Radiology

REVIEWS AND COMMENTARY • STATEMENTS AND GUIDELINES – HOW I DO IT

How I Do It: Evaluating Cardiac Implantable Devices and Noncardiac Mimics on Chest Radiographs

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Cardiac implantable electronic devices (CIEDs), including pacemakers and defibrillators, are increasingly used to manage various cardiac conditions. This article reviews the radiographic appearance, typical components, and placement of CIEDs, including newer technologies like leadless pacemakers and MRI-conditional devices. The article also highlights the imaging findings of common complications such as lead dislodgement, fracture, and perforation, emphasizing the role of imaging in early detection and intervention. Additionally, the radiographic identification of other cardiac and noncardiac devices with similar-appearing imaging features is addressed. Other cardiac devices covered in this article include those for cardiac monitoring, ventricular assistance, and cardiac repair. Noncardiac mimics include deep brain, vagal nerve, and phrenic nerve stimulators as well as breast implant radiofrequency markers. Accurately identifying these devices and their positioning on chest radiographs facilitates the early detection of complications and directs appropriate patient care.

Cardiac implantable electronic devices (CIEDs), which include pacemakers and defibrillators, play a crucial role in improving the health of millions of individuals worldwide. As the global population ages, the number of CIEDs implanted is increasing, with an estimated 1 million to 1.4 million pacemakers and 150 000–200 000 implantable cardioverter defibrillators (ICDs) placed annually (1–4). Technological advances have led to the development of new devices, which, in conjunction with legacy devices, add to the variety of appearances and findings that may pose a diagnostic challenge for radiologists. Likewise, there are other cardiac support apparatuses, including ventricular assist devices and septal closure devices, and noncardiac devices that mimic CIEDs that radiologists need to recognize on chest radiographs. Noncardiac mimics include deep brain, vagal nerve, and phrenic nerve stimulators as well as breast implant radiofrequency markers. Given that cardiac and surgical devices may remain in patients for many years, it is essential to identify complications that may cause clinically significant morbidity or mortality.

This review describes CIEDs, other cardiac devices, and mimics; their normal radiographic appearance; and potential complications that may merit emergent communication with the ordering clinician.

Radiographic Interpretation

Implantable cardiac devices are commonly encountered during routine chest radiographic imaging. Chest radiography is often the first-line imaging examination after implantation or when there is clinical concern about complications. A systematic approach to interpretation includes correctly identifying the specific device and assessing for complications. Identification of a device can be aided by recognizing the anatomic position and characteristic device components or features, such as leads (insulated wires, such as those connecting a pulse generator and electrode tips in contact with the heart chamber walls) or radiographic markers (metallic marks, such as those used to identify the make and model of a pacemaker, usually adjacent to the pulse generator). In addition to the frontal chest radiograph, lateral projections and prior comparison studies, if available, are beneficial for identifying devices, localizing components, and assessing for complications. This article discusses key imaging features, differentiators of specific devices, and the imaging findings of frequently encountered complications.

Pacemakers and Defibrillators

Pacemakers

Pacemakers are CIEDs for the management of bradycardia. Chest radiographs are essential first-line imaging after pacemaker placement to confirm appropriate lead positioning and to identify potential complications. Understanding radiologic anatomy for localizing device components is crucial. In the posteroanterior and anteroposterior views, the right atrium and right ventricle (RV) and corresponding chamber leads should be visible. The various models of pacemakers can be classified based on the number and position of the leads: unicameral (single chamber—RV), bicameral (dual chamber—right atrium and RV), and biventricular. In the case of biventricular pacing, also known as cardiac resynchronization therapy, the third lead follows the path of the coronary sinus, with the lead tip positioned in a cardiac vein (either the middle or lateral cardiac vein), thus contacting the left ventricle (LV) and allowing synchronization of both ventricles (5). Types of pacemakers include conventional and leadless; these can be permanent or temporary as well as MRI conditional or MRI safe.

Conventional Pacemakers

Conventional pacemakers have the same essential components: a pulse generator with a battery and electronics encompassing the connector ports and leads that reach the heart chambers (Fig 1A). The lead tips may have one of two means of fixation: passive, with plastic prongs attached to the trabecula (Fig 1B), or active, with a screw tip electrode embedded in the myocardium (Fig 1C) (5). Newer pacemakers are equipped with Bluetooth

Abbreviations

CIED = cardiac implantable electronic device, ICD = implantable cardioverter defibrillator, LV = left ventricle, RV = right ventricle

Summary

This article provides a comprehensive review of the radiographic appearances of cardiac implantable electronic devices, other cardiac support apparatuses, and similar-appearing noncardiac devices, emphasizing the importance of accurate identification and evaluation for potential complications.

Essentials

- Understanding the normal radiographic appearances of cardiac implantable electronic devices (CIEDs), other cardiac support apparatuses, and similar-appearing noncardiac devices on chest radiographs is crucial for accurate diagnosis and management of conditions.
- CIEDs include pacemakers and defibrillators, including newer technologies like leadless pacemakers and MRI-conditional devices; other cardiac devices include devices for cardiac monitoring, ventricular assistance, and cardiac repair.
- Similar-appearing noncardiac devices include deep brain, vagal nerve, and phrenic nerve stimulators as well as breast implant radiofrequency markers.
- Familiarity with device components and their anatomic positioning helps to correctly identify devices, differentiate normal from abnormal findings, and facilitate the diagnosis of potential complications.
- Radiologists must identify common complications such as lead dislodgement, fracture, and perforation, which often present clinically as device malfunctions but may first be detected on chest radiographs, thereby prompting appropriate evaluation and management.

capabilities, and it is important to correctly identify the antenna protruding from the generator to avoid misdiagnosing it as a fractured wire (Fig 1D) (6).

