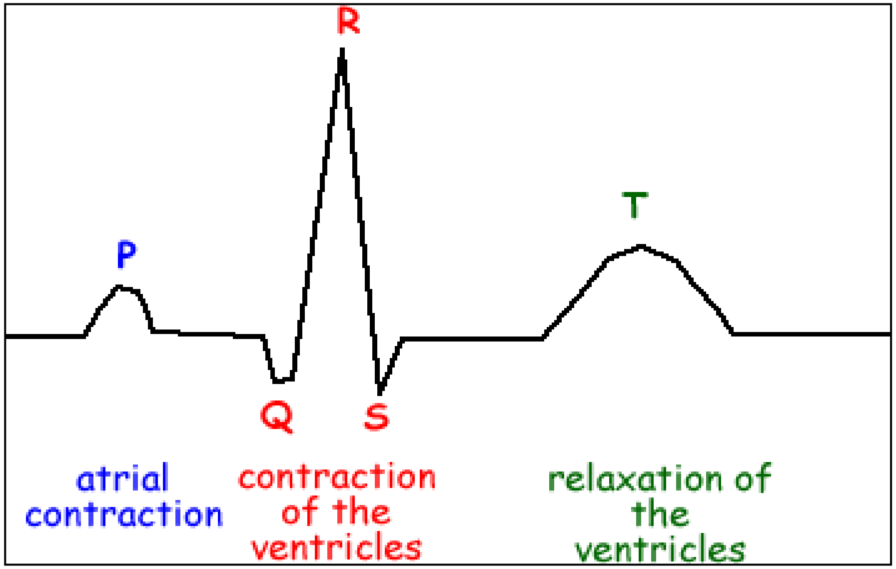
- electrocardiogram (ECG) is a recording of the electrical activity of the heart
- **P-wave**. Arterial contraction by SA node (arterial depolarization)
- **Q-waves**. Signals spread through ventricle
- **R-wave**. Contraction of left ventricle

(ventricular depolarization)

- **S-wave**. Contraction of right ventricle
- **T-wave**. Ventricle relaxation (ventricular repolarization)

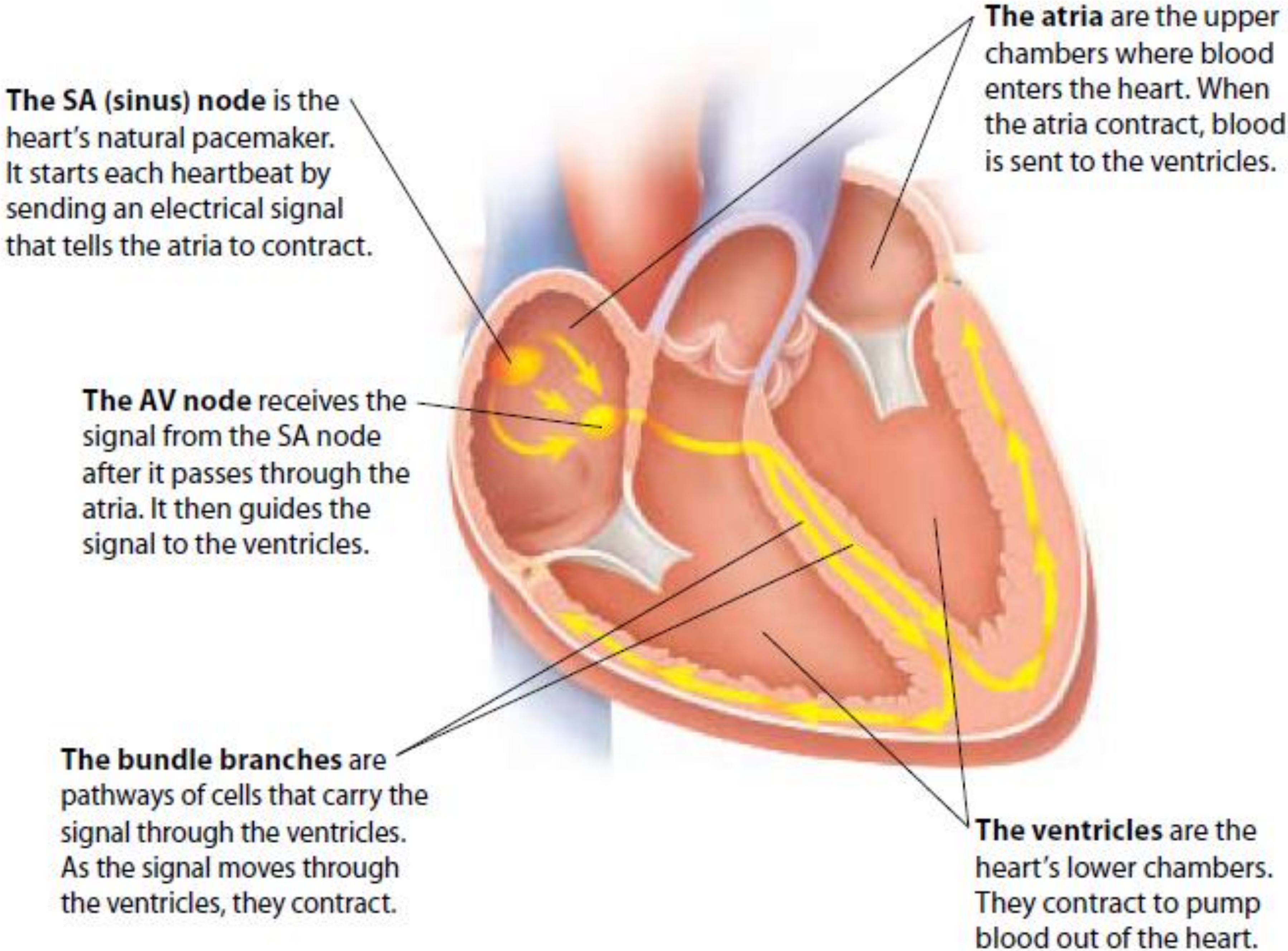


. ECG segment representing one heart cycle



Heart’s Electrical System

- Heart is a muscle that pumps blood throughout the body using an electrical system that tells your heart when to **contract (squeeze).**
- Problem in electrical system causes impaired heart beat
- Each heartbeat starts with an electrical signal.
- Signals are sent and received by special electrical cells within the heart called **nodes**.
- As the signals move through the heart, they tell the chambers that pump blood (called atria and ventricles) when to contract.
- When **active**, the signals from the nodes speed up to **pump blood faster**. When **resting**, the signals return to a normal pace


The SA (sinus) node is the heart's natural pacemaker. It starts each heartbeat by sending an electrical signal that tells the atria to contract.
The atria are the upper chambers where blood enters the heart. When the atria contract, blood is sent to the ventricles.
The AV node receives the signal from the SA node after it passes through the atria. It then guides the signal to the ventricles.
The bundle branches are pathways of cells that carry the signal through the ventricles. As the signal moves through the ventricles, they contract.
The ventricles are the heart's lower chambers. They contract to pump blood out of the heart.

