

# Radiography of Cardiac Conduction Devices: A Comprehensive Review<sup>1</sup>

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## ONLINE-ONLY CME

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## LEARNING OBJECTIVES

After completing this journal-based CME activity, participants will be able to:

- Describe the various types of CCDs.
- Recognize the normal and abnormal appearances of CCDs at chest radiography.
- List the potential acute and chronic complications of implantation of these devices.

## TEACHING POINTS

See last page

Radiology plays a crucial role in initial assessment and follow-up of cardiac conduction devices (CCDs). At least 1 million patients in the United States have permanent CCDs, which comprise pacemakers and implantable cardioverter-defibrillators. Chest radiography is unique because it is the only imaging modality that allows evaluation of the physical integrity of CCD leads. As a result, a basic knowledge of the normal and abnormal radiographic appearances of these devices and their various components is important. Radiologists should have a working knowledge of CCD anatomy as well as appropriate positioning and appearance of CCD leads and generators. Acute complications of CCD implantation include dysrhythmia, pneumothorax, perforation of the heart muscle or a vein, heart valve damage, lead damage, inadequate seating of the terminal connector pin, and presence of an air pocket. Chronic complications include twiddler syndrome, lead fracture, damage to the lead insulation, and lead displacement. Radiologists play an important role in management of patients with CCDs by providing vital information about the device, starting immediately after implantation and continuing throughout its duration in the patient. To fulfill this role, radiologists must have a firm understanding of CCDs and their evolving technology.

## Introduction

There are two types of cardiac conduction devices (CCDs): pacemakers and implantable cardioverter-defibrillators (ICDs). At least 1 million patients in the United States have permanent CCDs (1). Device implantation is only the initial phase in the lifelong care of these patients. **Chest radiography is the only imaging modality that allows thorough evaluation of the physical integrity of CCD leads (2).** As a result, radiologists interpreting chest radiographs must have a basic knowledge of the normal and abnormal radiographic appearances of these devices as well as their appropriate positioning.

In this article, we provide basic information about CCDs to familiarize radiologists with their normal and abnormal radiographic appearances. The appropriate terminology for description of CCDs is presented and their multiple components

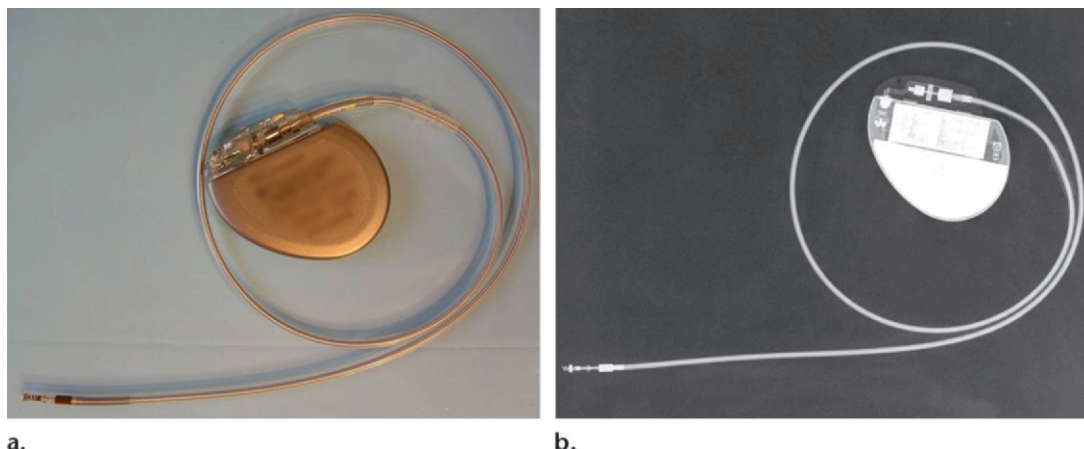
Teaching Point

**Abbreviations:** CCD = cardiac conduction device, ICD = implantable cardioverter-defibrillator

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**Figure 1.** Cardiac pacemaker. Photograph (a) and radiograph (b) show a single-chamber pacemaker before implantation.

are described. The relevant cardiac anatomy is reviewed and the normal radiographic features of CCDs are described. Finally, we discuss aberrant anatomy, follow-up of CCDs, and the acute and chronic complications of CCDs that should be identified and communicated to the clinician.

## Types of CCDs

### Pacemakers

A mechanical pacemaker is an electronic device used to provide small electrical stimuli to cause cardiac contraction during periods of bradycardia, when the intrinsic electrical activity of the heart is inappropriately slow or absent (Fig 1). The natural pacemaker of the heart is the sinoatrial node, which is located in the wall of the right atrium near the superior vena cava–right atrial junction. When the normal electrical pathways are disrupted by intrinsic disease, the result is bradycardia and arrhythmias. Myocardial infarction, degenerative aging of the atrioventricular node, or degeneration of the conduction tissues can also disrupt these pathways.

Different types of pacemakers are placed depending on the cause of bradycardia (Fig 2). A single-chamber pacemaker has one lead that paces either the right ventricle or right atrium. Most commonly, this lead is placed in the apex of the right ventricle and is used to pace the heart when there is a problem with the conduction pathways (Fig 2a). Uncommonly, a single lead may be placed in the right atrium when an atrial dysrhythmia due to sinoatrial node dysfunction or an aberrant additional sinoatrial node pacemaker focus is present. In this case, the conduction tissues are normal; once the

impulses are properly generated, they can travel unimpeded to the ventricles.

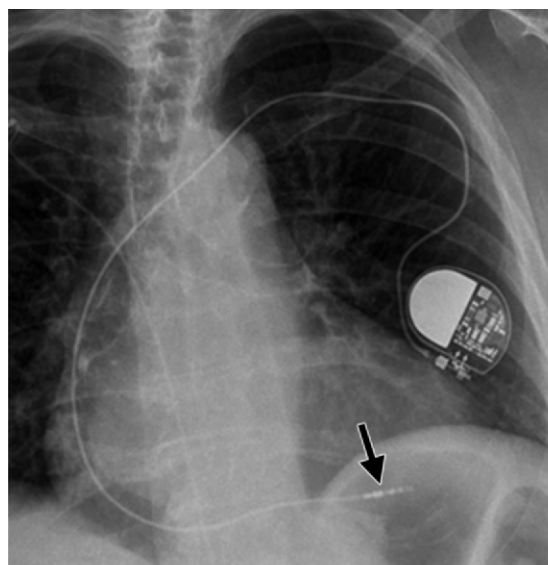
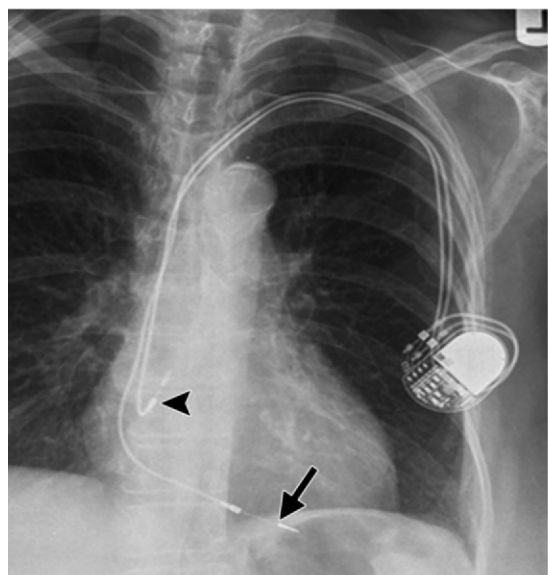
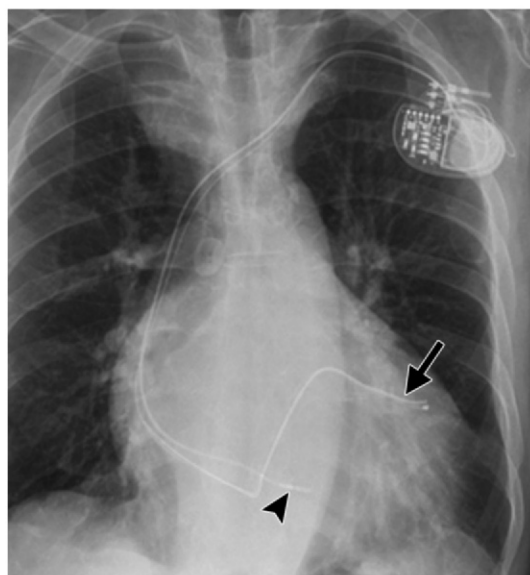
A dual-chamber pacemaker has two leads: one in the right atrium and one in the right ventricle (Fig 2b). This type of pacemaker helps coordinate signals to and contractions of the atria and ventricles.

