Learning objectives

To help radiologists recognize the different types of heart pacemakers and automatic implantable cardioverter defibrillators (ICDs) and their proper position on chest x ray.

To learn the indications for their use.

To know particular scenarios as a result of abandoned leads, anatomical variants and unusual implantations.
Background

Cardiac conduction devices (CCD), which comprise pacemakers and implantable cardioverter-defibrillators\(^1\), are one of the most frequently used medical devices and they are being increasingly employed in patients suffering from cardiac rhythm disturbances and heart failure.

Radiologists should have a working knowledge of the different types of CCD as well as appropriate positioning and indications.

Some concepts to review:

- **Cardioversion**: delivery of energy that is synchronized to the large R waves of the QRS complex. This prevents delivery of the shock during the vulnerable period (or relative refractory period. T-wave) of the cardiac cycle, which could induce a situation with pulse to ventricular fibrillation.
- **Defibrillation** (unsynchronized cardioversion): is a nonsynchronized delivery of energy during any phase of the cardiac cycle. Defibrillation is a much higher electrical current than when uses a pacemaker, and is given in a single output\(^1\). It is the treatment for immediately life-threatening arrhythmias on which the patient does not have pulse. This occurs in the rhythms of cardiac arrest that needs defibrillation (ventricular fibrillation and pulseless ventricular tachycardia)\(^1\).
- **Pacemaker**: uses low electrical impulses, delivered by electrodes contracting the heart muscles, to regulate the beating of the heart.
- **Implantable cardioverter-defibrillators (ICDs)**: have the ability to treat many types of heart rhythm disturbances by means of pacing, cardioversion, or defibrillation. The difference between pacemakers and ICDs is that pacemakers are also available as temporary units and are generally designed to correct slow heart rates, i.e. bradycardia, while ICDs are often permanent safeguards against sudden life-threatening arrhythmias.

The aim of the first two is to deliver electrical energy to the heart that causes all of the heart cells to contract simultaneously. This interrupts abnormal electrical rhythm, and allows the sinus node to resume normal pacemaker activity. The pacemaker does not try to stop an arrhythmia and the primary purpose of a pacemaker is to maintain an adequate heart rate. ICD are often permanent safeguards against sudden life-threatening arrhythmias.
PACEMAKERS:

A cardiac pacemaker is composed of two main elements: (a) a pulse generator (battery pack and control unit) and (b) lead wires with electrodes for contact with the endocardium or myocardium.

The name of the pacemaker has 3 main letters.

I: The first letter is the chamber(s) paced. Since pacing the heart is the primary function of the pacemaker, this function is given position 1. A device used to pace in only one chamber will be represented by either the letter A (atrial) or V (ventricular), devices that are capable of pacing in both chambers are represented by the letter D (dual).

II: The second letter is the chamber(s) sensed. The letter designations for position 2 are the same as the designations for position 1. A device used to sense in only one chamber will be represented by either the letter A (atrial) or V (ventricular), devices that are capable of sensing in both chambers are represented by the letter D (dual).

III: The third letter is the mode(s) of response to sensing: triggered (T) or inhibited (I). Position 3 is directly tied into position 2: without sensing, there can be no mode of response to sensing. When inhibited (I), the mode of response is to withhold a pacemaker output in the presence of a sensed event. In a VVI pacemaker, the pacemaker senses a ventricular event and withholds the ventricular output. This mode is suitable when no synchronization with the atrial beat is required, as in atrial fibrillation. If the pacemaker is programmed to the DDI mode, the pacemaker simply inhibits the output of the device in the chamber where any signal is sensed.

The letter D (dual) in the third position indicates that the device will respond to the sensed signal by either inhibiting the pacemaker response, tracking the sensed event, or inhibiting the output on the sensed channel and triggering an output to maintain AV synchrony. The most common example of the letter D in the 3rd position can be seen with DDD pacemakers. A sensed atrial signal will cause the device to inhibit the atrial output, a timer then starts that will cause a triggered ventricular output after a certain interval. If the patient has an intrinsic R wave (ventricular systole) during the triggering interval, the pacemaker will inhibit the ventricular output.