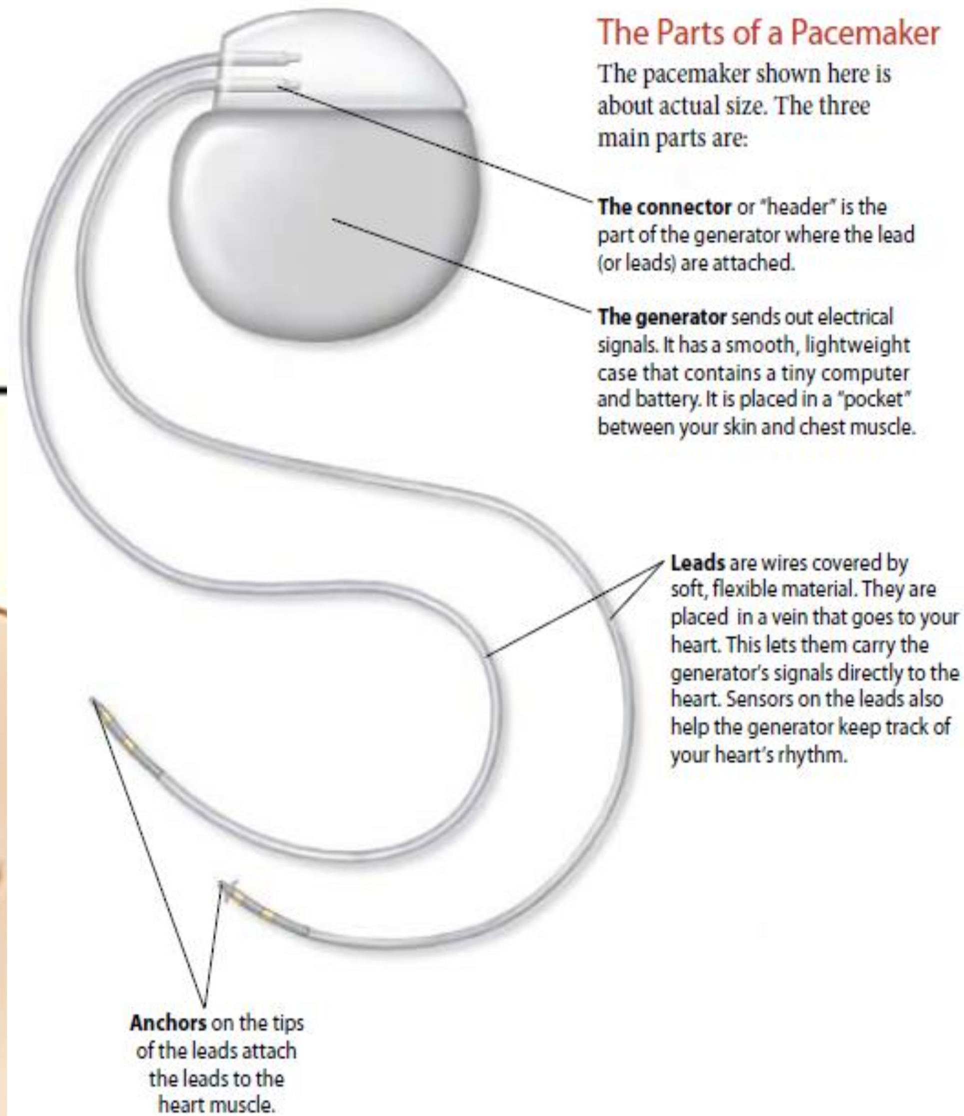
Cardiac Pacemakers

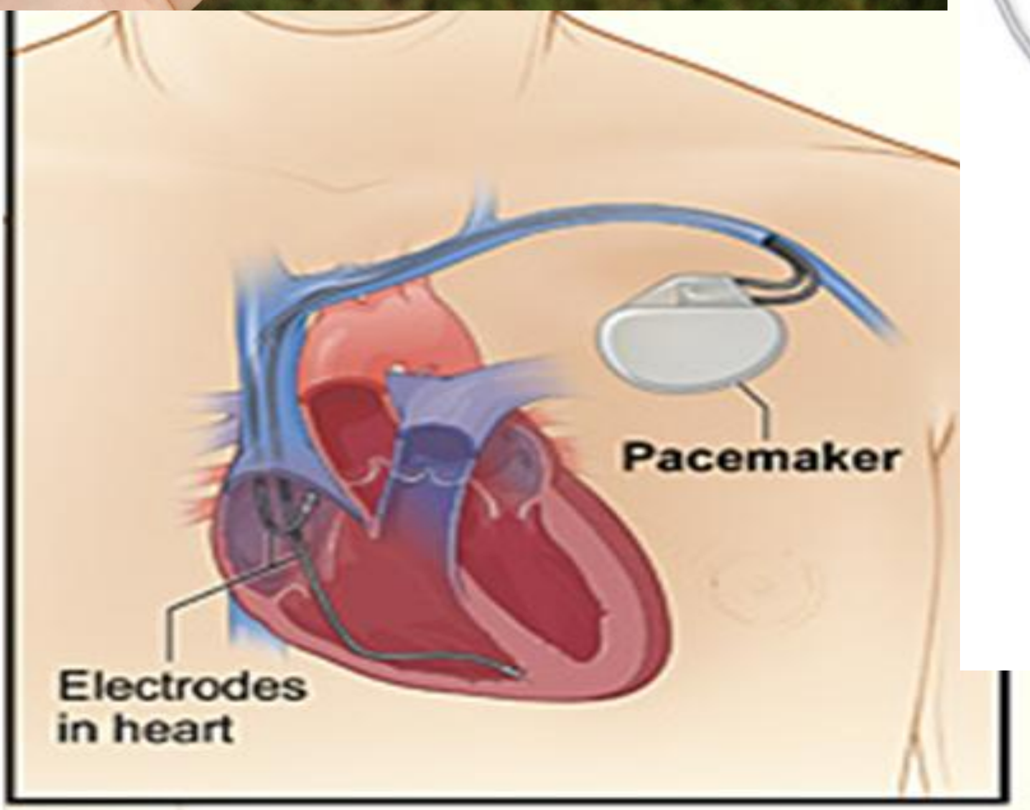
- A pacemaker is a small device that's placed in the chest or abdomen to help control abnormal heart rhythms. This device uses electrical pulses to prompt the heart to beat at a normal rate
- An electric simulator that produces periodic electric pulses that are conducted to electrodes terminated within the lining of the heart.
- The stimulus thus conducted to the heart causes it to contract.
- Used during disease states in which the heart is not stimulated at a proper rate on its own.
- used to treat arrhythmias
- A heartbeat that's too fast is called **tachycardia**
- A heartbeat that's too slow is called **bradycardia**

Understanding Pacemakers

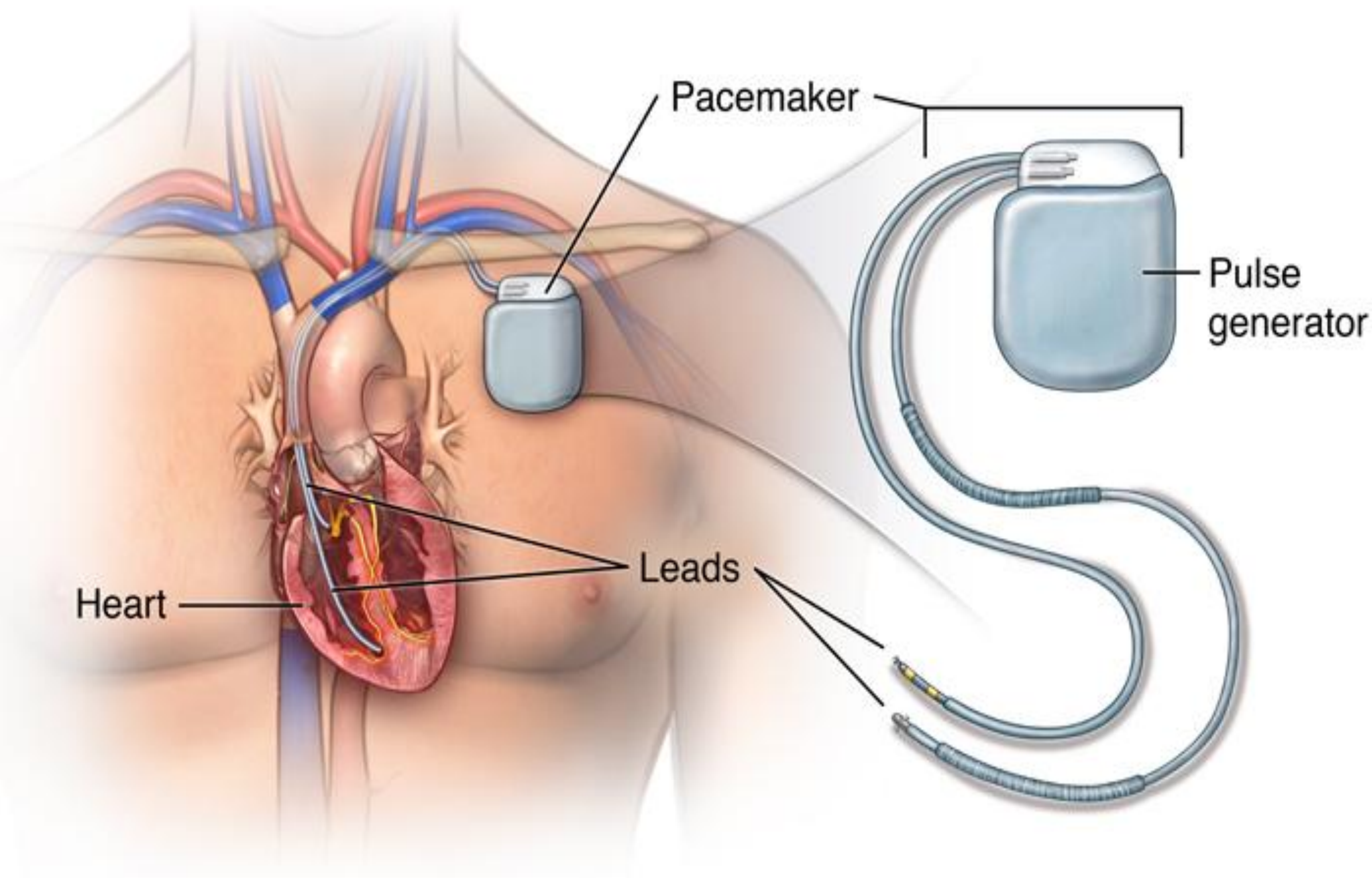
- A pacemaker is a small, lightweight electronic device that helps correct a slow heartbeat
- signals tell the chambers in your heart when to contract.
- heart beating at the right pace.
- Sensors in the pacemaker also keep track of your activity level and can adjust the signals as needed

Cardiac Pacemakers





Pacemaker



Indications for pacemaker

- normal resting heart rate ranges from **60 to 100** bpm
- SA node dysfunction leading to sinus **bradycardia**, including frequent sinus pauses;
- AV or intraventricular conduction block, when the signals from SA node are normal but fail to be transmitted between the atria and the ventricles or within the ventricles;

Pacemaker Design

1. Pulse generator 2. Leads

Pulse generator

In **permanent pacemaker** is encapsulated in a metal can, to protect the generator from electromagnetic interference

permanent

Temporary pacing system generator is externally contained in a small box

Temporary

Transcutanus external pacing system house the generator in a piece of equipment similar to portable ECG monitor