A biventricular pacemaker (aka a cardiac resynchronization therapy device) has at least one right ventricular lead and one left ventricular lead. It may have a right atrial lead as well. The left ventricular lead traverses the coronary sinus into a posterior or lateral cardiac vein (Fig 2c), allowing access to the lateral left ventricle wall for left ventricular pacing. Biventricular pacemakers stimulate simultaneous contraction of the left and right ventricles, resulting in a more efficient pumping action. These devices are commonly used when there is moderate to severe drug-refractory congestive heart failure with associated interventricular or intraventricular dyssynchrony; they are also used in cases where there is a weakened and enlarged heart.

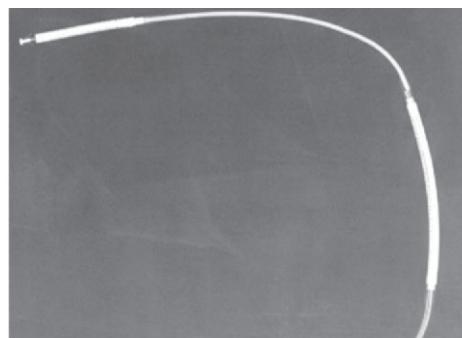
### Implantable Cardioverter-Defibrillators

An overwhelming majority of sudden cardiac deaths from coronary disease (approximately 310,000 per year) are thought to be from ventricular fibrillation (3). An ICD is an electronic device capable of generating a large amount of electrical energy in a single output used to defibrillate the heart. It is used to directly treat tachydysrhythmias to prevent cardiac arrest.

The device is most often composed of a single lead with two shock coils (Fig 3). When placed, the lead is positioned so that the shock coils are located in the region of the brachiocephalic vein–superior vena cava junction and in the right

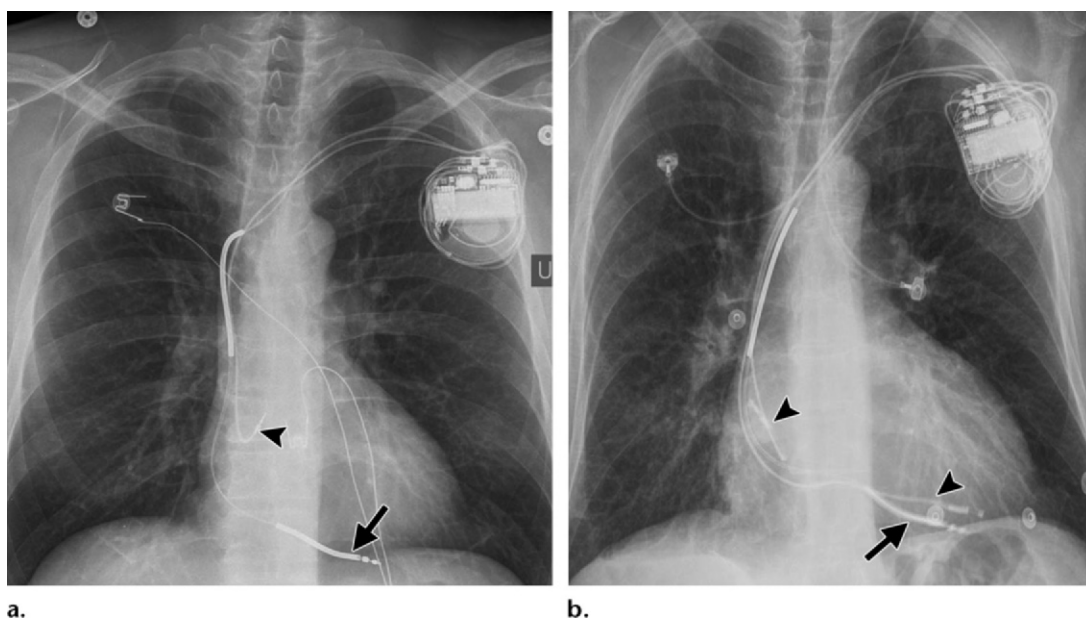
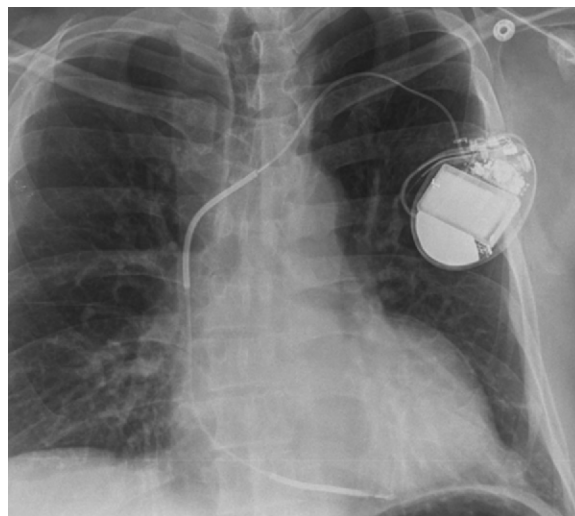
**a.****b.****c.**

**Figure 2.** Three types of cardiac pacemakers. **(a)** Frontal chest radiograph shows a single-chamber pacemaker with a single lead in the right ventricle (arrow). **(b)** Frontal chest radiograph shows a dual-chamber pacemaker, which has leads in the right atrium (arrowhead) and right ventricle (arrow). **(c)** Frontal chest radiograph shows a biventricular pacemaker with one right ventricular lead (arrowhead) and one left ventricular lead (arrow). A biventricular pacemaker may also have a right atrial lead.

**a.****b.**

**Figure 3.** ICD lead. Photograph **(a)** and radiograph **(b)** show an ICD lead before implantation. The single lead has two shock coils, which are capable of generating a large amount of electrical energy in a single output to defibrillate the heart. The shock coils appear as thick bands along the course of the lead.

**Figure 4.** Normal radiographic appearance of an ICD. On a frontal chest radiograph, the shock coils of an ICD lead appear as sections of thickened metallic opacity that terminate in the regions of the superior vena cava and right ventricle.



**Figure 5.** ICD-pacemaker combinations. **(a)** Frontal chest radiograph shows an ICD–dual-chamber pacemaker combination. The combined pacemaker-ICD lead terminates in the apex of the right ventricle (arrow). The second pacemaker lead is in the right atrium (arrowhead). **(b)** Frontal chest radiograph shows an ICD–biventricular pacemaker combination. The tip of the combined pacemaker-ICD lead is in the right ventricular apex (arrow). The other pacemaker leads are in the right atrium (left arrowhead) and along the lateral wall of the left ventricle (right arrowhead).

ventricle (Fig 4). If the device senses a tachyarrhythmia such as ventricular tachycardia or ventricular fibrillation, it sends a defibrillation shock to cardiovert the heart.