MRI-Conditional and MRI-Safe Pacemaker Models

Considering that 75%–80% of patients with permanent pacemakers will need MRI examination at some point (5), developing devices that can be safely used in MRI scanners is a priority. Various radiologic societies have provided recommendations for MRI in patients with CIEDs (7–11), which rely on identifying a device as MRI conditional (ie, compatible with MRI only under specific operating conditions with respect to magnetic field strength, maximum magnetic field gradient, and maximum specific absorption rate) or MRI safe (ie, presenting no known hazards in any MRI scanner given the nonconducting, nonmetallic, and/or nonmagnetic characteristics of the device) (12,13). MRI compatibility is determined by the device manufacturer. For patients unsure of their pacemaker model, specific details on a chest radiograph can help identify the device (14), as well as MRI contraindications such as lead abandonment, displacement, or fracture (15,16). Some MRI-conditional models have unique features, such as an undulating line above the model initials and a radiopaque coil on the proximal tip of the connecting lead (Fig 1E). Although the presence of these markers may be helpful, the safest and most effective approach is to identify the model and search the manufacturer database to confirm MRI compatibility (15). New deep learning algorithms have been developed to identify the manufacturers and models of permanent pacemakers, with accuracies ranging from 95.8% to 100% (17–20); however, until such software is widely available and in use, radiologists remain primarily responsible for accurately identifying cardiac devices and providing appropriate management recommendations.

Temporary Pacemakers

Temporary transvenous pacemakers are used as a bridge to permanent pacemaker implantation, usually when a high-grade atrioventricular block is diagnosed in an emergent setting. Characteristic imaging findings show the generator external to the patient, predisposing it to mobility at subsequent imaging, and a single pacing lead in the RV with a transjugular approach (Fig 2). Permanent pacemakers are implanted within the chest wall, are fixed in location, and may have multiple leads.

Leadless Pacemakers

Leadless pacemakers, such as the Nanostim (Abbott) and the Micra (Medtronic), were first approved by the Food and Drug Administration in 2016 as a transcatheter pacing system implanted entirely in the RV via peripheral femoral vein access. The device appears as cylindrical hardware on chest radiographs, measuring approximately 15 mm and projecting over the RV, with four self-expanding nitinol prongs protruding from one end adjacent to the electronics on the tip (Fig 3). Current indications include persistent atrial fibrillation with slow ventricular response, patients prone to recurrent infections, complications

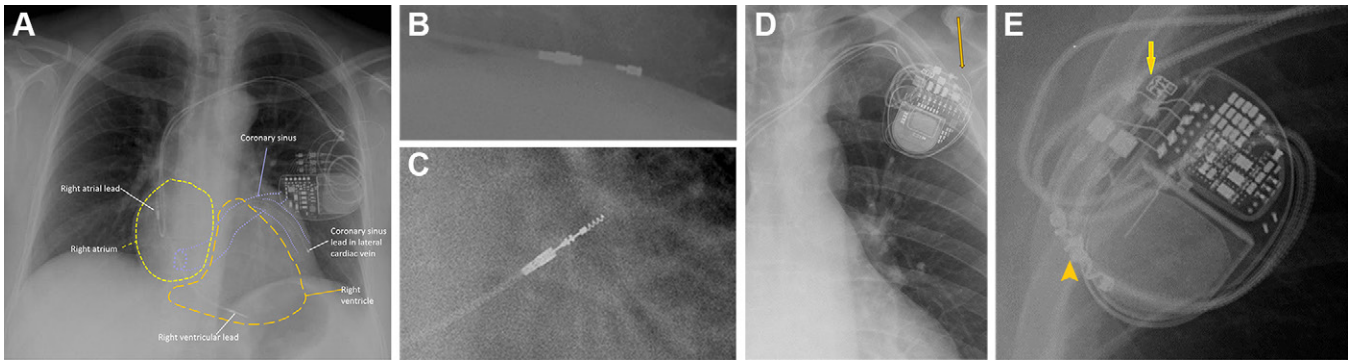

Figure 1: Cardiac pacing devices. **(A)** Posteroanterior chest radiograph shows a conventional pacemaker with typical components, including a generator (battery, electronics, and lead connectors) and electrode wires. Radiographic anatomy and correct lead positioning in the right chambers and lateral cardiac vein are labeled. **(B, C)** Detail magnifications of chest radiographs show **(B)** passive and **(C)** active fixation leads. **(D)** Detail magnification of a chest radiograph shows a Bluetooth-enabled pacemaker antenna (arrow), not to be confused with a broken wire. **(E)** Detail magnification of a chest radiograph shows an MRI-conditional device, which can be identified by the undulating line above the model initials (arrow) and the radiopaque coil on the proximal tip of the connecting lead (arrowhead).