The letter T in the third position is rarely encountered. XXT pacing will produce pacemaker output spikes concurrently with intrinsic sensed events (essentially pseudo fusion beats). It paces when detects an intrinsic activity. It is, however, an excellent way to observe the
location of sensing of intrinsic events. If a sensing problem is suspected, programming to a XXT mode may allow the clinician to observe exactly where in the timing of the device, the sensing abnormality is occurring.

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<tr>
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<th>II</th>
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<td>Chamber(s) Sensed</td>
<td>Mode(s) of response</td>
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<tr>
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<td>V = Ventricle</td>
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<tr>
<td>A = Atrium</td>
<td>A = Atrium</td>
<td>I = Inhibited</td>
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<td>D = Dual (A&amp;V)</td>
<td>D = Dual (A&amp;V)</td>
<td>D = Dual. Triggered / inhibited</td>
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<td>0 = None</td>
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Findings and procedure details

We illustrate with cases from our files the imaging characteristics of transient pacemakers (transvenous, transcutaneous and epicardial), permanent pacemakers (epicardial and endocardial) and ICDs. We review how to identify, in the chest X-ray the different types of CCD as well as their normal location.

The different types of devices are shown with the pacemaker code and the indications.

In "PARTICULAR SCENARIOS" we highlight cases that can be misleading or situations potentially dangerous (e.g. twiddling pacemaker) in which timely reporting provides important information that can improve patient care.

1.- THE DIFFERENT TYPES OF CARDIAC CONDUCTION DEVICES AND THEIR PROPER POSITION ON CHEST X RAY.

1.1. PACEMAKERS:

1. **Single - chamber pacemaker:**

   a. **Atrial pacemaker (AAI):** Fig. 1 on page 15 it is possible to recognize this pacemaker at the plain chest film. It has only one lead that is located in the right atrium. On the lateral view, the right atrial lead has a "J-shaped" appearance entering the right atrium and then curving upward and anteriorly to its proper position in the right atrial appendage. It paces the atrium, but inhibit if senses intrinsic activity. Is the mode of choice when atrioventricular conduction is intact but the natural pacemaker, the sinoatrial node is unreliable - sinus node disease (SND) or an aberrant additional sinoatrial node pacemaker focus is present. It should not be indicated en BAV, because it does not sense the ventricle and it can inhibit after atrial intrinsic activity.

   Medical practice, however, has shifted to predominant implantation of dual chamber pacemaker (DDD) even in these cases to prevent atrioventricular conduction disturbances that could develop in the future.

   b. **Ventricular pacemaker (VVI):** Fig. 2 on page 15 it is possible to recognize this pacemaker at the plain chest film. It has one lead placed in the apex of the right ventricle (arrow). The right ventricular apex (arrow) has been used for cardiac stimulation because
this position, at the apex, is easily accessible and is associated with a stable position of
the electrode with a low dislodgement rate. It paces the ventricle, but inhibit if senses
intrinsic activity. Is not commonly used.

c. AOO, VOO, DOO, DDI y DVI: The single chamber units VOO or AOO are used when
fixed rate pacing is preferred (ventricular fixed rate pacing or atrium fixed rate pacing);
the dual chamber modes are DOO (fixed rate). DDI and DVI are less used.