Transcutanus

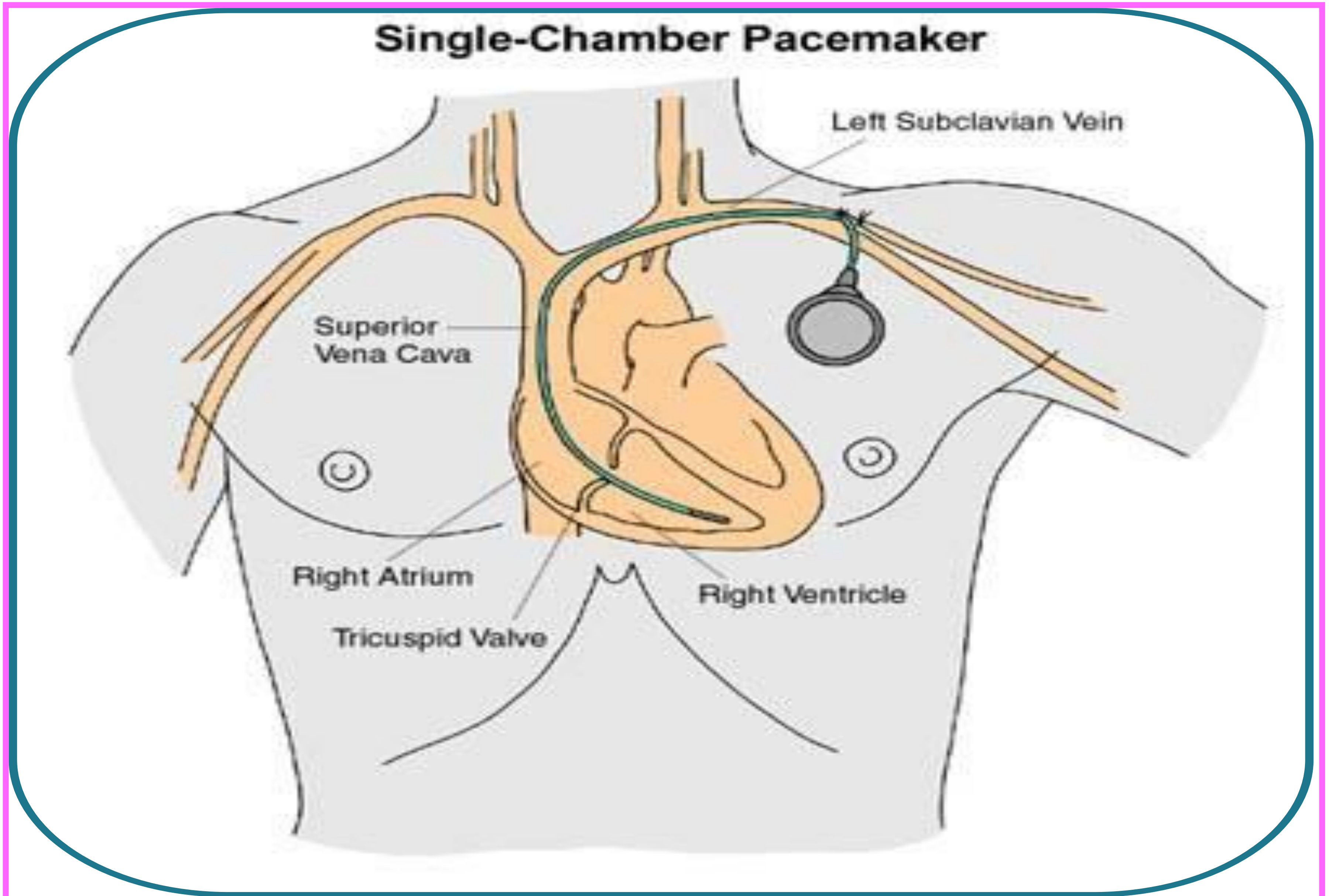
Pacemaker Design

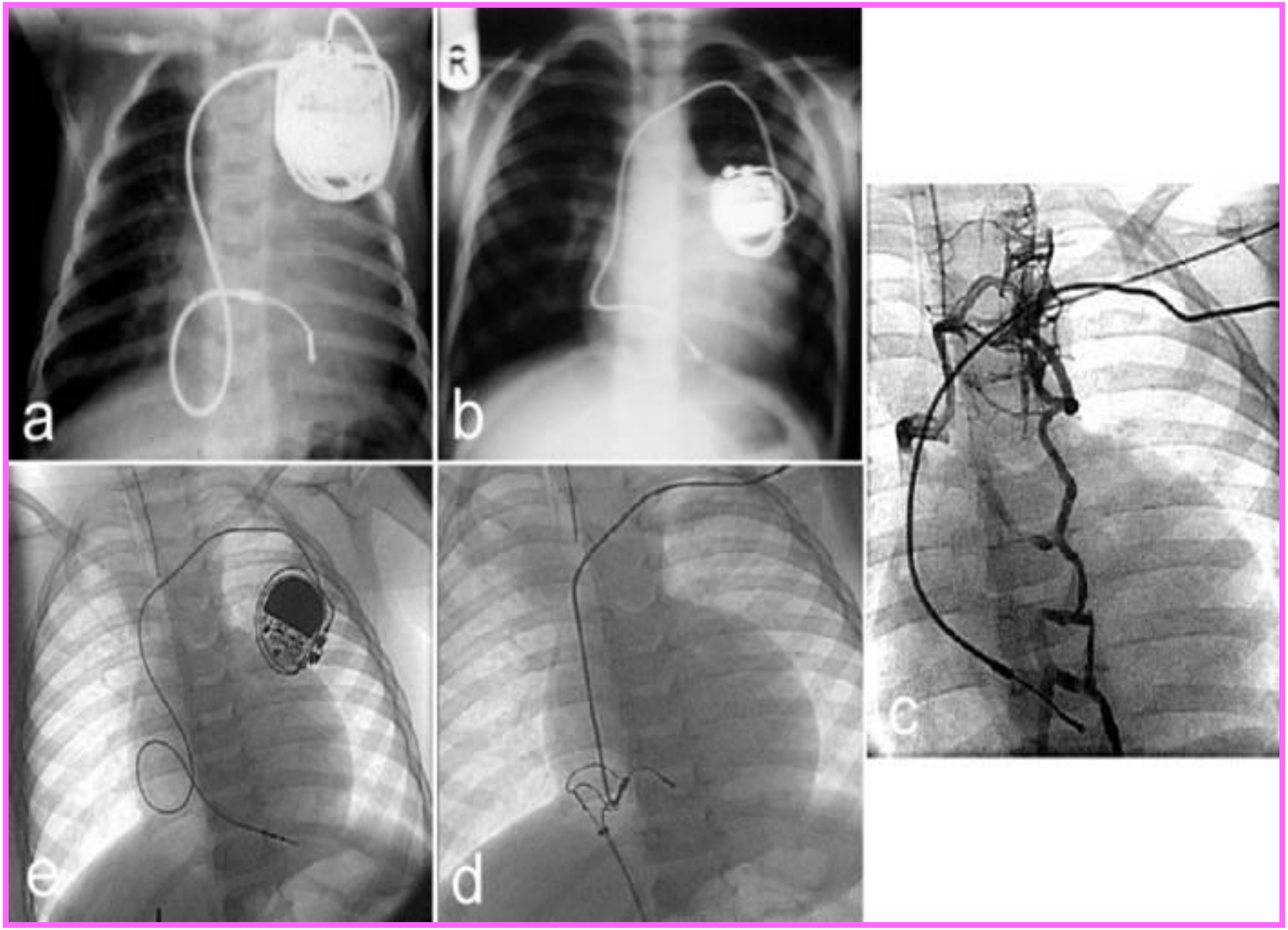
Pacemaker lead

1. **Single chamber (unipolar) pacemaker**

- Lead placed in atrium or ventricle
- Produce large spic on the ECG
- Sensing and pacing in the chamber where the lead is located
- More likely to be affected by electromechanically interference