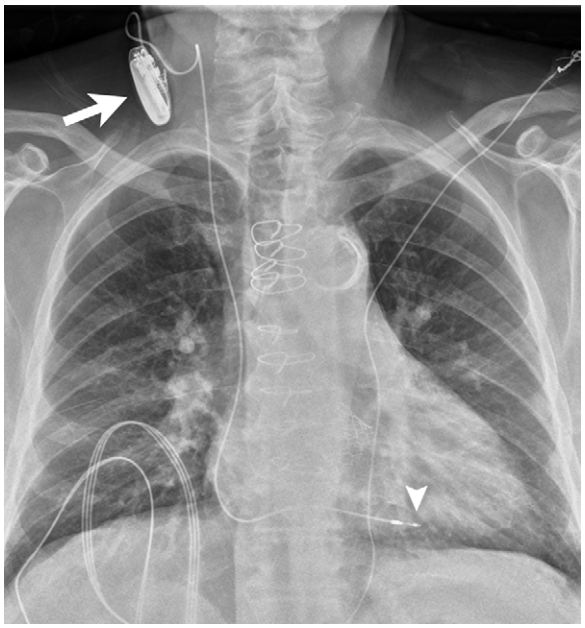

Figure 2: Temporary pacemaker. Anteroposterior chest radiograph shows a transjugular pacing device placed as a bridge to permanent pacemaker placement. The image shows the external generator (arrow) with correct placement of the lead (arrowhead) projecting over the right ventricle.

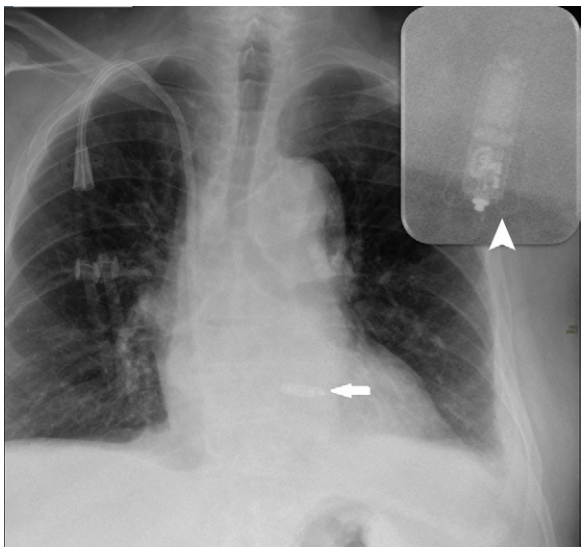

Figure 3: Leadless pacemaker. Anteroposterior portable chest radiograph shows the normal appearance and location of a leadless pacemaker. The device is cylindrical (arrow) with electronics, battery, and metallic prongs (inset, arrowhead) at the tip, allowing for fixation and signal conduction within the right ventricular myocardium.

associated with conventional permanent pacemakers, or challenging vascular access (21,22).

Defibrillators

ICDs have a slightly different appearance than pacemakers, as the primary lead contains two coils: one located at the superior vena cava and the other in the RV, with a pacing electrode tip (Fig 4A) (5). Identifying the position of these coils is crucial as proper placement is required for adequate depolarization of the myocardium, allowing for reset of the cardiac impulse.

In contrast to conventional ICDs, which have transvenous leads implanted within the heart, subcutaneous ICDs avoid the vessels and cardiac chambers and are preferred in patients at risk for infection or vascular complications (23–25). With subcutaneous ICDs, the pulse generator is implanted laterally or posteriorly, typically along the midaxillary line, with the defibrillating lead positioned within the midline anterior chest subcutaneous tissues (Fig 4B, 4C). This positioning is a key feature distinguishing subcutaneous ICDs from conventional transvenous ICDs.

Pacemaker Complications

Common pacemaker complications detectable on chest radiographs include lead disconnection, dislodgment, fracture, and perforation. These complications can manifest clinically as pacemaker malfunction, such as failure to generate or capture a pulse. To identify findings at chest radiography that may be contributory to pacemaker complications, radiologists must be vigilant in assessing the position of pacemaker components and follow the leads along their full extent on the chest radiograph.

Lead Disconnection

Lead disconnection manifests as a failure to generate an electric pulse, often detected by the cardiologist or electrophysiologist. At chest radiography, lead disconnection can be identified based on the position of the connector pin. If the terminal connector pin is disengaged from the metallic connector port, the impulse is not transmitted from the generator, resulting in malfunction (Fig 5A).

Lead Dislodgement

Lead dislodgment is suspected when the pulse generated does not transmit as expected. On chest radiographs, an atrial lead may be displaced through the tricuspid valve into the RV, or an RV lead may disengage from the myocardium, resulting in a loss of sensing and pacing capabilities (Fig 5B, 5C). Correcting the lead position can restore proper function.

Lead Fracture

Lead fracture clinically manifests as a failure to capture. Chest radiographs can help determine whether the failure to capture is due to genuine device failure or a functional issue. As part of a systematic assessment, radiologists should evaluate the complete path of each wire, especially lateral to the subclavian vein entry, where entrapment between the clavicle and first rib can pinch and break the lead (Fig 5D). Lead fracture can lead to more severe complications, such as migration of the fractured lead into the RV or pulmonary artery (26).