2. Dual chamber pacemaker (VDD o DDD): it is possible to recognize them at the plain
chest film.

a. DDD: Fig. 3 on page 16 two leads positioned, in the right atrium (arrowhead) and
right ventricle (arrow). The pacemaker records both atrial and ventricular rates and can
pace either chamber when needed. It covers all the options.

b. VDD: Fig. 4 on page 17 it has one single lead with bipolar electrodes in the right
atrium (to sense) (arrowheads) and single electrode in the right ventricle (to sense and
pace). The atrial bipolar electrodes are called dipole. In this example, the ventricle is
the chamber paced but the pacemaker is capable of sensing in both the atrium and the
ventricle. When the problem is a high degree atrioventricular block (AVB) with normal
sinus function, the pacemaker is required to detect (sense) the atrial beat and after a
normal delay (0.1-0.2 seconds) trigger a ventricular beat, unless it has already happened
(sense the ventricle).

Compared with DDD systems, implantation and fluoroscopy times are signifi-
cantly shortened.

3. Biventricular pacemaker: use for resynchronization therapy, when there is
drug refractory heart failure with interventricular or intraventricular dysynchrony.
Biventricular pacemakers stimulate simultaneous contraction of the left and right
ventricles, resulting in a more efficient pumping action.

a. Three chamber pacemaker: Fig. 5 on page 18 There are one lead at the right
atrium, one at the right ventricle and one lead at the left ventricle (arrow) which
goes through the coronary sinus into a left lateral cardiac vein for left ventricular
pacing. Current Cardiac resynchronization therapy usually involves atrial synchronized
ventricular pacing to optimize atrioventricular timing with biventricular pacing to promote
ventricular synchrony.
b. **Biventricular pacemaker**: (not shown) one lead at the right ventricle and another lead goes through the coronary sinus to the left ventricle.

### 1.2. IMPLANTABLE CARDIOVERTER-DEFIBRILLATORS

1. **Automatic implantable cardioverter defibrillator (AIDC or ICD)**: Fig. 6 on page 19 it is designed for both patient monitoring and therapy. It is equipped for defibrillation in case of a malignant arrhythmia instead of pacemakers. Is composed of a single lead with two shock coils, located in the region of the brachiocephalic vein-superior vena cava junction (arrowhead) and in the right ventricle (arrow). Is possible to recognize this device at the plain chest radiography, because it shows the two thick shock coils that are essential for the diagnosis. The key to distinguish between ICD and pacemaker leads is that shock coils appear as two separate thick metallic segments along the length of the ICD lead, whereas pacemaker leads appear as smaller leads with a stable diameter along their length.

### 1.3. ICD AND PACEMAKER COMBINATIONS

This configuration is known as cardiac resynchronization therapy and is used to treat congestive heart failure when the patient is at high risk of sudden cardiac arrest from arrhythmias.

1. **Automatic implantable cardioverter defibrillator** (white arrowhead and arrow) + **Dual chamber pacemaker** (black arrowhead and arrow): Fig. 7 on page 20 Exhibits the same characteristics as those shown by the previous device but adds a biventricular pacemaker with one right ventricular lead (black arrow) and one left ventricular lead (black arrowhead). The pacemaker can also be located in RA (right atrial) and RV (not shown). The automatic implantable cardioverter defibrillator (AICD or ICD) is a cardiac device designed for both patient monitoring and therapy (see 1.2.1).

2. **Automatic implantable cardioverter defibrillator** (white details) + **Three chamber pacemaker** (black details): Fig. 8 on page 21 The tip of the combined pacemaker-ICD lead is in the right ventricular apex (black arrowhead). The other pacemaker leads are in the right atrium (big black arrow) and along the lateral wall of the left ventricle (small black arrow). The automatic implantable cardioverter defibrillator (AICD or ICD) is a cardiac device designed for both patient monitoring and therapy (see 1.2.1).
1.4. TEMPORARY CARDIAC PACING

1. **Epicardial pacemaker**: Fig. 9 on page 22 (fig C: scan view) it can be atrial or ventricular, uni or biventricular, temporary or less frequently permanent. The main indication for inserting an epicardial pacing wires is during cardiac surgery as well as in the post-operative period to prevent arrhythmias. Permanent epicardial pacemakers are often required in children because of their small size, congenital cardiac defects with right-to-left shunts, or lack of access to the chamber requiring pacing (see medical indications for other indications).