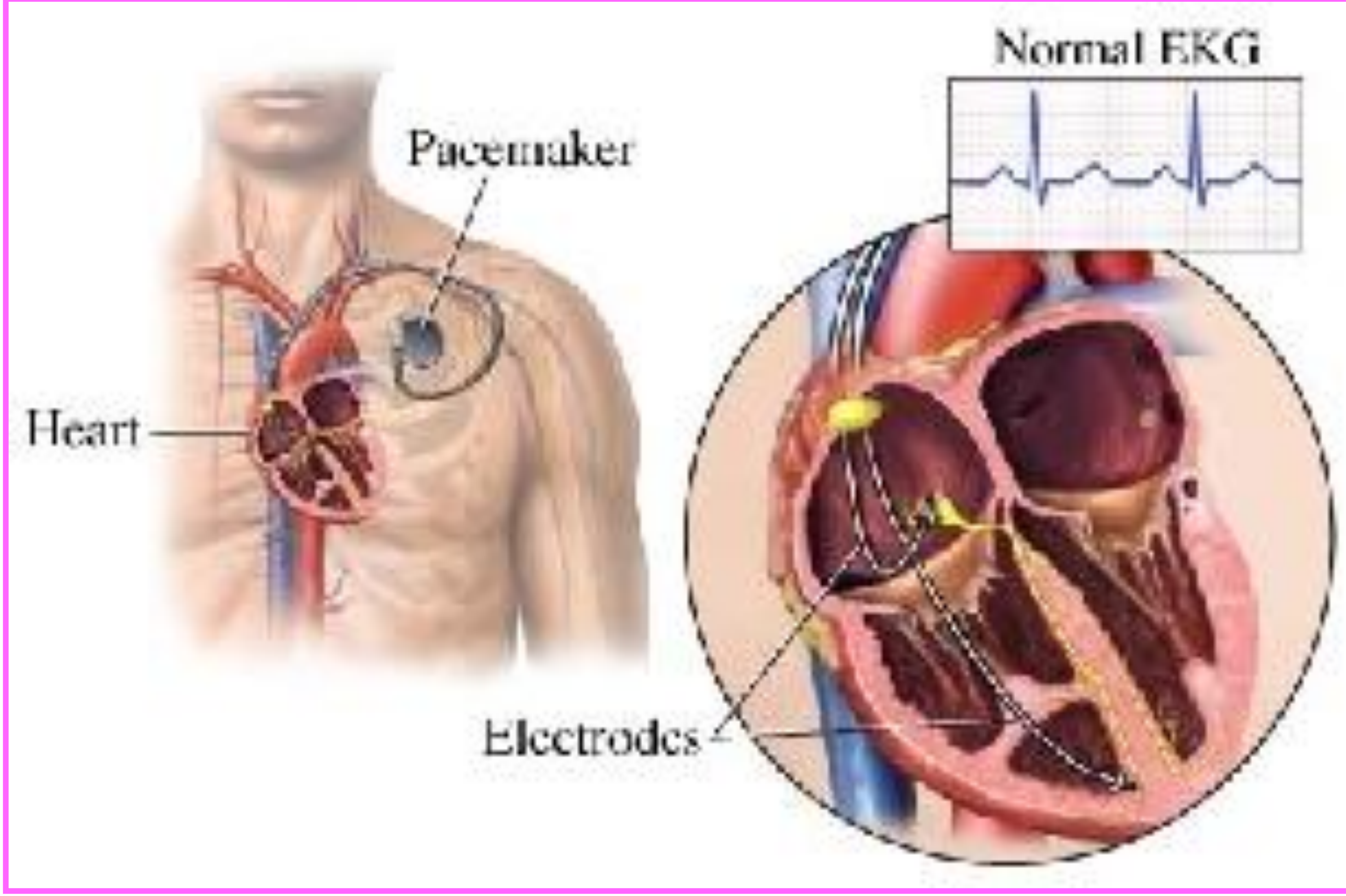
Single chamber (unipolar

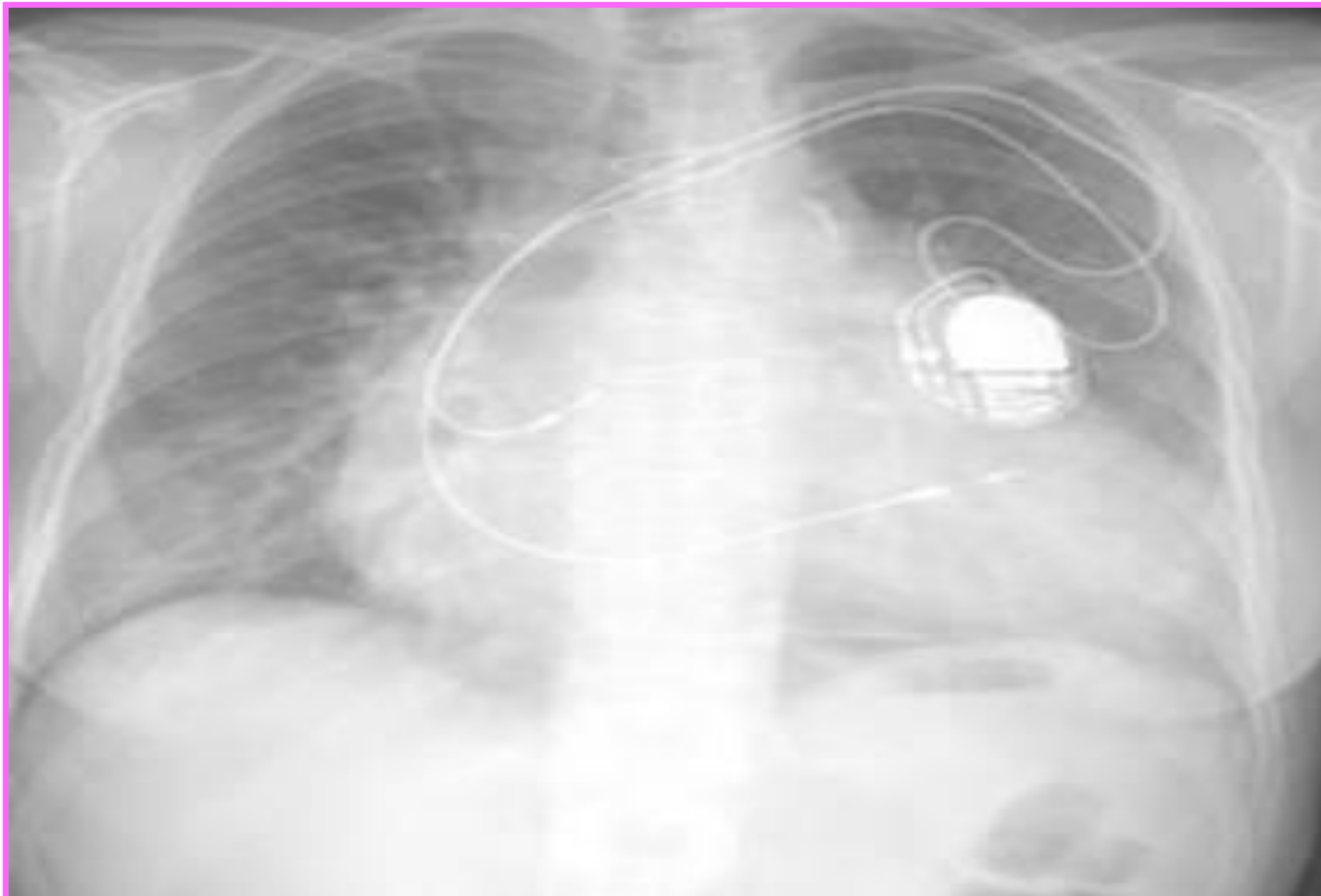



a
b
c
d
e
R

Dual-chamber (bipolar) pacemaker

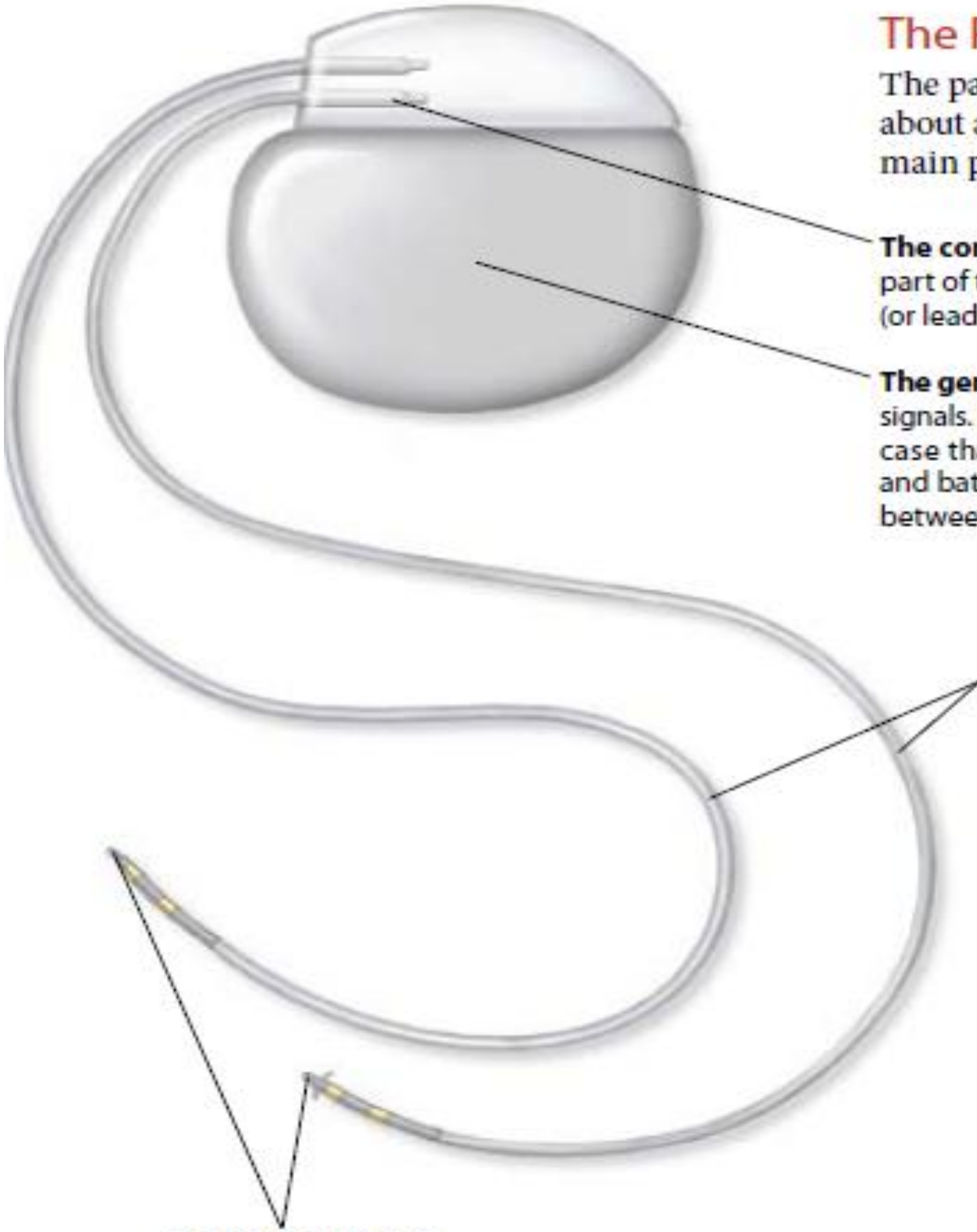
- One Lead located in the atrium and one in the ventricle
- Sensing and pacing in both chambers mimicking the normal heart function
- Produce in visible spic in the ECG
- Less affected by electromechanical interference.


Normal EKG
Pacemaker
Heart
Electrodes



The Parts of a Pacemaker

The pacemaker shown here is about actual size. The three main parts are:



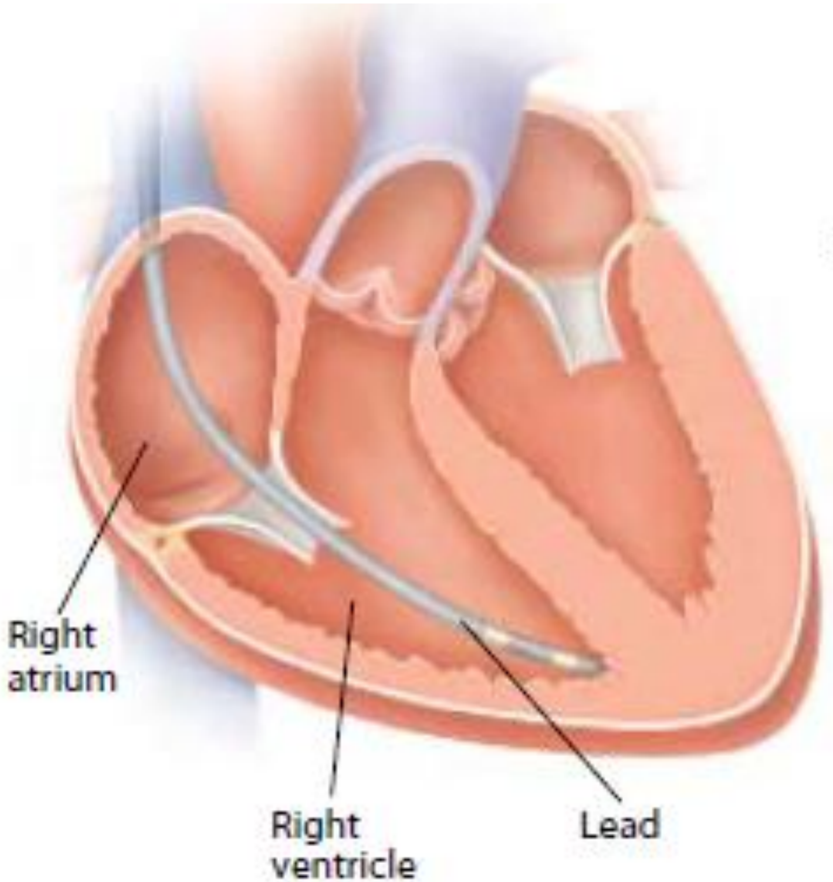
The connector or "header" is the part of the generator where the lead (or leads) are attached.