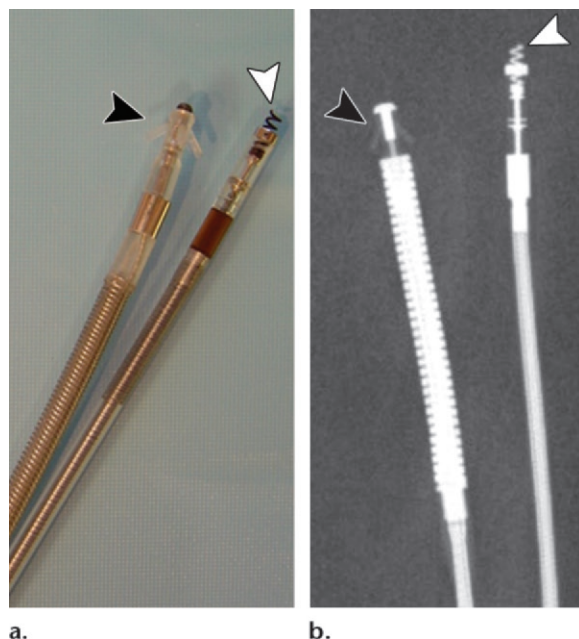
### ICD and Pacemaker Combinations

Pacemaker and ICD leads can be used together in multiple combinations (Fig 5). Commonly, a biventricular pacemaker is combined with an ICD (Fig 5b). In this configuration, there are three leads: two pacemaker leads in the right

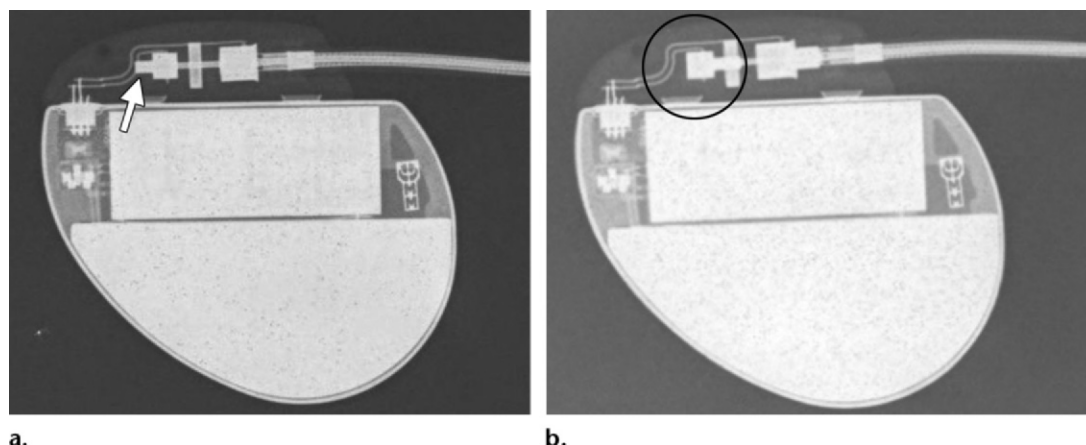
atrium and in the posterior cardiac vein to the left ventricle and a combined pacemaker-ICD lead in the right ventricle.

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. The device can resynchronize the left and right ventricular chambers for more effective contraction and cardiac output. Cardiac resynchronization therapy has been shown to reduce mortality by up to 34% in patients with congestive heart failure and improve their quality of life (4).





**Figure 6.** Lead fixation. Photograph (a) and radiograph (b) show the appearance of lead fixation mechanisms before implantation. Passive fixation mechanisms maintain lead position in the heart by means of prongs (black arrowhead) that anchor in the cardiac trabeculae. Active fixation mechanisms maintain lead position by means of a helical screw (white arrowhead) that penetrates into the myocardium.



**Figure 7.** Terminal connector pin. Radiographs show an engaged (arrow in a) and a nonengaged (circle in b) terminal connector pin. The terminal connector pin of a CCD lead must be well seated in the generator connector block for the device to function properly.

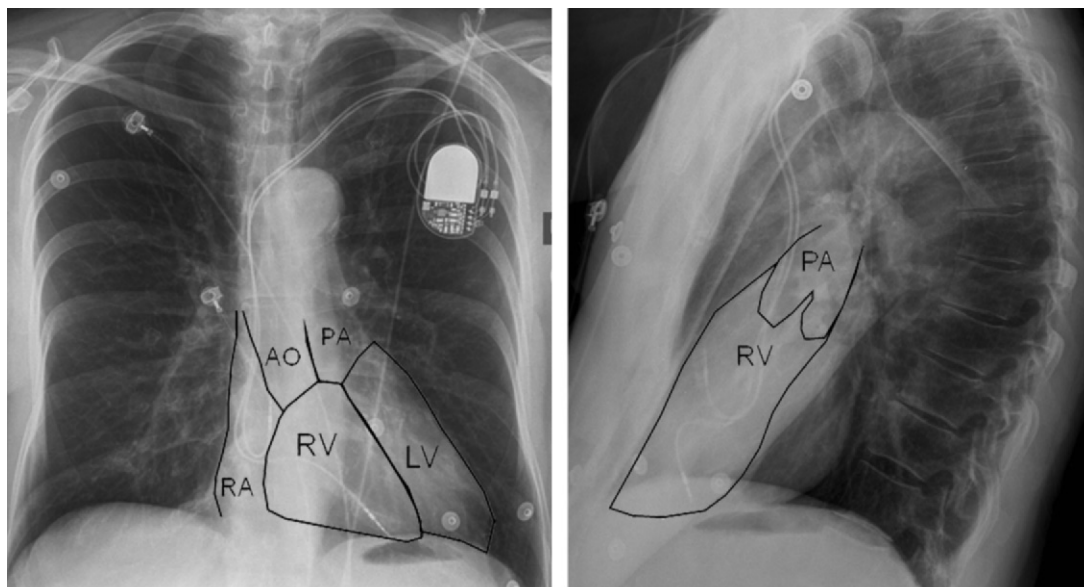
### Components of a CCD

The two main components of a CCD are the pulse generator and the pacemaker or ICD leads (5). The pulse generator is a complex device with basic components consisting of hardware, programmable software, and a lithium iodide battery with a 5–10-year lifespan.

The lead design consists of five major components: a conductor, insulation, an electrode or electrodes, a fixation mechanism, and a terminal connector pin. The conductor is the wire that connects the stimulating and sensing electrode or electrodes to a proximal terminal connector pin. Lead insulation can be silicone rubber or polyurethane. Electrodes can be unipolar or bipolar.

CCD leads are secured in the heart by means of passive or active fixation (Fig 6). Passive fixation mechanisms use tines, fins, helices, or conical structures at the tip of the lead to lodge in the cardiac trabeculae and thus maintain lead stability. Active fixation mechanisms use a corkscrew helix at the tip of the lead to screw into the myocardium, allowing stable positioning in a wide variety of intracardiac locations.

Proximally, CCD leads have a terminal connector pin that connects the lead to the generator by means of the connector block (Fig 7). It is essential that the connector pin be well seated in the connector block for proper functioning of the device.



**Figure 8.** Normal cardiac anatomy. Frontal (**a**) and lateral (**b**) chest radiographs show the aorta (AO in **a**), left ventricle (LV in **a**), main pulmonary artery (PA), right atrium (RA in **a**), and right ventricle (RV).

### Radiographic Evaluation of CCDs and Relevant Cardiac Anatomy

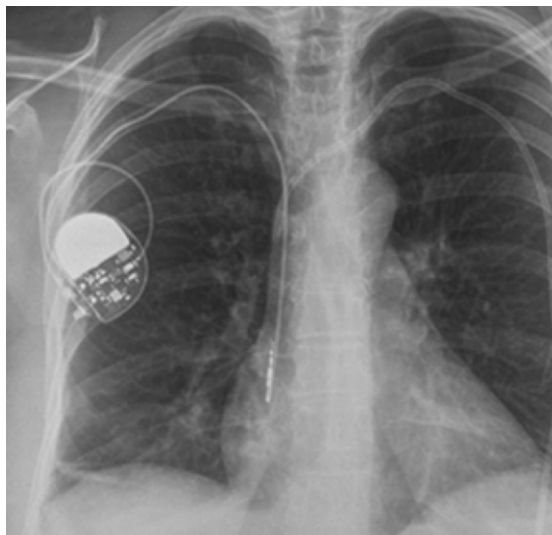
Chest radiography is a common study in the majority of radiology practices. As a result, radiologists who interpret these studies will see various types and combinations of CCDs during daily reading. **To evaluate for correct CCD lead positioning, it is helpful to have a good understanding of the associated normal cardiac anatomy (Fig 8) as well as an awareness of the possible variant anatomy that may affect lead position.**

The preferred implant site for a right atrial pacemaker lead is in the right atrial appendage. The coarse trabeculae within the atrial appendage aid in anchoring the lead, particularly with a passive fixation mechanism. Because the right atrial appendage is located superiorly to the body of the right atrium, the right atrial lead should first course inferiorly into the right atrium and then curve upward and anteriorly when it is properly positioned (Fig 9a, 9b, 9e, 9f). Some

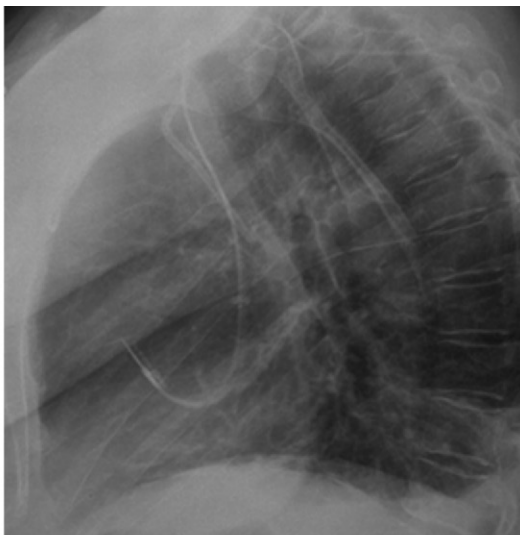
right atrial leads have a preformed “J loop” to aid in directing the lead superiorly into the right atrial appendage. Slight redundancy is normally left in the lead to avoid tension at the lead tip during deep inspiration and arm movement. Too much redundancy may predispose the patient to lead displacement, cardiac ectopy, and possible chronic perforation at the lead tip.