2. **Transcutaneous temporary pacemaker** (white arrows): Fig. 10 on page 23 is a noninvasive way of pacing. Transcutaneous and transvenous cardiac pacing are the most commonly used methods for temporary pacing of the heart. The main factor that dictates the use of one approach instead of another is the urgency of the need for pacing. In an emergency, transcutaneous pacing is the method of choice because it is the fastest method of cardiac pacing. Nevertheless, transvenous pacing has several advantages over the transcutaneous method: enhanced patient comfort, greater reliability, and the ability to pace the atrium.

   The purpose of temporary pacing is the reestablishment of circulatory integrity and normal hemodynamics that are acutely compromised by a slow or fast heart rate.

   In the transcutaneous temporary pacemaker the negative electrode pad is located at the cardiac apex, and the positive electrode pad can be located on the right chest on the subclavicular area (anterior/lateral position) or on the posterior left chest beneath the scapula and lateral to the spine (anterior/posterior position).

3. **Temporary transvenous pacemaker**: Fig. 11 on page 24 Chest X Ray shows a transvenous pacing electrode into the right ventricle (black arrows). Note the partially displaced pads of transcutaneous cardiac pacing used previously (white arrows). Transvenous and transcutaneous cardiac pacing are the most commonly used methods for temporary pacing of the heart. The main factor that dictates the use of one approach instead of another is the urgency of the need for pacing. In an emergency, transcutaneous pacing is the method of choice because it is the fastest method of cardiac pacing. Nevertheless, transvenous pacing has several advantages over the transcutaneous method: enhanced patient comfort, greater reliability, and the ability to pace the atrium.

   The purpose of temporary pacing is the reestablishment of circulatory integrity and normal hemodynamics that are acutely compromised by a slow or fast heart rate.

   Several types of pulse generators are available which permit single and dual chamber pacing. The single chamber units function in a VVI or AAI mode if demand pacing is used or in a VOO or AOO mode when fixed rate pacing is preferred (ventricular fixed
rate pacing or atrium fixed rate pacing); the dual chamber modes are DOO (fixed rate), DVI or DDD.

4. **Transesophageal temporary pacemaker**: located at esophagus. The catheter is uncomfortable to place, pacing is unreliable, and pain is common because it requires high current and pulse width for adequate and continual capture. For these reasons, transesophageal pacing is not routinely used, although it may have a role in pediatrics for diagnostic purposes.

2.- **MEDICAL INDICATIONS FOR THEIR USE.**

- **Pacemakers either single or dual chamber, Transcutaneous temporary pacemaker, Temporary transvenous pacemaker, Transesophageal temporary pacemaker**: when there is a problem with the conduction pathways, with bradyarrhythmias or tachyarrhythmias that causes severe hemodynamic impairment. The most frequent use of temporary pacing, both in adults and pediatric population, is for therapy of symptomatic bradycardia due to either sinus node dysfunction or atrioventricular (AV) nodal block.
- **Three chamber pacemaker or biventricular pacemaker**: use for resynchronization therapy, in order to increase the cardiac output.
- **Implantable cardioverter defibrillator (ICD)**: gives defibrillation that is a much higher electrical current than when uses a pacemaker, and is given in a single output. Defibrillation is the treatment of choice for malignant arrhythmias (ventricular tachycardia or ventricular fibrillation).
- **Epicardial pacemakers**: they can be used as a temporary pacing method during cardiac surgery as well as in the post-operative period. Permanent epicardial pacemakers are often required in children because of their small size, congenital cardiac defects with right-to-left shunts, or a lack of access to the chamber requiring pacing. Adults with congenital heart disease may require permanent epicardial pacing instead of using the most conventional transvenous method based on anatomic complexity, vascular access challenges, surgical scars, venous anomalies, and intracardiac shunts. Permanent epicardial pacing is also an alternative method to left ventricular pacing in cardiac resynchronization therapy when pacing via the coronary sinus is not possible or suboptimal.