The generator sends out electrical signals. It has a smooth, lightweight case that contains a tiny computer and battery. It is placed in a "pocket" between your skin and chest muscle.

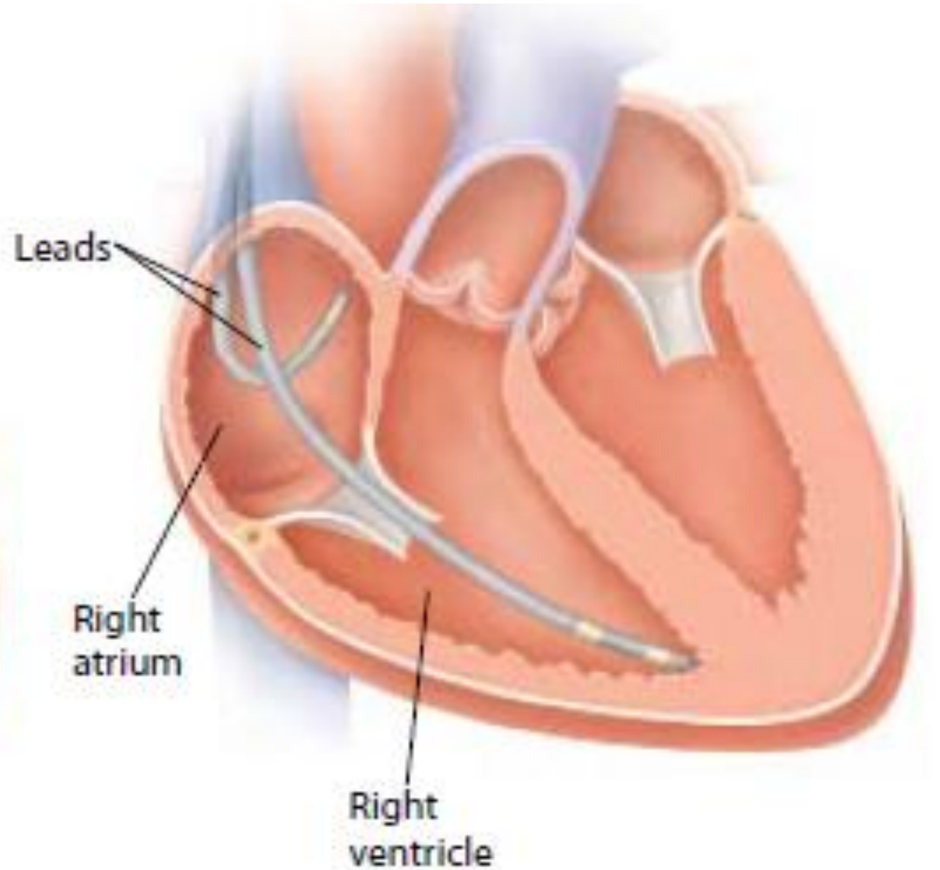
Leads are wires covered by soft, flexible material. They are placed in a vein that goes to your heart. This lets them carry the generator's signals directly to the heart. Sensors on the leads also help the generator keep track of your heart's rhythm.

Anchors on the tips of the leads attach the leads to the heart muscle.

Types of Pacemakers



A single-chamber pacemaker has one lead. The lead is usually attached to the right ventricle (the exact placement inside the ventricle may vary).



A dual-chamber pacemaker has two leads. One attaches to the right atrium. The other attaches to the right ventricle. Having two leads helps coordinate the signals that tell these chambers when to contract.

- ***Bi-ventricular pacemaker***
- three leads – first into right atrium, second into right ventricle and third into the left ventricle
- It is applied when both ventricles do not contract at the same time and are not synchronized with the atria

Pacemaker types according to the programming

- ***A fixed-rate pacemaker***
- Device produces pace pulses at a steady rate, regardless of the heart’s own electrical activity.
- A fixed-rate pacemaker cannot detect intrinsic heartbeats and emits electrical impulses at the same time when the heart’s own pacemaker fires, causing competitive beats.
- ***Pacemaker “on demand”***
- Such a device monitors the heart rhythm and generates electrical pulses only if the heart is beating too slowly or if it misses a beat.
- ***Rate-responsive pacemaker***
- Such a device speeds up or slows down the heart rate depending on how active is the person.
- The optimal heart rate is determined by additional sensor for person’s activity based on body movement or a breathing sensor, which detects the respiration rate.

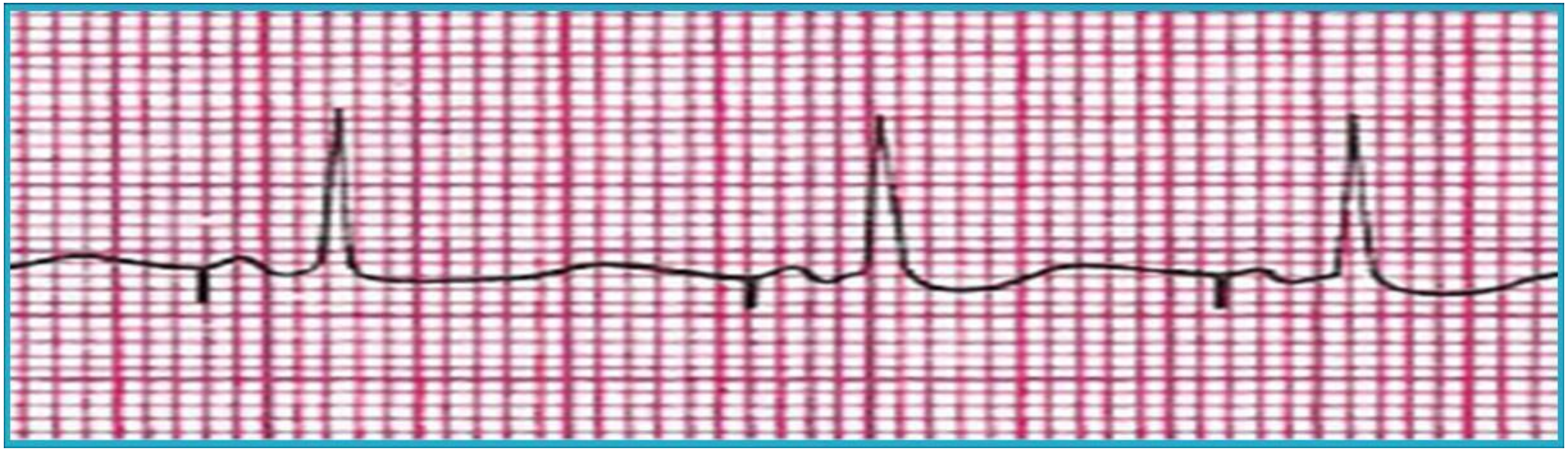
Pacemaker function

1. **Pacing function**
2. **Sensing function**
3. **Capture function**

1. Pacing function

Atrial pacing:

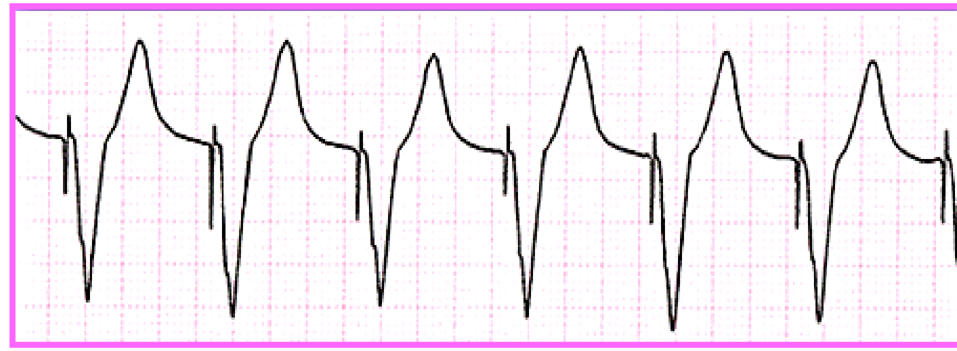
Stimulation of RT atrium produce spic on ECG preceding P wave



1. Pacing function (Cont..)

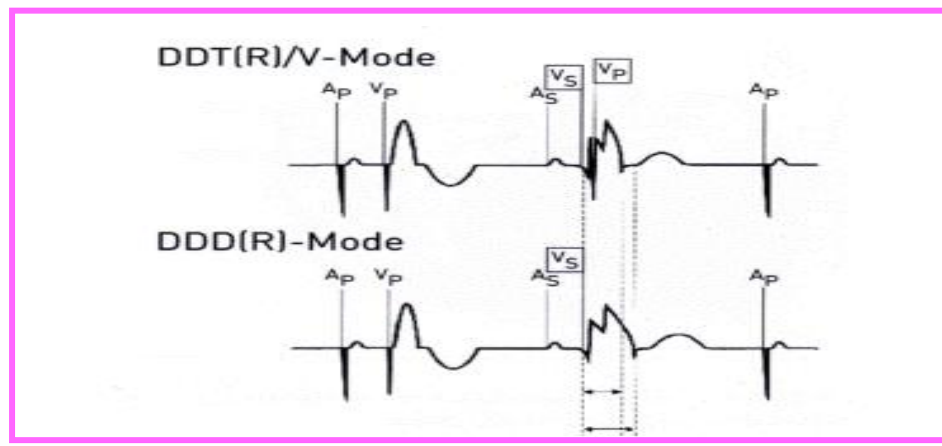
Ventricle pacing :

Stimulation of RT or LT ventricle produce a spic on ECG preceding QRS complex



AV pacing:

Direct stimulation of RT atrium and either ventricles mimic normal heart conduction



2. Sensing function

Sensing :

Ability of the cardiac pace maker to see intrinsic cardiac activity when it occurs

Demand:

Pacing stimulation delivered only if the heart rate falls below the preset limit.

Fixed:

No ability to sense. constantly delivers the preset stimulus at preset rate.