The proper position of a right ventricular pacemaker or ICD lead is at the apex of the right ventricle. On a frontal radiograph, the tip of the right ventricular lead should be seen to the left of the spine. On the lateral view, it should be seen pointing anteriorly and slightly superiorly (or inferiorly) into the right ventricular apex (Fig 9c–9f). Although the ventricular apex is the preferred site, the lead may be placed in other locations such as the right ventricular outflow tract in certain circumstances. However, this location is not standard; if it is used, one should confirm with the cardiologist that this is the intended location of the lead (Fig 10).

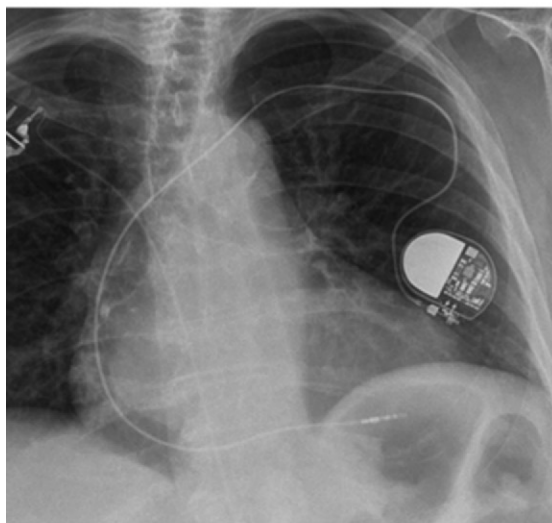
**Figure 9.** Correct placement of right atrial and right ventricular leads for single-chamber and dual-chamber pacemakers. (**a**, **b**) Frontal (**a**) and lateral (**b**) chest radiographs show a single-chamber pacemaker with a right atrial lead. On the lateral view, the right atrial lead demonstrates a “J-shaped” appearance as it first enters the right atrium and then curves upward and anteriorly to its proper position in the right atrial appendage. (**c**, **d**) Frontal (**c**) and lateral (**d**) chest radiographs show a single-chamber pacemaker with a right ventricular lead. On the frontal view, the tip of the right ventricular lead should be to the left of the spine. On the lateral view, the lead should course anteriorly into the apex of the right ventricle. (**e**, **f**) Frontal (**e**) and lateral (**f**) chest radiographs show a dual-chamber pacemaker with correctly positioned leads in the right atrium (arrow) and right ventricle (arrowhead). On the lateral view, note the correct J-shaped appearance of the right atrial lead and the anterior position of the right ventricular lead.



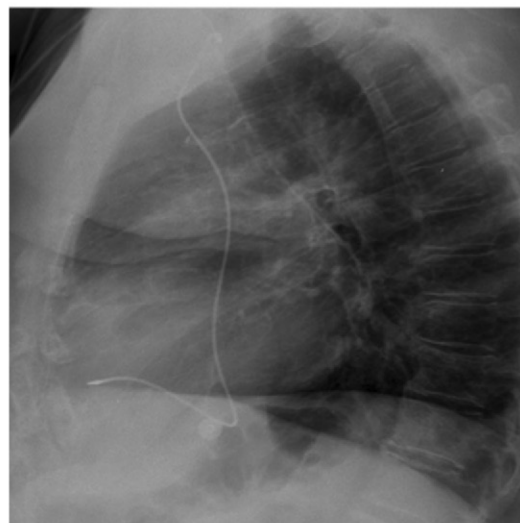
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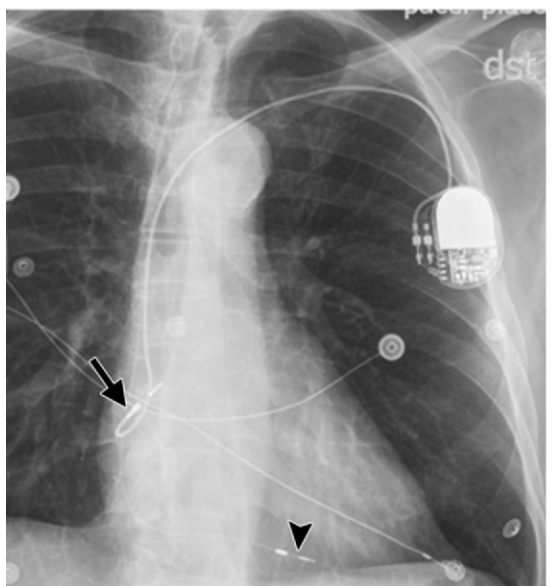
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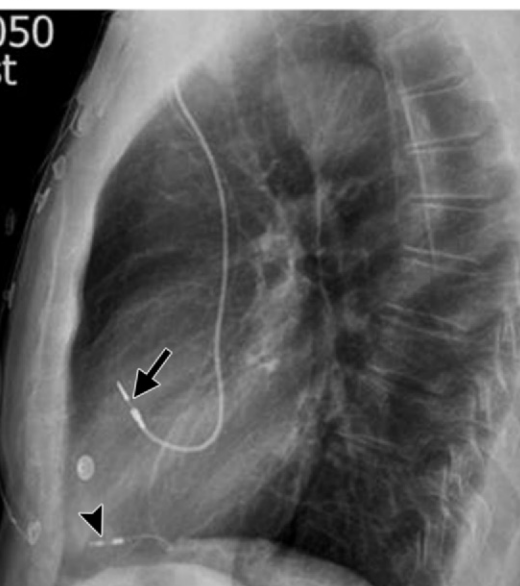
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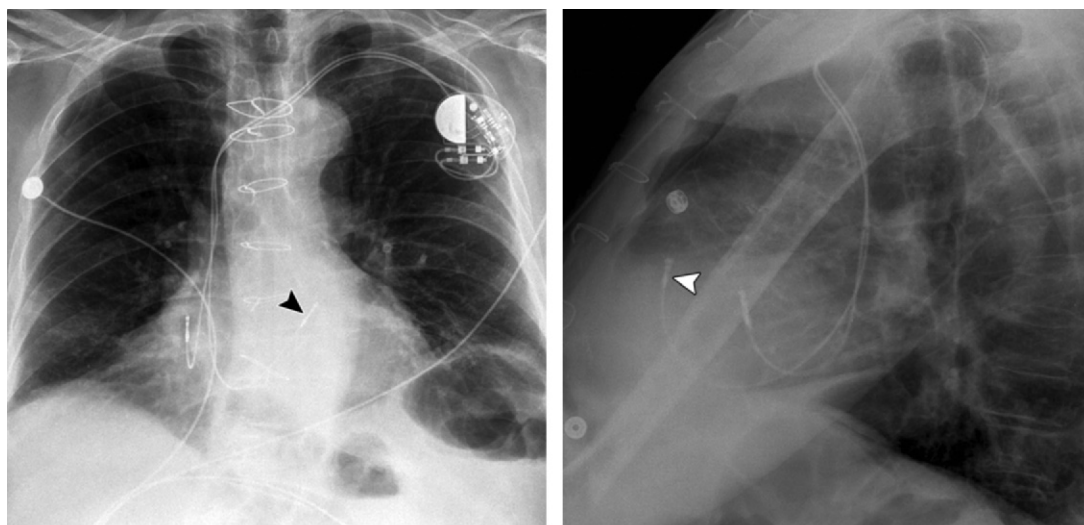