3.- **PARTICULAR SCENARIOS**
3.1. RIGHT VENTRICULAR OUTFLOW TRACT IMPLANTATION OF THE RV LEAD PACEMAKER: Fig. 12 on page 25

- The RV lead is usually placed at the RV apex because it is easily accessible with a low dislodgement rate. This position, however, is associated with a dyssynchronous left ventricular contraction.
- Alternative stimulation sites such as the right ventricular outflow tract (just below the pulmonary valve) (arrow) or mid-inter-ventricular septum (approximately at the level of the superior aspect of the tricuspid valve) have been studied because of a potentially better haemodynamic effect compared to right ventricular apex pacing. The results, however, are controversial. This position is not standard; when used, it should be confirmed with the cardiologist that this is the intended location of the lead.

3.2. VDD PACEMAKER PLUS AN ABANDONED LEAD OF A PREVIOUS PACEMAKER OF THE SAME TYPE: Fig. 13 on page 26

- Abandoned leads may be misleading if the radiologist is not familiar with them. Radiologist should always check out how many leads are connected to the pulse generator.
- The figures show the two normal connecting ports of a VDD generator (stars) and a non connected lead (arrow) that corresponds to the previous pacemaker.
- Lead extraction is a seldom performed procedure that involves meaningful risks. After being in place for several weeks, pacemaker leads become "epithelialized" and firmly attached to the myocardial wall. When a pacemaker is changed, the leads are simply cut for removal of the control pack, and they are left in place because they are adherent to the heart.

3.3. TWIDDLING PACEMAKER

- Fig. 14 on page 27 The figures show a Twiddling pacemaker, that has rotate on its transverse axis, but does not cause any of the macrodislocation lead-dysfunctioning syndromes.
- The macrodislocation lead-dysfunctioning syndromes include Reel, Twiddler’s and Ratchet syndromes. They differ from each other in the causing mechanism. They appear when leads are dislodged due to repetitive muscular movements or patients manipulation. These situations could produce a wrong function of the pacemaker. The ipsilateral phrenic
nerve can be stimulated, resulting in diaphragmatic pacing and the sensation of abdominal pulsations.

- Chest X-ray is a simpler and better method for diagnosis and therefore it is always requested when such a complication is suspected because it can easily differentiate between these three syndromes, with a comparison to the original implant position.

- Twiddler's syndrome is caused by retraction and dislocation of the electrodes due to rotation of the generator around its long axis (defined by the lead). As the generator rotates, the lead twists over itself, giving it a characteristic and definitive appearance.

- Reel Syndrome: ventricular lead retraction and dislodgement secondary to rotation of the pulse generator on its transverse (sagittal) axis with subsequent coiling of the lead. It results in a proximal migration of the lead, which is wrapped around the generator. Reel syndrome commonly occurs within a month of implantation and normally there is no damage of the leads. This is the reason why normally there is no need of lead change, unlike Twiddler's syndrome where the leads are usually damaged and their replacement is usually mandatory.

- Ratchet syndrome is caused by retraction and electrode dislodgement with ratcheting but without coiling of the generator due to progressive displacement of the electrodes from their fixing protections.
3.4. DDD PACEMAKER WITH INCORRECT POSITION OF THE LEADS

- **Fig. 15** on page 28 Atrial lead is in the right ventricle (arrow) and ventricular lead is positioned away from right apex (arrowhead).