Triggered:

Delivers stimuli in response to (sensing)cardiac event

Capture function

Capture:

Ability of the pacemaker to generate a response from the heart (contraction) after electrical stimulation

1. Electrical capture :

Indicated by P or QRS following and corresponding to a pacemaker spike.

2. Mechanical capture:

Palpable pulse corresponding to the electrical event.

The Implantation Procedure

- Placing a pacemaker inside the body is called **implantation**
- A pacemaker can be implanted in either side of the chest, but is most often placed on the left side.
- The procedure usually takes 1 to 2 hours.

Getting Ready for the Procedure

- Tell the doctor in advance about any medications
- Ask the doctor what to do if you take prescription blood thinners, such as Coumadin or Plavix. Stop taking aspirin, ibuprofen, and naproxen if directed
- Ask an adult family member or friend to give you a ride home after the procedure
- Tell the doctor if you’re left-handed or right-handed
- Don’t eat or drink anything after mid-night, the night before your procedure

Before Implantation

- On the day of procedure, arrive at hospital on time
- sign some forms and change into a patient gown
- IV to provide fluids and medication. Medication to help relax the patient
- The skin where pacemaker will be implanted is washed. Any hair in the area may be removed

During the Procedure

- most common method for implanting a pacemaker is called endocardial (“inside the heart”) implantation
- Medications are given to prevent pain
- An incision is made beneath your collarbone. A small “pocket” for the generator is then created
- The leads are guided through a vein into the heart. An x-ray monitor helps the doctor guide the leads into place.
- The leads are attached to the heart using small anchors on the tips of the leads
- The generator is attached to the leads
- The incision is closed with sutures, surgical glue, or staples

Risks and Complications

- Although complications are rare, implantation does have certain risks:
- Bleeding
- Infection or nerve damage at the incision site
- Severe bruising or swelling at the incision site
- Puncture of the lung or heart muscle
- Tearing of the vein or artery wall
- Clotting or air bubbles in the vein
- Heart attack, stroke, or death

Development of Cardiac Pacemakers

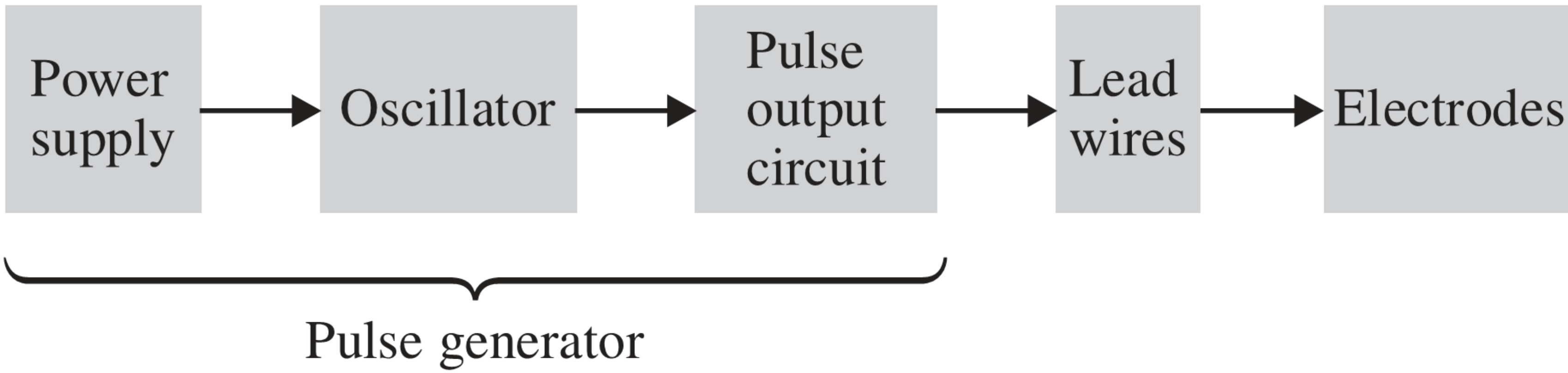
- The practical use of an implantable device for delivering a controlled, rhythmic electric stimulus to maintain the heartbeat is relatively recent: Cardiac pacemakers have been in clinical use only slightly more than 50 years.
- Although devices have gotten steadily smaller over this period (from 250 grams in 1960 to less than 25 grams today and even smaller to the size of a AAA battery with recent leadless designs), the technological evolution goes far beyond size alone.
- Early devices provided only single-chamber, asynchronous, *nonprogrammable* pacing coupled with questionable reliability and longevity.
- Today, advanced electronics afford dual-chamber multi *programmability,* diagnostic functions, rate response, data collection, and exceptional reliability, and lithium-iodine power sources extend longevity to upward of 10 years.

- And recently , complications and problems faced with the need of a surgical pocket for implantation of the device and the application of lead systems forced scientist to propose/develop leadless cardiac pacemakers.

- As a world first, a leadless cardiac pacemaker developed by St. Jude Medical (called Nanostim, which has one-tenth the size of existing cardiac pacemakers) is implanted into a patient in USA on early February 2014.

- After St. Jude Medical (end of February 2014), another well known pacemaker company Medtronic repeated the same milestone by implanting its own leadless pacemaker (Micra, which they claim to be the world’s smallest)into a patient.

Asynchronous Pacemakers



- An asynchronous pacemaker is one that is free running.
- Its electric stimulus appears at a uniform rate regardless of what is going on in the heart.

Asynchronous Pacemakers

- The oscillator establishes the pulse rate for the pacemaker

- The pulse rate controls the pulse output circuit that provides the stimulating pulse to the heart.

- The pulse is conducted along the lead wires to the cardiac electrodes.

Requirements

- Each block must be highly reliable
- The package of an implanted pacemaker
  - Must be compatible and well tolerable by the body.
  - Must provide the necessary protection to the circuit components to ensure reliability.
  - Must be designed to operate well in the corrosive environment of the body
  - Must occupy minimal volume or mass.

Cardiac Pacemakers-Design

- They are packaged in hermetically (airtight) sealed metal packages.
  - Titanium
  - Stainless steel

- Special electron beam or laser welding techniques are used to seal these packages without damaging the electronic circuit or the power source.

- Metal packages takes less volume and are more reliable than polymer-based packages.

Power Supply

- Battery made up of primary cells were used in 1970s. Required replacement in every two years.

- **Currently Lithium Iodide batteries are used**
  - Increased life time
  - Open circuit voltage of 2.8 V.
  - Highly reliable
  - Relatively High source resistance is a major limitation.

Timing Circuit

- Implemented by free running oscillators
- Advanced pacemakers have timing circuits to determine when a stimulus should be applied to the heart.
- Complex logic circuits, quartz crystal control & Microprocessor based circuits are in use today.

Output Circuit/Pulse Generator

- Produces the actual electrical stimulus that is applied to the heart.

- Generates an electrical stimulus pulse that has been optimized for stimulating the myocardium through the electrode system that is being applied with the generator.

- Constant-voltage or constant-current amplitude pulses are the two usual types of stimuli produced by the output circuit.

Output Circuit…

- Constant-voltage amplitude pulses are typically in the range of 5.0 to 5.5 V with a duration of 500 to 600 μs.

- Constant-current amplitude pulses are typically in the range of 8 to 10 mA with a pulse duration ranging from 1.0 to 2.0 ms.

- Pulse rates ranges from 70 to 90 beats per minute.

Lead Wires & Electrodes

- **Requirements:**
  - Must be mechanically strong
  - Must be able to withstand constant motion of the beating heart.
  - Must maintain good electrical insulation to prevent the possibility of shunting important stimulating current away from its intended point of application on the heart.

Lead Wires & Electrodes…

- Consists of interwound helical coils of spring-wire alloy molded in a silicone-rubber or polyurethane cylinder.

- The helical coiling of wire minimizes the stress applied to it.

- Multiple strands serve as insurance against failure of the pacemaker following rupture of a single wire.

- The soft compliant silicone rubber encapsulation both maintains flexibility of the lead-wire assembly and provides electrical insulation and biological compatibility.

Bipolar & Unipolar electrodes

- ***Unipolar***
  - A single electrode is in contact with the heart, and negative-going pulses are connected to it from the generator.
  - A large indifferent electrode is in contact located somewhere else in the body, usually mounted on the generator, to complete the circuits.
- ***Bipolar***
  - In the bipolar system, two electrodes are placed within or on the heart, and the stimulus is applied across these electrodes.

Electrodes

- Can be placed on the external surface of the heart (epicardial electrodes)

or

- Buried within the heart wall (intramyocardial electrodes)

or

- Pressed against the inside surface of the heart (endocardial or intraluminal electrodes)

Electrodes

- Made of materials that do not
  - Dissolve during long term implantation
  - Cause undue irritation to the heart tissue adjacent to them
  - Undergo electrolytic reactions when stimulus is applied.

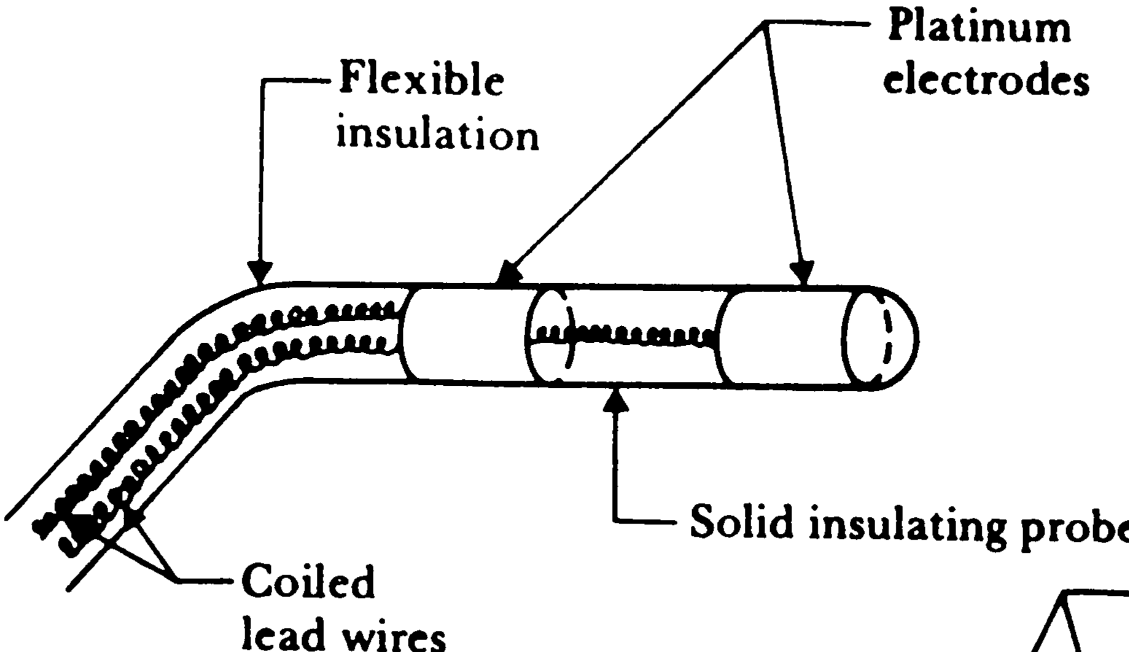
- Made of same materials as the lead wire to avoid junctional problems.