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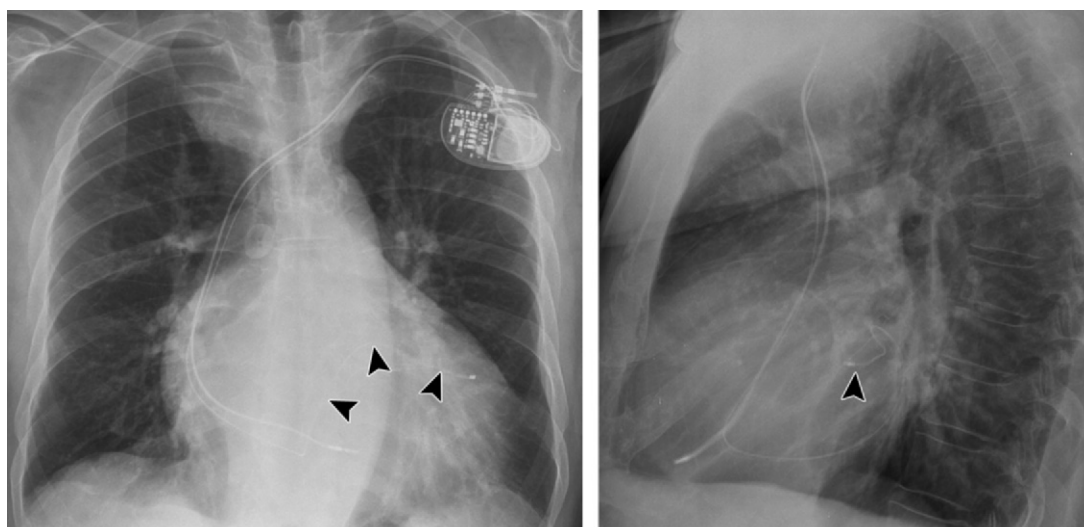


f.





**Figure 10.** Abnormal position of a right ventricular lead. Frontal (**a**) and lateral (**b**) radiographs show a dual-chamber pacemaker with an abnormally positioned right ventricular lead in the right ventricular outflow tract. The right ventricular lead (arrowhead) has an abnormal upward curvature on both views. The right atrial lead is normally positioned.



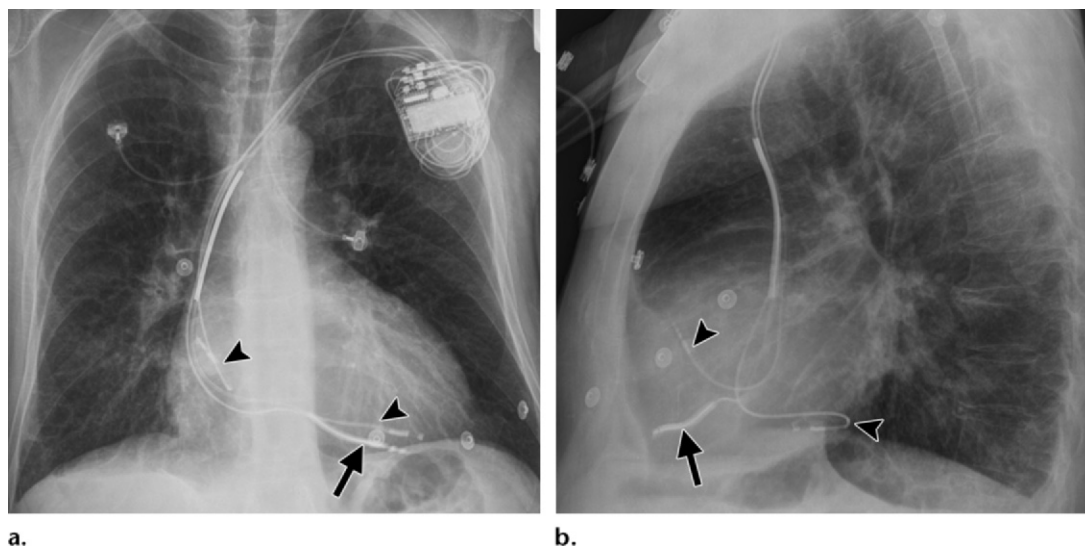
**Figure 11.** Correct placement of a left ventricular lead for a biventricular pacemaker. (**a**) Frontal chest radiograph shows the expected serpentine course of the left ventricular lead (arrowheads) in the posterior cardiac vein. (**b**) On a lateral chest radiograph, the left ventricular lead courses posteriorly (arrowhead).

With a biventricular pacemaker, the left ventricular lead is placed through the coronary sinus into a cardiac vein, usually along the lateral or posterior free wall of the left ventricle. The left ventricular lead will course inferiorly and laterally on a frontal radiograph and posteriorly on the lateral view (Fig 11). On a frontal radiograph alone, it may not be possible to distinguish whether a ventricular lead is in the posterior coronary vein or the right ventricular apex. The lateral view provides confirmation of the anterior location of a right ventricular lead or the posterior course of a left ventricular lead.

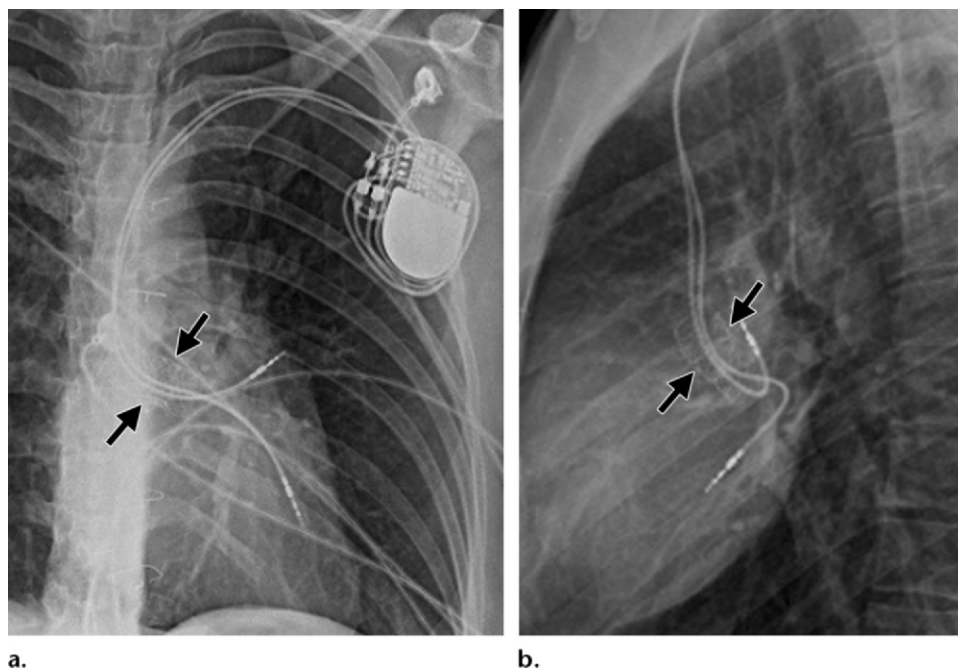
The key to distinguishing between ICD and pacemaker leads is the presence of the ICD shock coils. These shock coils appear as two separate thick metallic segments along the length of the ICD lead, whereas pacemaker leads appear as smaller leads with a stable diameter along their length (Fig 12).

Chest radiography requires sufficient penetration to fully examine the device generator as well as the course and integrity of its leads. At least two orthogonal views are necessary for accurate determination of the exact location of the lead





**Figure 12.** Correct placement of leads for an ICD–biventricular pacemaker combination. Frontal (**a**) and lateral (**b**) chest radiographs show the thick shock coils of an ICD lead (arrow), which make it easy to identify as it terminates anteriorly in the right ventricular apex. The pacemaker leads (arrowheads) appear as two thinner wires that end in the right atrium and along the lateral wall of the left ventricle. On the lateral view, note the J-shaped appearance of the right atrial lead and the posterior course of the left ventricular lead.



**Figure 13.** Aberrant lead course in a patient with surgically corrected transposition of the great vessels. Frontal (**a**) and lateral (**b**) chest radiographs show a dual-chamber pacemaker with leads that pass through an interatrial baffle (arrows).