3.5. VVI PACEMAKER THROUGH A PERSISTENT LEFT SUPERIOR VENA CAVA (PLSVC)

- **Fig. 16** on page 29 Although PLSVC represents the most common congenital venous anomaly of the thoracic systemic venous return it is reported to occur in only 0.3% to 0.5% of individuals in the general population.
- Most commonly PLSVC coexists with a right SVC (superior vena cava) (80% - 90% of cases).
The PLSVC usually drains into the right atrium via the coronary sinus, resulting in no hemodynamic consequence (80% to 92% of cases). In approximately 10% to 20% the PLSVC drain via the left atrium, either through the coronary sinus or through the left superior pulmonary vein. In the instance of bilateral SVCs, the right SVC generally drains normally into the right atrium.
Fig. 1: AAI (arrows)

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Fig. 2: VVI Lead well located at the apex of the right ventricle (arrow)

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Fig. 3: DDD two leads positioned, in the right atrium (arrowhead) and right ventricle (arrow)

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**Fig. 4:** VDD it has one single lead with electrodes in the right atrium (to sense) (arrowheads) and in the right ventricle (to sense and pace). It senses atrial (arrowheads) and ventricular activity, but only paces in the ventricle. The atrial bipolar electrodes are called dipole.

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**Fig. 5:** THREE CHAMBER PACEMAKER it include one lead at the left ventricle (arrow) which goes through the coronary sinus into a left lateral cardiac vein for left ventricular pacing.

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**Fig. 6:** AICD or ICD (AUTOMATIC IMPLANTABLE CARDIOVERTER DEFIBRILLATOR). It is equipped for defibrillation in case of a malignant arrhythmia instead of pacemakers. Is possible to recognize this device at the plain chest radiography, because it shows the two thick shock coils that are essential for the diagnosis (arrowhead and arrow)

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**Fig. 7:** AICD or ICD (white arrowhead and arrow)- BIVENTRICULAR PACEMAKER COMBINATION - right ventricular lead (black arrow) and left ventricular lead (black arrowhead)

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Fig. 8: AICD or ICD (white details) - THREE CHAMBER PACEMAKER COMBINATION (black details): combined pacemaker-ICD lead in the right ventricular apex (black arrowhead), in the right atrium (big black arrow) and along the lateral wall of the left ventricle (small black arrow).

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**Fig. 9: EPICARDIAL PACEMAKER**

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Fig. 10: TRANSCUTANEOUS TEMPORARY PACEMAKER (white arrows)

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Fig. 11: TEMPORARY TRANSVENOUS PACEMAKER into the right ventricle (black arrows). Note the partially displaced pads of transcutaneous cardiac pacing used previously (white arrows)

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Fig. 12: RIGHT VENTRICULAR OUTFLOW TRACT IMPLANTATION OF THE RV LEAD PACEMAKER (arrow) Alternative stimulation sites have been studied because of a potentially better haemodynamic effect compared to right ventricular apex pacing. The results, however, are controversial. This position is not standard; when used, it should be confirmed with the cardiologist that this is the intended location of the lead.

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**Fig. 13:** VDD PACEMAKER PLUS AN ABANDONED LEAD OF A PREVIOUS PACEMAKER OF THE SAME TYPE Abandoned leads may be misleading if the radiologist is not familiar with them. The figures show the two normal connecting ports of a VDD generator (stars) and a non connected lead (arrow) that corresponds to the previous pacemaker.

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Fig. 14: TWIDDLING PACEMAKER. It has rotate on its transverse axis, but does not cause any of the macrodislocation lead-dysfunctioning syndromes.

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**Fig. 15:** DDD PACEMAKER WITH INCORRECT POSITION OF THE LEADS

Atrial lead is in the right ventricle (arrow) and ventricular lead is positioned away from right apex (arrowhead).

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Fig. 16: VVI PACEMAKER THROUGH A PERSISTENT LEFT SUPERIOR VENA CAVA (arrow)

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**Table 1: TWIDDLING PACEMAKER**

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Conclusion

Chest radiographs showing pacemakers and implantable cardioverter defibrillators contain relevant information that the radiologist has to know for a more accurate report and better understanding of the clinical setting of the patient.
References