Lead Perforation

Lead perforation of the RV is a known rare but potentially serious complication, with different clinical presentations based on the timing of onset. Prevalence ranges from 0.4% to 1% during implantation (27) to 15% for late-onset findings detected at CT (28). Acute lead perforation typically manifests within hours after pacemaker insertion as chest pain and shortness of breath and can potentially lead to hemopericardium and cardiac tamponade. At initial assessment with chest radiography, findings may include an enlarged cardiac silhouette and a

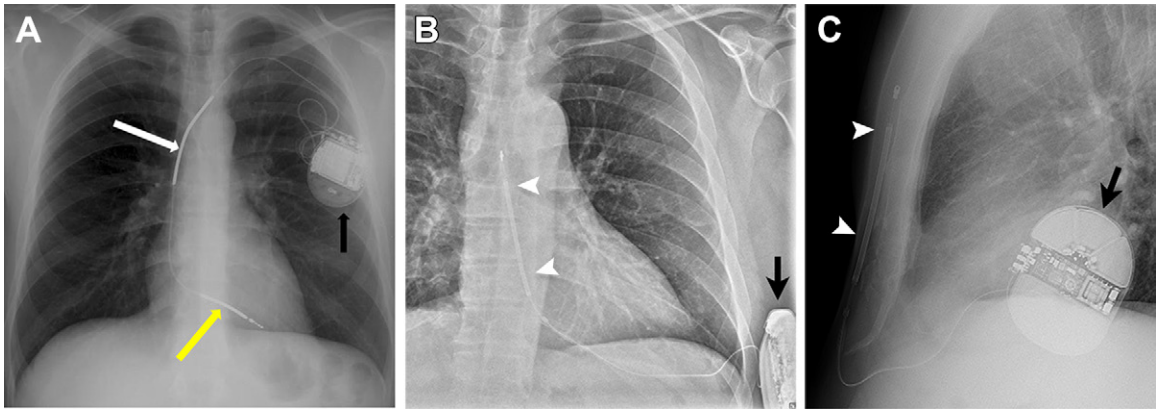

Figure 4: Implantable cardioverter defibrillators (ICDs). **(A)** Conventional ICD. Posteroanterior chest radiograph demonstrates two high-density defibrillating coils on an electrode correctly placed in the region of the superior vena cava (white arrow) and right ventricle (yellow arrow), with associated implanted generator (black arrow). **(B, C)** Subcutaneous ICD. **(B)** Posteroanterior and **(C)** lateral chest radiographs show the generator (arrow) implanted within the posterolateral chest wall, while the defibrillating lead (arrowheads) is located within the midline subcutaneous tissues anterior to the sternum.

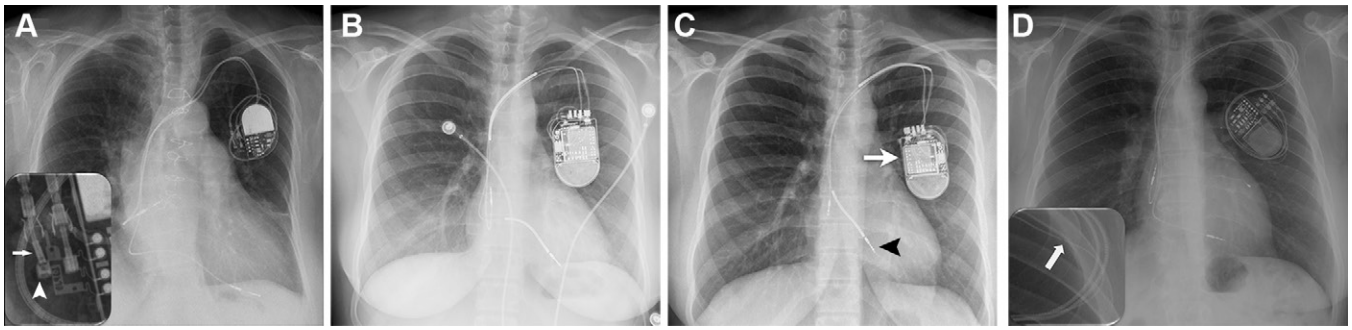

Figure 5: Pacemaker complications. **(A)** Disconnected lead. Posteroanterior chest radiograph shows that the connector pin (inset, arrow) is not fully inserted into the connector port (inset, arrowhead), resulting in incomplete contact with the conducting terminal and failure to transmit the pulse. (Image courtesy of Juan-Carlos Diaz, MD, Chile.) **(B, C)** Displaced lead. **(B)** Posteroanterior chest radiograph in a patient with an implantable cardioverter defibrillator shows appropriate device and lead positioning. **(C)** Posteroanterior chest radiograph obtained after sensing malfunction shows reversed left-right orientation of the generator (arrow) and retraction of the right ventricular defibrillating lead (arrowhead) due to manual manipulation of the generator (pacemaker twiddler syndrome). **(D)** Fractured lead. Frontal chest radiograph demonstrates fracture of the left coronary venous lead (inset, arrow) in a patient with device malfunction.

low-positioned RV lead tip (Fig 6A). Direct perforation may be suspected at chest radiography, but cross-sectional imaging is required for confirmation. Chest CT is used to characterize the course and location of the RV lead tip. Tip extension of more than 5 mm beyond the RV free wall is concerning for myocardial perforation rather than tenting (29). Associated findings may include hemopericardium and the presence of the lead tip within or beyond the pericardial sac (Fig 6B).

Subacute lead perforation may be an incidental finding at imaging. Up to 15% of patients with RV lead perforation are asymptomatic, with no electrophysiologic dysfunction, as a small perforation may still provide sufficient myocardial contact for pacing (26). Subacute lead perforation may also be suspected by cardiologists during follow-up visits when pulse generation dysfunction is detected. Some patients may present with hiccups if lead perforation results in diaphragmatic pacing. Initial imaging with chest radiography can show the RV lead tip beyond the cardiac margin, raising concern for perforation (Fig 6C, 6D). CT is a more definitive examination that can confirm the RV lead tip traversing the myocardium and lying beyond the pericardial sac, contacting the anterior chest (Fig 6E). CT evaluation to define regional anatomy is critical not only for diagnosis but also for management.