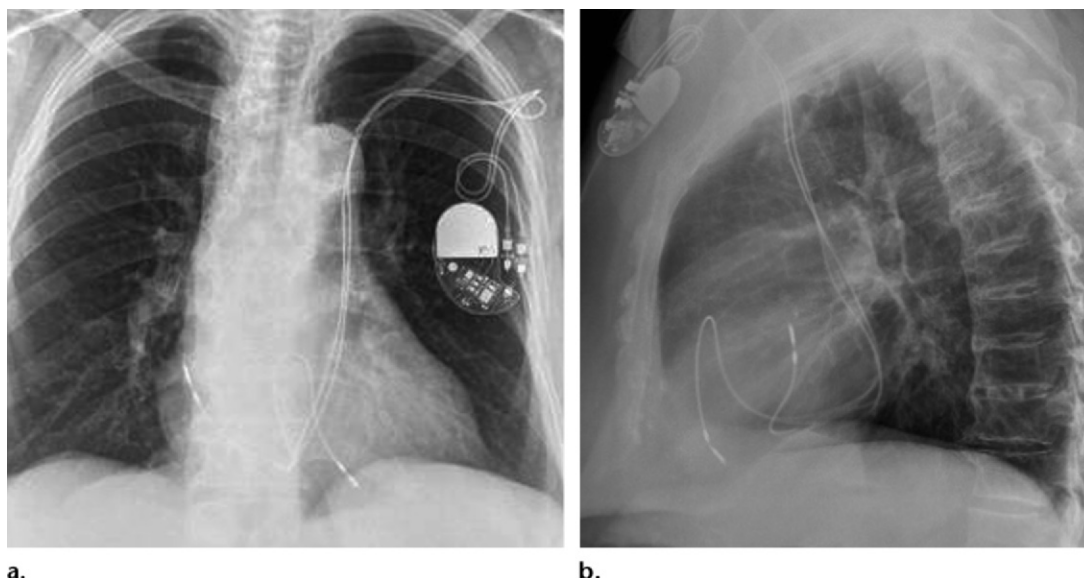
#### Teaching Point

tips. It is imperative to be meticulous in examining the integrity of each lead along its entire course, since clinically important lead irregularities are frequently subtle and may be seen only with image magnification.

#### CCDs and Aberrant Anatomy

CCD leads may take circuitous paths to their final position. The leads may be truly malpositioned or

simply appear incorrectly placed due to normal variant or aberrant anatomy. Aberrant lead courses can be seen with congenital heart disease such as a patent foramen ovale, transposition of the great vessels (Fig 13), and congenitally corrected transposition of the great vessels. Normal anatomic



**Figure 14.** Aberrant lead course in a patient with a persistent left superior vena cava. Frontal (**a**) and lateral (**b**) chest radiographs show a dual-chamber pacemaker with leads that course through a persistent left superior vena cava.

variants such as a persistent left-sided superior vena cava (Fig 14) can also result in an unexpected lead course. A sound knowledge of normal lead configuration and position aids in recognition of a variant or aberrant lead course.

### Follow-up of CCDs

After placement of a new CCD or introduction of a new patient into their practice, cardiologists will obtain posteroanterior and lateral chest radiographs to evaluate the position and integrity of the leads. These images also provide a radiographic baseline for future evaluation. Follow-up of CCDs consists of three phases after initial implantation.

In the early surveillance phase, the device is evaluated 4–6 weeks after placement. Next is a maintenance phase, in which the device is evaluated every 6–12 months. An intensified monitoring phase is initiated as the generator battery approaches the end of its life. Chest radiography may be performed during each of these phases as part of the comprehensive device evaluation.

### Complications of CCDs

Problems with a CCD that are identifiable at chest radiography may be related to the device

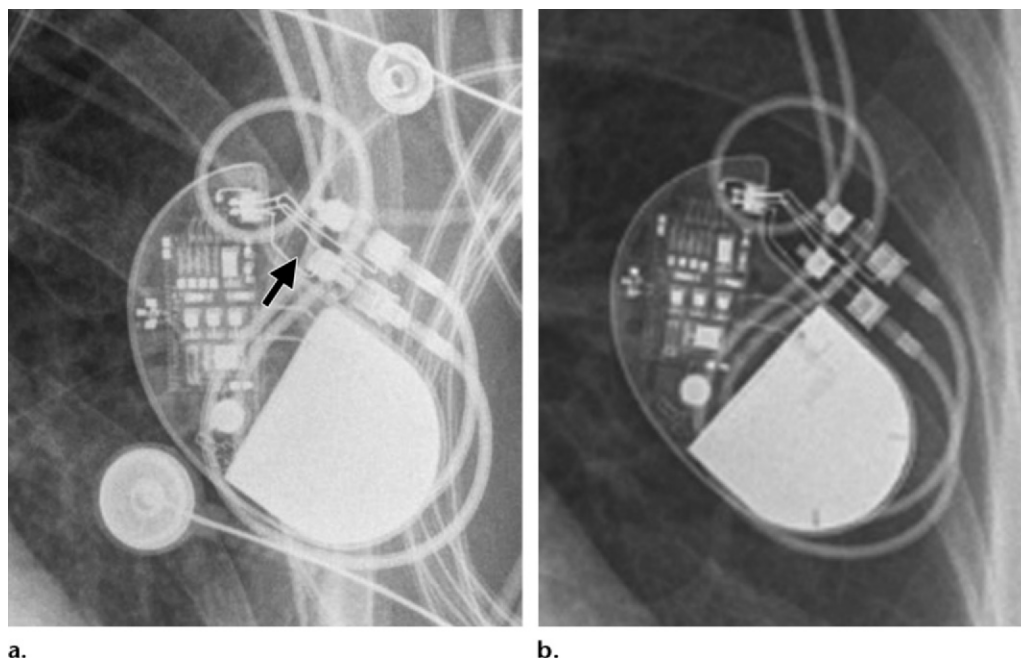
generator or leads. Complications can be divided into two groups based on the elapsed time since device implantation.

Acute complications are present at the time of or immediately after CCD implantation. These include bradyarrhythmia or tachyarrhythmia related to improper lead placement and connection, pneumothorax, perforation of the heart muscle or a vein, heart valve damage, and lead damage. Pneumothorax and hemothorax are potential immediate complications that should be looked for on every chest radiograph obtained immediately after a procedure. These complications can occur during the venous access required to place the device.

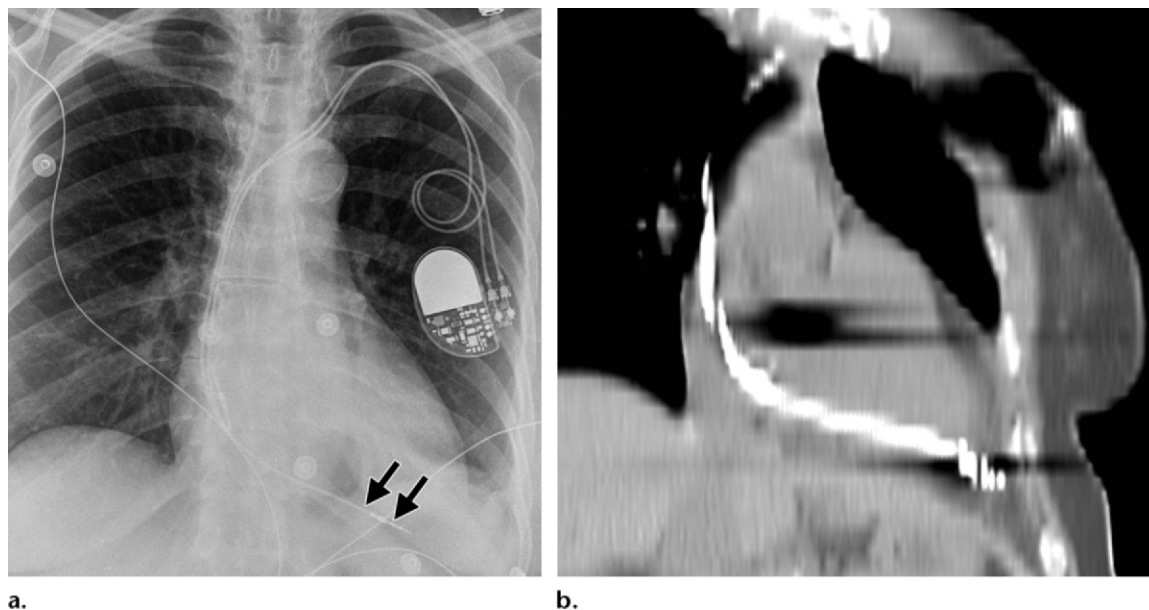
**On a postplacement chest radiograph, the most commonly encountered acute generator-related complication is improper or inadequate seating of the terminal connector pin or pins within the connector block (Fig 15).** This can cause an open circuit and resultant failure of the unconnected lead to capture the cardiac rhythm.