- A dense capsule formation around electrode is made
  - to minimize biological interaction.
  - To increase the threshold required for stimulation.

Electrodes…

- Materials used are:
  - Platinum
  - Alloys of platinum with stainless steel, carbon, and titanium, etc…

Bipolar intraluminal & Intramyocardial electrodes



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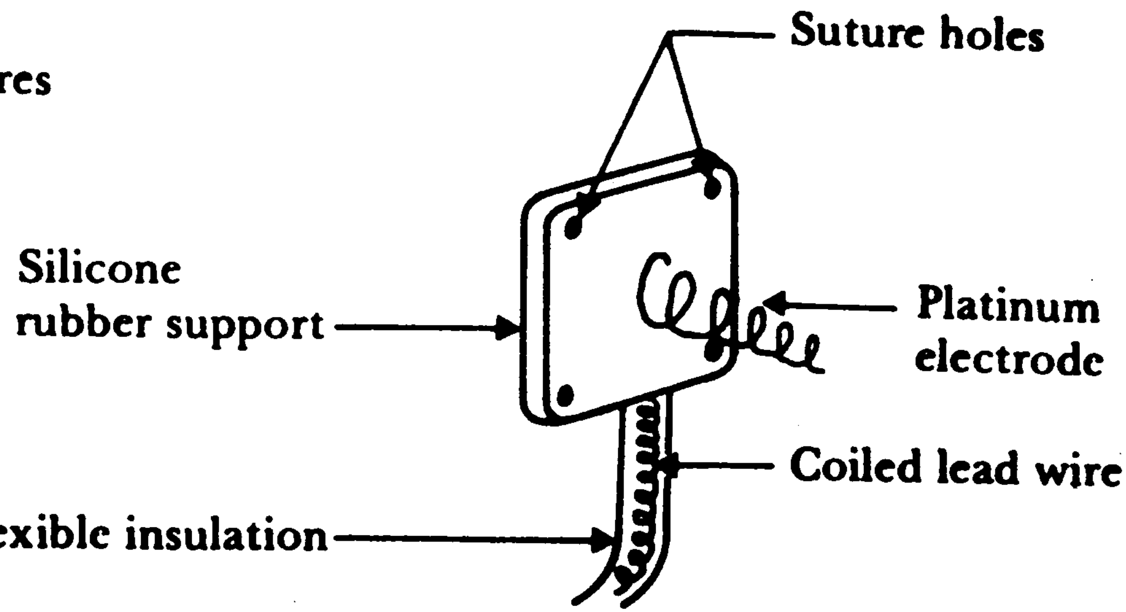


(b)

Bipolar intraluminal & Intramyocardial electrodes

- The conducting bands around the circumference of the solid intraluminal probe contact the internal surface of the heart wall and electrically stimulate it.

- The intramyocardial electrode is placed on the exterior surface of the heart.

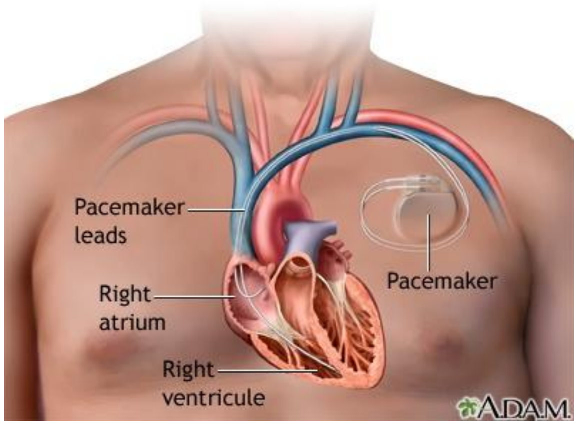
- A puncture wound is made in the wall of the heart, and the helical spiral-shaped electrode is placed in the this hole.

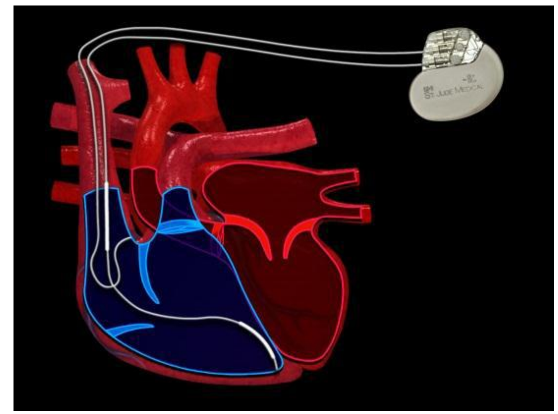
- To hold the electrode in place, the silicone-rubber supporting piece is then sutured to the external surface of the heart.

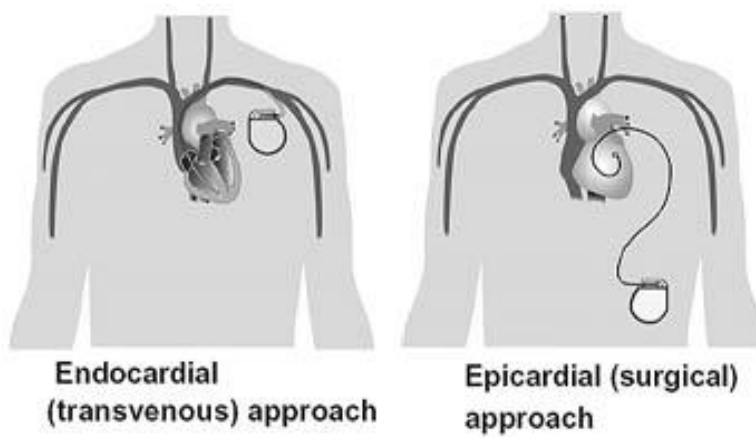
Bipolar intraluminal & Intramyocardial electrodes

- This flexible back support provides a good mechanical match between the electrode and the heart wall.
- For bipolar intramyocardial stimulation, a pair of these electrodes is attached to the myocardium.

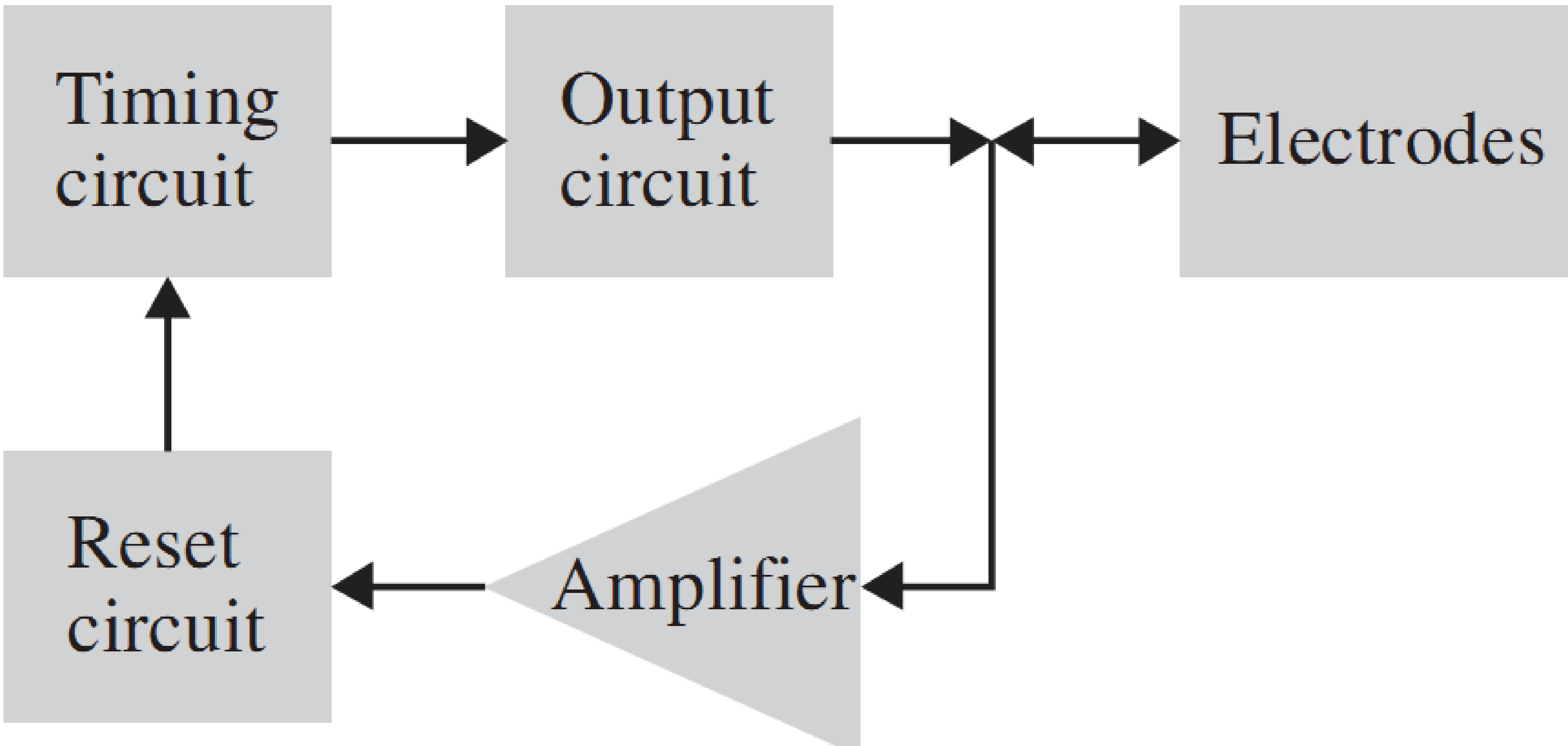
intraluminal electrodes / transvenous pacemaker