Cardiac Monitoring Devices

Loop Recorder

Subcutaneous implantable cardiac loop recorders allow clinicians to monitor long periods of cardiac rhythm and are typically deployed in cases of unexplained recurrent syncope without a diagnosis (30). These devices store patient-activated and auto-activated recordings of cardiac episodes and can be used to identify paroxysmal atrial fibrillation or postural orthostatic tachycardia syndrome (commonly called POTS) (31–33). Loop recorder devices vary in size but are typically rectangular and overlie the cardiac silhouette on the frontal chest radiograph and the anterior superficial chest wall on the lateral projection (Fig 7A, 7B). They are distinguished from leadless pacemakers by their larger size and subcutaneous location.

Pulmonary Artery Pressure Monitor

Although pulmonary arterial catheters provide real-time pressure monitoring, patients with chronic heart failure may benefit from the placement of a permanent pulmonary artery pressure monitor. Pressure-sensing devices, such as the CardioMEMS HF System (Abbott), allow for remote, wireless pulmonary artery pressure monitoring and have been shown to significantly reduce

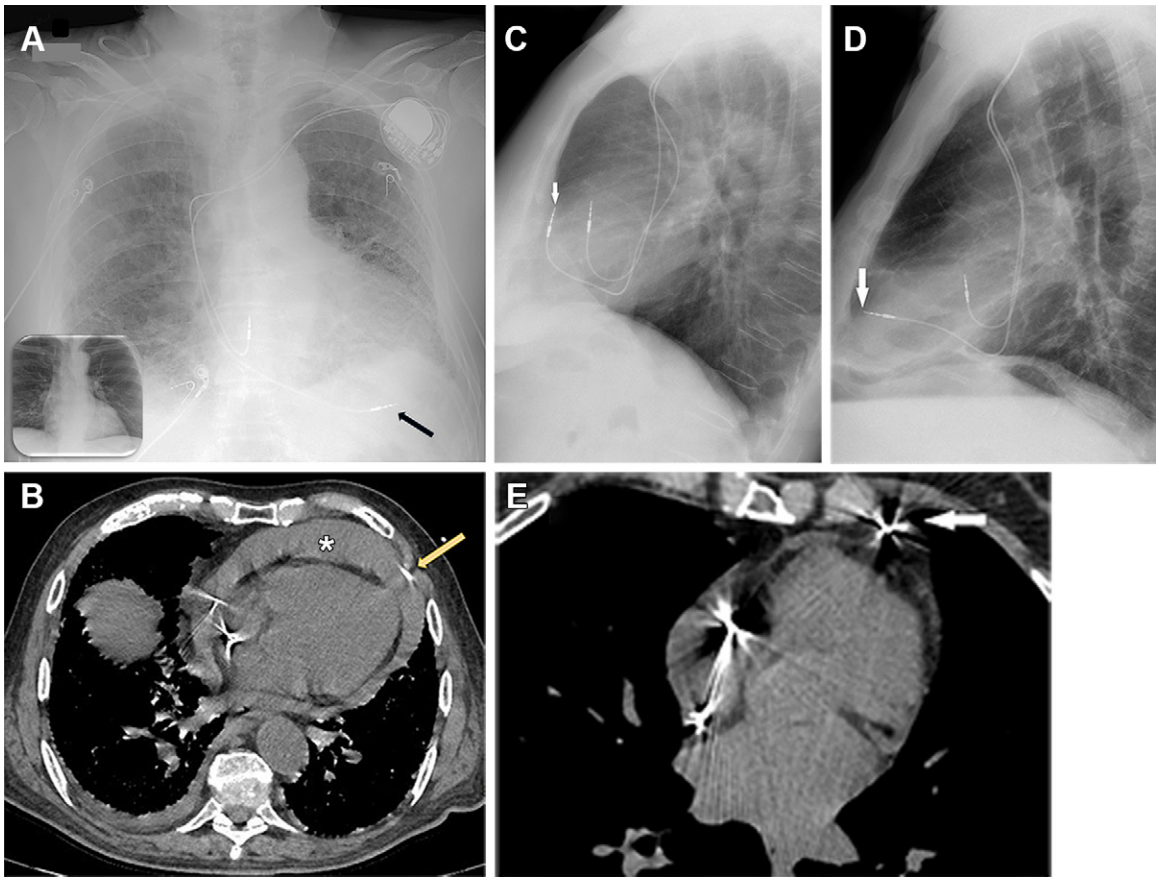

Figure 6: Pacemaker lead perforation. **(A)** Anteroposterior chest radiograph shows new cardiomegaly and the right ventricular (RV) pacing lead tip (arrow) positioned inferiorly along the projected RV margin. Inset shows the normal cardiac silhouette before pacemaker placement. The change in heart size, in conjunction with the lead position, is concerning for myocardial perforation and hemopericardium. **(B)** Axial nonenhanced chest CT image in the same patient as in **A** reveals high-attenuation fluid within the pericardial sac (*), suggestive of hemopericardium, with the RV tip (arrow) within this collection, consistent with lead perforation. **(C)** Lateral chest radiograph in a different patient shows abnormal positioning of the RV pacing lead tip (arrow) beyond the cardiac margin, in contact with the chest wall. **(D)** Lateral chest radiograph shows normal positioning of the RV lead (arrow). **(E)** Axial chest CT in the same patient as in **C** shows the RV lead tip perforating the myocardium and contacting the anterior chest wall (arrow) without discernible pericardial fluid, suggesting subacute perforation.

heart failure hospital admissions and improve patient quality of life (34,35). The pressure monitor is a small device that is ideally placed in the descending portion of the left pulmonary artery using a femoral or internal jugular vein endovascular approach. At chest radiography, the pulmonary artery pressure monitor is typically seen in the left infrahilar region and is located posteriorly on the lateral projection. The device appears as a small cylindrical structure with radiopaque borders. Two distinct round markers are visible at both the proximal and distal ends, giving it a characteristic appearance (Fig 7C–7E).