Another acute lead-related complication is myocardial perforation or abnormal myocardial penetration. The frontal chest radiograph may demonstrate an atypical position of the right ventricular lead where it wraps around the cardiac apex, projecting more caudally than normal (Fig 16a). A pleural or pericardial effusion may

**Teaching Point**

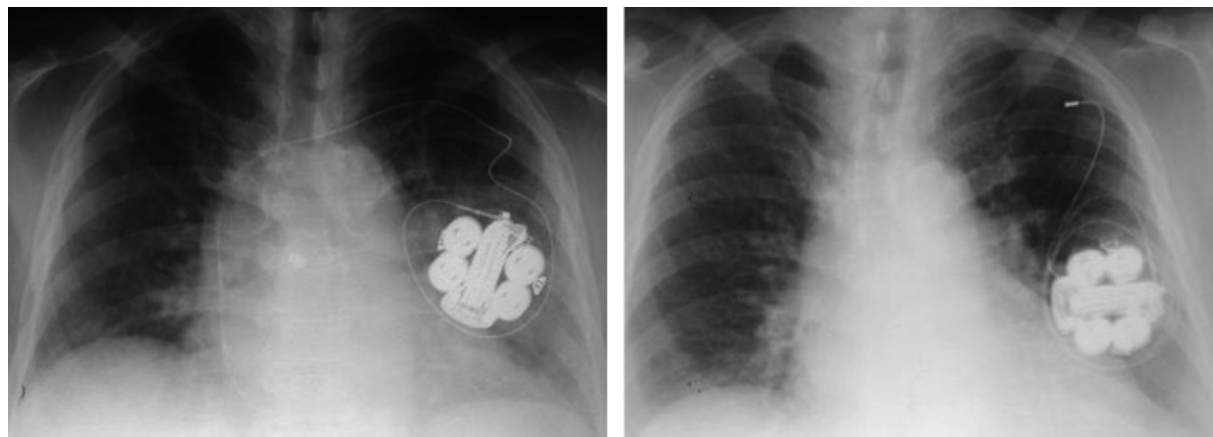


**a.** **b.**  
**Figure 15.** Unengaged terminal connector pin. **(a)** Radiograph shows a disengaged bottom terminal connector pin (arrow); the result is failure to capture the cardiac rhythm. The upper terminal connector pin is normally seated. **(b)** Follow-up radiograph obtained after correction shows proper seating of both connector pins within the connector block.

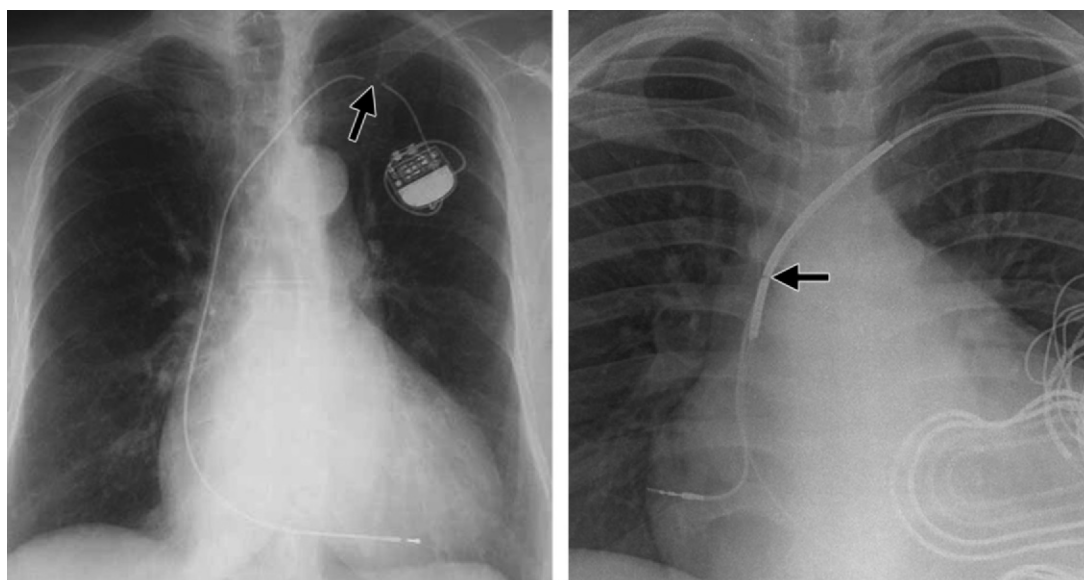


**a.** **b.**  
**Figure 16.** Myocardial perforation. **(a)** Frontal chest radiograph shows more caudal positioning of the right ventricular pacemaker lead (arrows) than expected. There is also a postprocedure pleural effusion. **(b)** Oblique coronal reformatted image from follow-up chest computed tomography (CT) shows the tip of the right ventricular lead in the epicardial fat, a finding consistent with myocardial perforation.





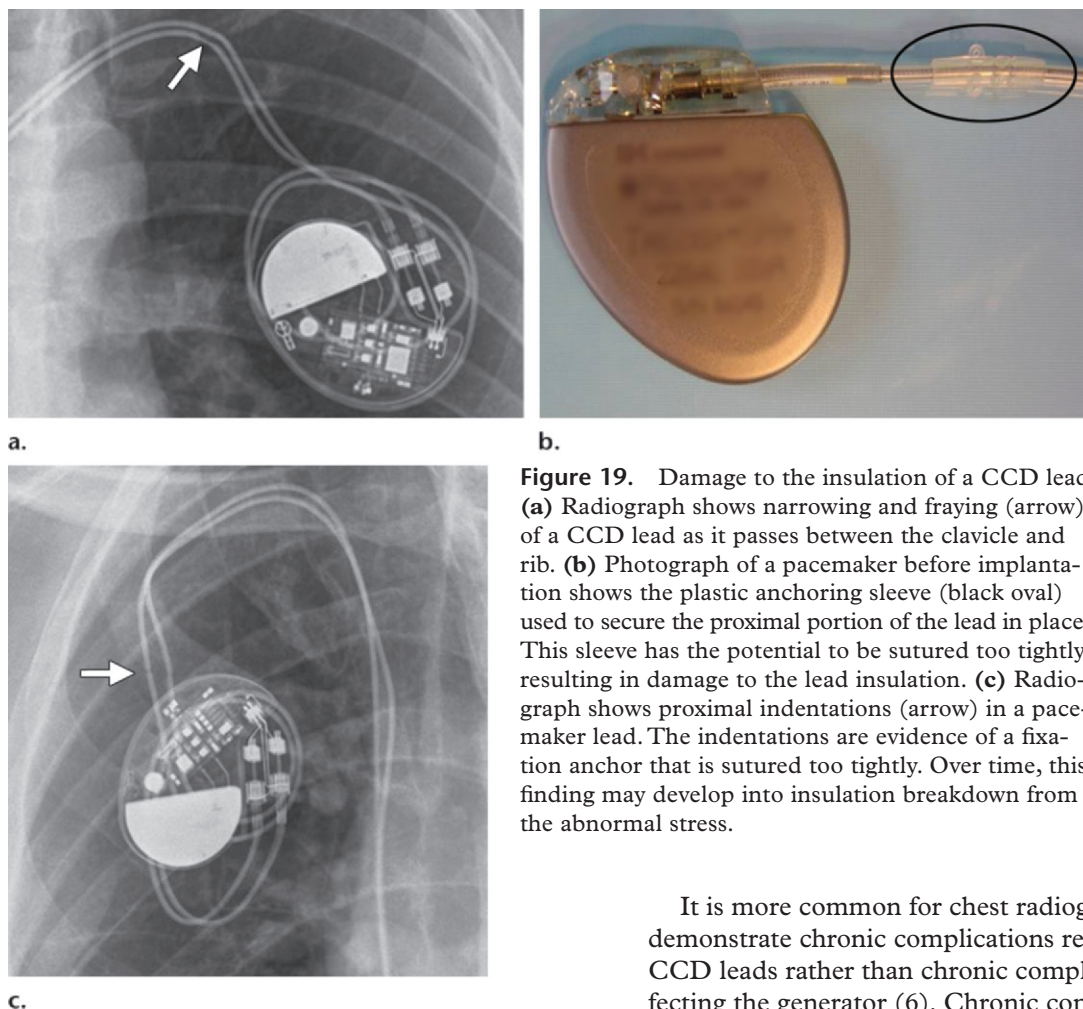
**Figure 17.** Twiddler syndrome. **(a)** Initial frontal chest radiograph shows a normal-appearing single-chamber pacemaker with the lead correctly positioned in the right ventricle. **(b)** Follow-up image obtained 1 year later shows interval winding of the lead around the generator and resultant retraction of the lead from its normal position in the heart. In this syndrome, the patient inadvertently or deliberately rotates the pacemaker generator within its subcutaneous pocket. (Reprinted, with permission, from *LearningRadiology.com*.)