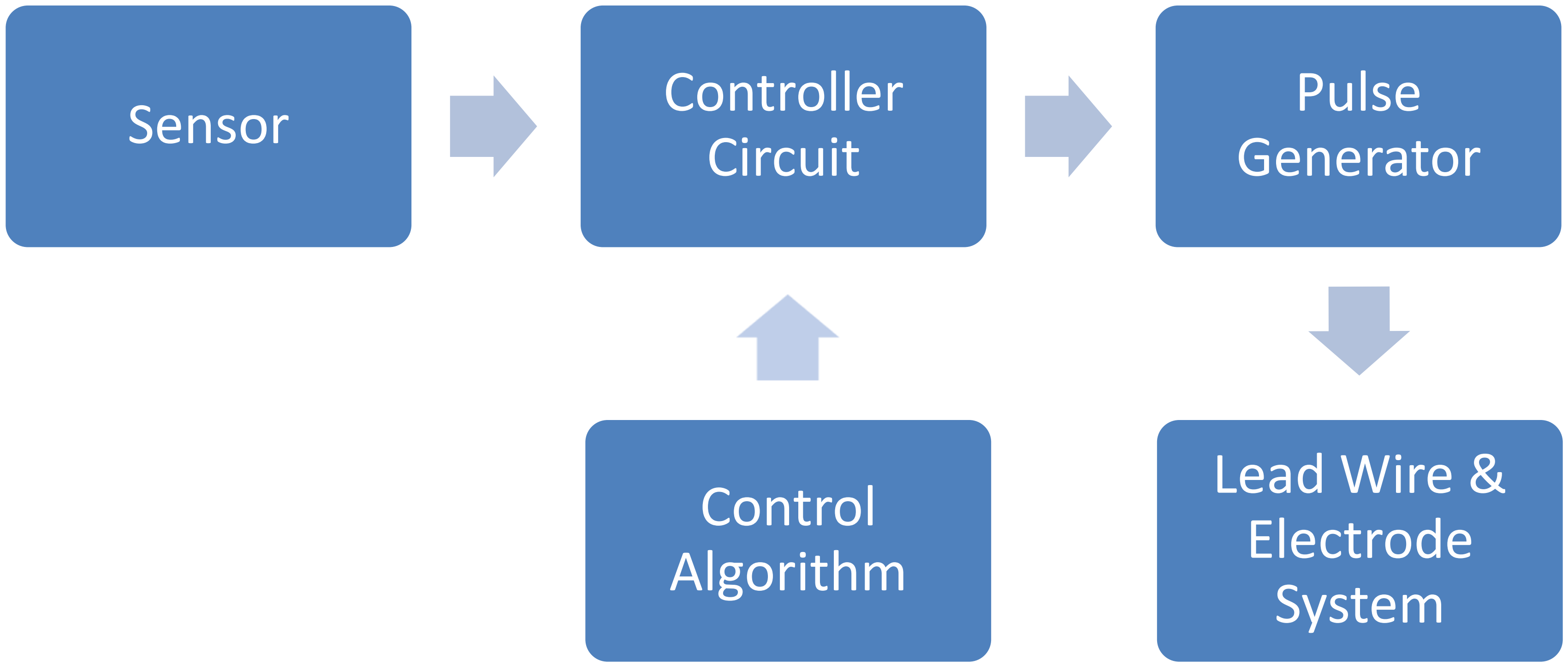
Demand-type Synchronous Pacemaker



Demand-type Synchronous Pacemaker

- It has a feedback loop.
- After each stimulus the timing circuit reset itself.
- Waits for a predetermined interval to provide the next stimulus.
- If during this interval, a natural beat occurs in the ventricle, the feedback circuit amplifies it and this signal will reset the timer.

Rate-Responsive Pacemaker



Rate-Responsive Pacemaker

- Includes a control system
- A sensor is used to convert a physiological variable in the patient to an electric signal that serves as an input to the controller circuit.
- The controller circuit is programmed to control the heart rate on the basis of the physiological variable that is sensed.
- The controller can determine whether any artificial pacing is required and can keep the pacemaker in a dormant state when the patient’s natural pacing system is functional.

Rate-Responsive Pacemaker…

- The sensor can be located

  - Within the pacemaker itself

  - At some other point within the body.
    - Connected to the pacemaker by a lead-wire system

Physiological variables that have been sensed by Rate-Responsive Pacemakers.

Physiological Variable	Sensor
Right Ventricle blood temperature	Thermistor
ECG Stimulus-to-T wave interval	ECG Electrodes
ECG R-wave area	ECG Electrodes
Blood pH	Electrochemical pH Electrode
Rate of change of right ventricular pressure	Semiconductor strain guage pressure sensor
Venous blood oxygen saturation	Optical oximeter
Respiratory rate and /or volume	Thoracic electric-impedance plethysmography
Body Vibration	Accelerometer

Leadless Pacemaker;why ?

- While conventional pacemakers can improve a patient’s quality of life and may even prolong it, physicians and patients have long asked for a pacemaker that does not require an unsightly surgical pocket that may restrict a patient’s mobility or become infected. They also want a solution that eliminates leads, which in rare cases may fail or dislodge.

- Conventional pacemakers require the doctor to make a surgical incision in the chest where a pacemaker permanently sits in a pocket under your skin. The doctor then implants thin insulated wires – which are called leads - from the pacemaker through the veins into your heart. These leads deliver electrical pulses that prompt your heart to beat at a normal rate.

- Although the incidence of pacemaker complications is relatively low (about 4%), when complications occur, they typically happen in the pocket where the pacemaker is implanted or with the leads.
- In about 1% of patients, the pocket may become infected. In about 3% of patients, the leads may move out of place causing complications.

- While rare, complications can have a serious impact on a patient's quality of life and also can be expensive to address. Even if complications do not occur, all patients have a scar and lump where pacemaker is implanted.
- In addition, previous research has shown that as many as six out of 10 patients experience reduced mobility in the shoulder region where the pacemaker is implanted

- With the development of leadless pacemakers, the surgical pocket and leads are eliminated, which means reducing the risks associated with these complications.
- Other possible advantages of the leadless pacemaker include no visible pacemaker device under a patient's chest skin, no incision scar on the chest and no restrictions on a patient's activities.
- The device's benefits may also allow for less patient discomfort, infections, and device complications and dysfunction.
- In addition, the free-standing, battery-operated pacemaker device is designed to be fully retrievable from the heart.

Leadless Pacemaker Design

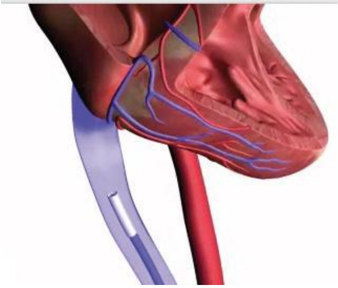
- Similar to standard cardiac pacemakers, leadless pacemaker device treats a heart rate that is too slow called bradycardia. It works by closely monitoring the heart's electrical rhythms and if the heart beat is too slow (or in an irregular pattern) it provides electrical stimulation therapy to regulate it. It also communicates to a programming system like a standard pacemaker

- Unlike standard pacemakers, leadless pacemaker is designed as a small cylindrical pacemaker.

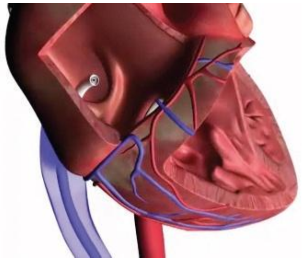
- The device is comprised of a pulse generator that includes computer chips, small long lived battery in a sealed case that resembles a AAA battery and a steroid-eluting electrode that sends pulses to the heart when it recognizes a problem with the heart’s rhythm.

- The device, resembling a small, metal silver tube, is only a few centimeters in length, making it less than ten percent the size of a standard pacemaker.
- But, unlike standard pacemakers, it resides entirely in the right ventricle of your heart.
- This pacemaker requires no leads, no chest incision, no scar and no permanent lump under the skin where the pacemaker sits. The pacemaker battery life is equivalent to that of similar standard single chamber pacemakers.

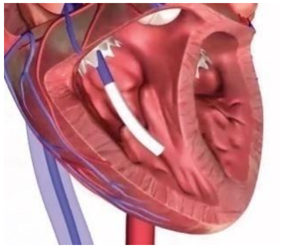
Leadless Pacemaker Implantation



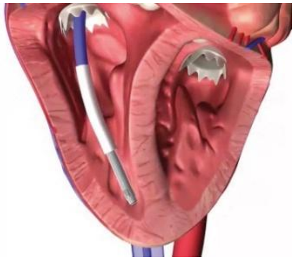
1. A catheter that contains the leadless pacemaker is passed through a small puncture in the groin and then into the femoral vein.



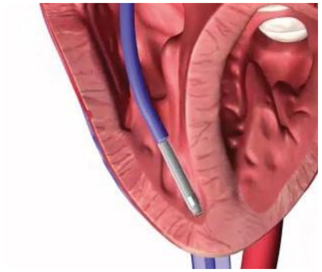
2. Using X-ray images as a guide, the doctor guides the catheter to the right atrium of the heart and through the tricuspid valve.



3. The catheter with the pacemaker is then guided into the right ventricle.



4. The doctor carefully places the pacemaker and secures it to the wall at the bottom of the right ventricle.



5. The pacemaker is then tested to ensure it is secured to the wall and programmed correctly.

6. The catheter is removed and the pacemaker stays within the right ventricle.