Ventricular Assist Devices

Ventricular assist devices may be placed surgically or via percutaneous endovascular technique to manage right- or left-sided heart failure, either permanently or as a bridge to recovery.

LV Assist Devices

An implantable LV assist device consists of LV inflow, pump, outflow, and driveline components. These devices have a distinct appearance at chest radiography, with some variability depending on the model. The HeartMate II (Abbott) has a prominent inflow cannula surgically placed within the LV in the long axis and is affixed at the apex (Fig 8A, 8B). The pump is external to the LV and connects to the inflow cannula via a bend-relief articulation. The nonradiopaque outflow cannula extends from the pump along the retrosternal space and anastomoses with the ascending aorta. The inflow and pump have been integrated on the newer HeartMate 3 model (Abbott) (Fig 8C).

Most complications associated with LV assist devices are first suspected clinically based on low-flow alarms (36,37), prompting imaging evaluation (38,39). Inflow obstruction by thrombus or myocardium cannot be directly evaluated at chest radiography; however, changes in inflow cannula positioning may suggest the diagnosis, as inflow obstruction during systole may be more likely if the cannula is oriented toward the anterior wall or septum (Fig 8D, 8E) (38). Outflow obstruction is most often due to thrombus and is best evaluated on contrast-enhanced CT images because the outflow cannula is not visible on radiographs (Fig 8F, 8G). Driveline infection is a common soft-tissue infection in patients with LV assist devices. The infection occurs around the driveline (cable) used to power the device. This complication does not manifest with device alarms. Instead, it may manifest clinically as signs and symptoms of infection, including tenderness, fluctuance, or frank purulent discharge around the driveline (40). Cross-sectional imaging may show subcutaneous fat stranding and a discrete fluid collection surrounding or adjacent to the driveline.

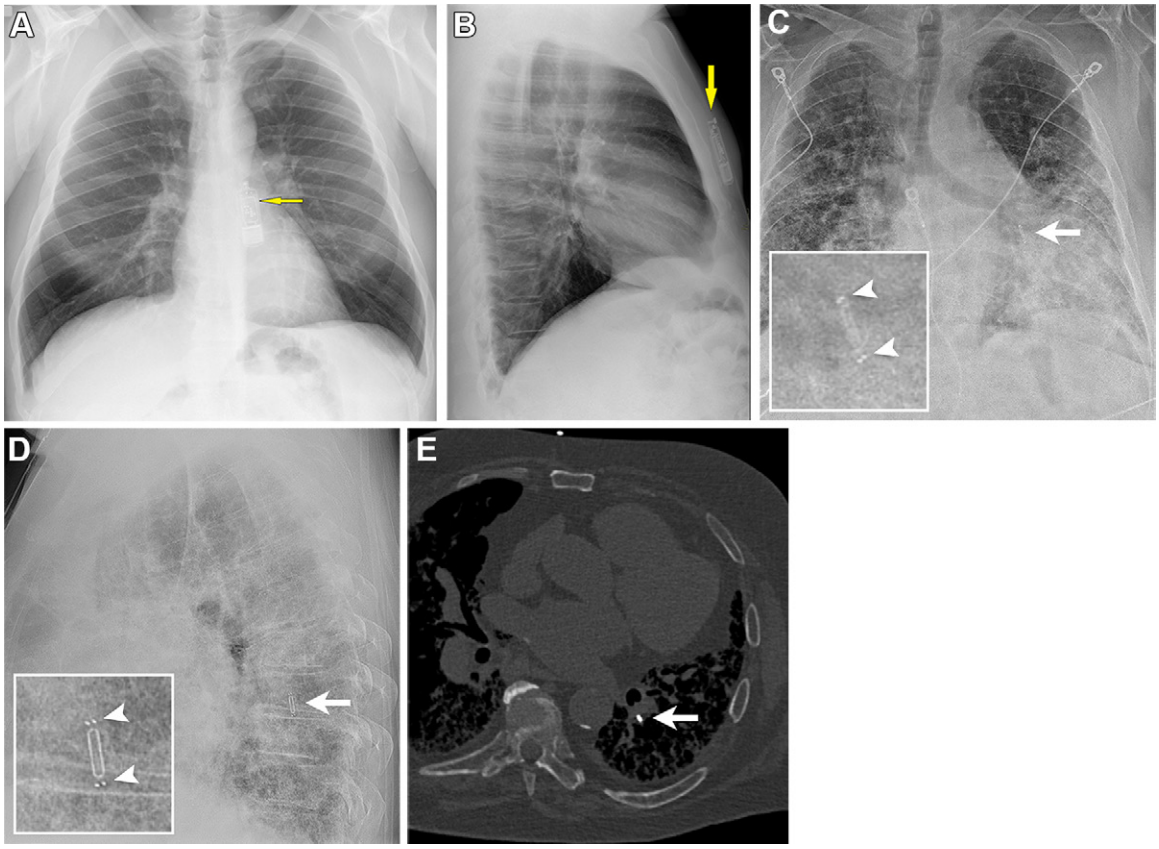

Figure 7: Cardiac monitoring devices. **(A, B)** Loop recorder. **(A)** Frontal and **(B)** lateral chest radiographs demonstrate normal placement of a cardiac loop recorder (arrow) implanted subcutaneously in the left parasternal region in a patient with suspected paroxysmal arrhythmias. The device can be distinguished from a leadless pacemaker based on its larger size and subcutaneous location, best seen on the lateral projection. **(C–E)** Pulmonary artery pressure monitor. **(C)** Frontal and **(D)** lateral chest radiographs show the normal location of a pulmonary artery pressure monitoring device (arrow) in the left infrahilar region corresponding to the lower lobe pulmonary artery, as confirmed on the **(E)** axial noncontrast chest CT image. Magnified views (insets in **C** and **D**) detail the characteristic dual rounded markers at the proximal and distal ends (arrowheads).