**Figure 18.** Lead fracture. **(a)** Frontal chest radiograph shows a complete fracture (arrow) of a single-chamber pacemaker lead at the junction of the left first rib and clavicle. **(b)** Frontal chest radiograph shows a fracture (arrow) of the proximal shock coil of an ICD lead.

develop as an associated finding. Electrocardiographically gated CT of the chest could be recommended for evaluation of the lead position, preferably in the diastolic phase, to confirm

suspected myocardial perforation or penetration (Fig 16b). If the tip of the ventricular lead is within 3 mm of the epicardial fat, myocardial penetration should be suspected. If the lead tip is identified within the epicardial fat, myocardial perforation is likely (2).



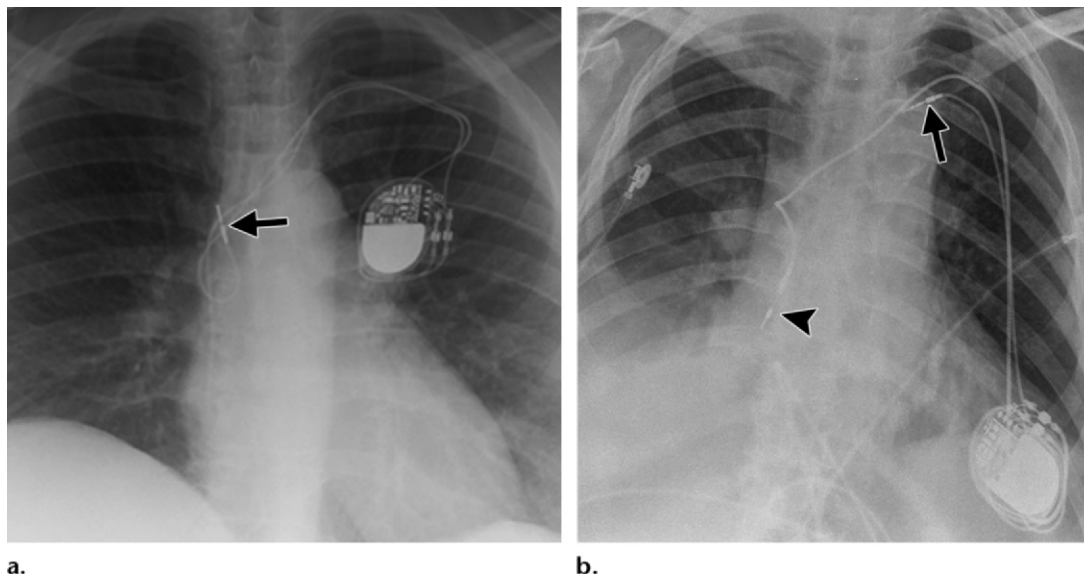
**Figure 19.** Damage to the insulation of a CCD lead. **(a)** Radiograph shows narrowing and fraying (arrow) of a CCD lead as it passes between the clavicle and rib. **(b)** Photograph of a pacemaker before implantation shows the plastic anchoring sleeve (black oval) used to secure the proximal portion of the lead in place. This sleeve has the potential to be sutured too tightly, resulting in damage to the lead insulation. **(c)** Radiograph shows proximal indentations (arrow) in a pacemaker lead. The indentations are evidence of a fixation anchor that is sutured too tightly. Over time, this finding may develop into insulation breakdown from the abnormal stress.

An additional acute complication that can be seen on radiographs is a “dry” pocket, which is air in the subcutaneous tissues surrounding the generator pack. This retained air can disrupt the normal lead circuitry, particularly in pacemakers with unipolar leads.

Chronic or delayed CCD complications occur as the device ages with the patient. Many chronic generator-related complications cannot be seen radiographically because they pertain to the electrical components of the generator. However, one notable generator-related complication with a specific radiographic appearance is twiddler syndrome. In twiddler syndrome, the patient, consciously or subconsciously, rotates the generator pack within the subcutaneous pocket, resulting in dislodgement of the leads as they become wound around the generator (Fig 17).

It is more common for chest radiographs to demonstrate chronic complications related to the CCD leads rather than chronic complications affecting the generator (6). Chronic complications related to CCD leads include lead fracture, damage to the lead insulation, and lead displacement. Over time, the conductor portion of the lead undergoes substantial mechanical stress with the potential for metal fatigue and fracture (Fig 18). *Rib-clavicle crush* is a generic term that can be used to refer to lead damage from subcutaneous structures before venous entry. These structures include the costoclavicular ligament, the subclavius muscle, and structures related to preexisting thoracic outlet syndrome.

Direct mechanical stress on the lead can also cause insulation damage and resultant lead dysfunction (Fig 19a). If the nonresorbable fixation suture used to secure the proximal anchoring sleeve of the lead to the fascia is too tight, it may also result in eventual damage to the lead insulation (Fig 19b, 19c). These lead-related complications are late



**Figure 20.** Lead displacement. **(a)** Frontal chest radiograph shows a dual-chamber pacemaker with the right atrial lead (arrow) dislodged into the superior vena cava. **(b)** Frontal chest radiograph shows a dual-chamber pacemaker with displacement of both leads. The right atrial lead (arrow) is retracted into the left subclavian vein. The right ventricular lead (arrowhead) is also retracted, with its tip no longer positioned within the apex of the right ventricle.

consequences of the techniques used during implantation of the device and can be present even if the procedure was initially uncomplicated.

On radiographs, commonly seen sites of lead failure are at the fulcrum of a freely moving lead with a stationary point such as the subclavian vein–first rib junction and at the site of excessively tight fixation sutures. In addition, CCD leads can become displaced from their proper original position over time, thus necessitating careful evaluation of lead position in studies when CCDs are present (Fig 20).

### Conclusions

CCDs continue to evolve in terms of therapeutic capability and complexity. They are being used with increasing frequency in the treatment of patients with dysrhythmia and congestive heart failure. The radiologist plays a key role in the care of these patients by properly describing the CCD type and thoroughly evaluating the entire device on chest radiographs. A working knowledge of CCD anatomy as well as appropriate positioning and appearance of CCD leads and generators is therefore required. With this knowledge, the radi-

ologist can confidently evaluate CCDs for normal placement as well as for the acute and chronic complications that may develop.

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## Radiography of Cardiac Conduction Devices: A Comprehensive Review

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### Page 1669

Chest radiography is the only imaging modality that allows thorough evaluation of the physical integrity of CCD leads (2).

### Page 1674 (Figure on page 1674)

To evaluate for correct CCD lead positioning, it is helpful to have a good understanding of the associated normal cardiac anatomy (Fig 8) as well as an awareness of the possible variant anatomy that may affect lead position.

### Page 1677

It is imperative to be meticulous in examining the integrity of each lead along its entire course, since clinically important lead irregularities are frequently subtle and may be seen only with image magnification.

### Page 1678 (Figure on page 1679)

On a postplacement chest radiograph, the most commonly encountered acute generator-related complication is improper or inadequate seating of the terminal connector pin or pins within the connector block (Fig 15).

### Page 1682

On radiographs, commonly seen sites of lead failure are at the fulcrum of a freely moving lead with a stationary point such as the subclavian vein–first rib junction and at the site of excessively tight fixation sutures.