Temporary LV or RV Assist Devices

Temporary LV or RV assist devices, such as the Impella (CP and 5.5 models, Abiomed), ProtekDuo (LivaNova), and Rotaflow (Maquet) systems, are used as short-term mechanical circulatory support in patients experiencing acute heart failure or cardiogenic shock. The Impella CP and 5.5 are temporary LV assist devices with a microaxial flow pump inserted percutaneously, typically via the femoral or subclavian artery, and advanced retrograde through the thoracic aorta into the LV. On chest radiographs, these devices have a characteristic appearance: a catheter (14F–21F) positioned superiorly within the proximal ascending aorta and inferiorly in the region of the LV (Fig 9A). The pump is located at the proximal end of the radiopaque device, below which is the outlet region within the ascending aorta. The inflow component is located distally at the device tip terminating in the LV, marked on the CP model by a radiopaque pigtail catheter. The Impella RP (Abiomed) is a similar device for temporary RV support placed via the inferior vena cava into the pulmonary artery. Radiographic evaluation focuses on confirming appropriate placement, as malpositioning may result in suboptimal function, device failure, or other complications (Fig 9B).

The Rotaflow, used for extracorporeal life support, is a temporary ventricular assist device often deployed in patients requiring extracorporeal membrane oxygenation. It can provide support for both the RV and LV (39). The device consists of an extracorporeal centrifugal flow pump connected to venous and arterial cannulas. At chest radiography, the positioning of the cannulas is crucial: The venous cannula is typically placed in the right atrium via the superior vena cava, and the arterial cannula is positioned in the aorta (Fig 9C). Radiographic evaluation focuses on confirming appropriate cannula placement and detecting any complications such as malposition or kinking.

Cardiac Repair Devices

Atrial Septal Defect Closure Devices

Current therapy for closure of atrial septal defects involves percutaneous access with the deployment of a septal occluder. These devices appear as high-density linear structures with disk-like features on each side of the atrial septum. Atrial septal defect closure devices are readily identifiable on chest radiographs by their characteristic appearance and location, which is higher than the projected atrioventricular valve position and is often better seen on the lateral projection (Fig 10A–10D).

Left Atrial Appendage Closure Devices

Dilatation of the left atrial appendage is a potential source of thrombus, which may embolize to the systemic circulation. Although surgical approaches may exclude the left atrial appendage

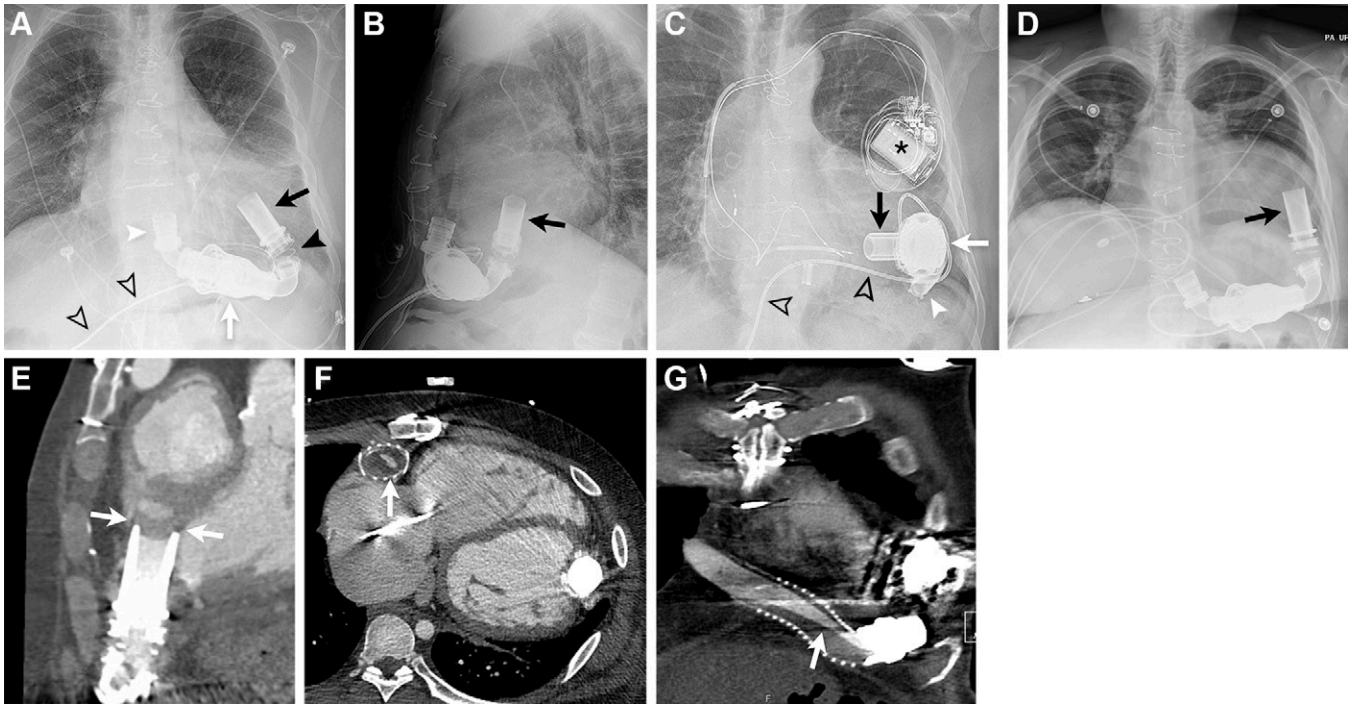

Figure 8: Left ventricular (LV) assist devices. **(A)** Frontal chest radiograph shows normal appearance and positioning of the HeartMate II (Abbott), with radiopaque inflow (black arrow), bend relief (black arrowhead), pump (white arrow), outflow (white arrowhead), and driveline (open arrowheads). Of note, the outflow cannula, with anastomosis to the ascending aorta, is not visible on radiographs. **(B)** The corresponding lateral radiograph demonstrates the normal anterior placement and orientation of the inflow (black arrow) along the LV axis. **(C)** Frontal chest radiograph shows the integrated inflow (black arrow) and pump (white arrow), the outflow (white arrowhead), and the driveline (open arrowheads) of an implanted HeartMate 3 (Abbott). An implantable cardioverter defibrillator device is also present (*). **(D, E)** Inflow obstruction. **(D)** Frontal chest radiograph in a patient with low-flow alarms demonstrates near vertical orientation of the inflow cannula (arrow), perpendicular to the LV axis. **(E)** Contrast-enhanced CT multiplanar reconstruction during systole shows complete inflow obstruction by the anterior myocardial wall (arrows). **(F, G)** Outflow obstruction. **(F)** Axial contrast-enhanced CT image and **(G)** multiplanar reconstruction demonstrate near occlusion of the outflow cannula by thrombus just beyond the pump (arrow).

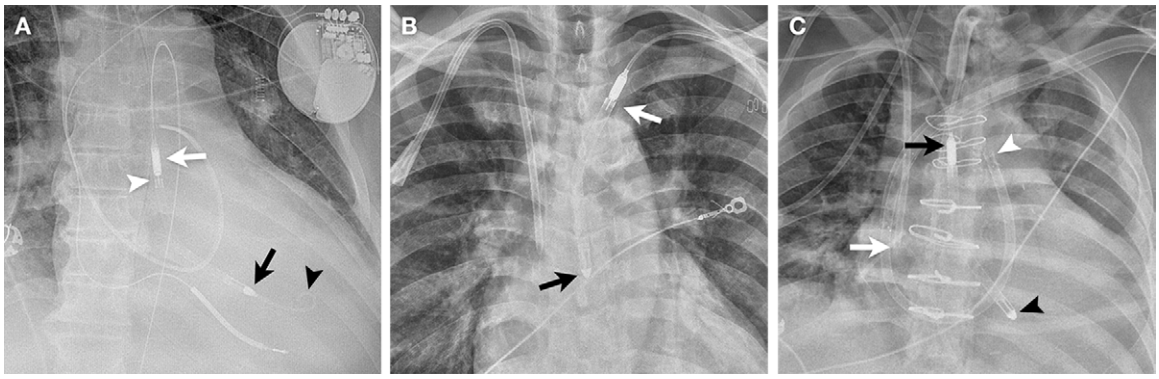

Figure 9: Temporary ventricular assist devices. **(A)** Frontal chest radiograph demonstrates an appropriately positioned Impella CP (Abiomed) temporary left ventricular (LV) assist device: The proximal pump (white arrow) and outflow (white arrowhead) are within the ascending aorta region, while the distal inflow, just proximal to the radiopaque tip (black arrow), is in the anatomic position of the LV. This specific model (Impella CP) has a pigtail component at the tip (black arrowhead). **(B)** Postprocedure anteroposterior portable chest radiograph shows a malpositioned Impella 5.5 (Abiomed) LV assist device. The device was inserted via the left subclavian artery. The radiograph reveals that the pump and outflow components (white arrow) are malpositioned above the top of the aortic arch within the subclavian artery, while the distal inflow is incorrectly situated in the ascending aorta (black arrow). **(C)** Anteroposterior portable chest radiograph demonstrates normal positioning of the right central venous catheter (white arrow) within the upper right atrium and the right pulmonary arterial catheter (white arrowhead) of a Rotaflow (Maquet) temporary right ventricular assist device, facilitating right ventricular bypass in the setting of right-sided heart failure. An Impella 5.5 LV assist device is also present, with proximal (black arrow) and distal (black arrowhead) components noted.

from the left atrium, current alternatives include occlusion devices placed within or across the appendage ostium. Various percutaneous occluders have been developed, with slight design differences, such as the Amplatzer Amulet (Abbott) and Watchman (Boston Scientific), which can appear similar to atrial septal defect closure devices, albeit in a different anatomic location (Fig 10E–10H). Permanent clamps may also be placed across the appendage at the time of cardiac surgery using an epicardial approach. One of the most common epicardial devices currently deployed is the AtriClip (AtriCure), which collapses the ostium and blocks blood flow to the appendage, providing electrical isolation and reducing contribution to atrial fibrillation. On chest radiographs, the

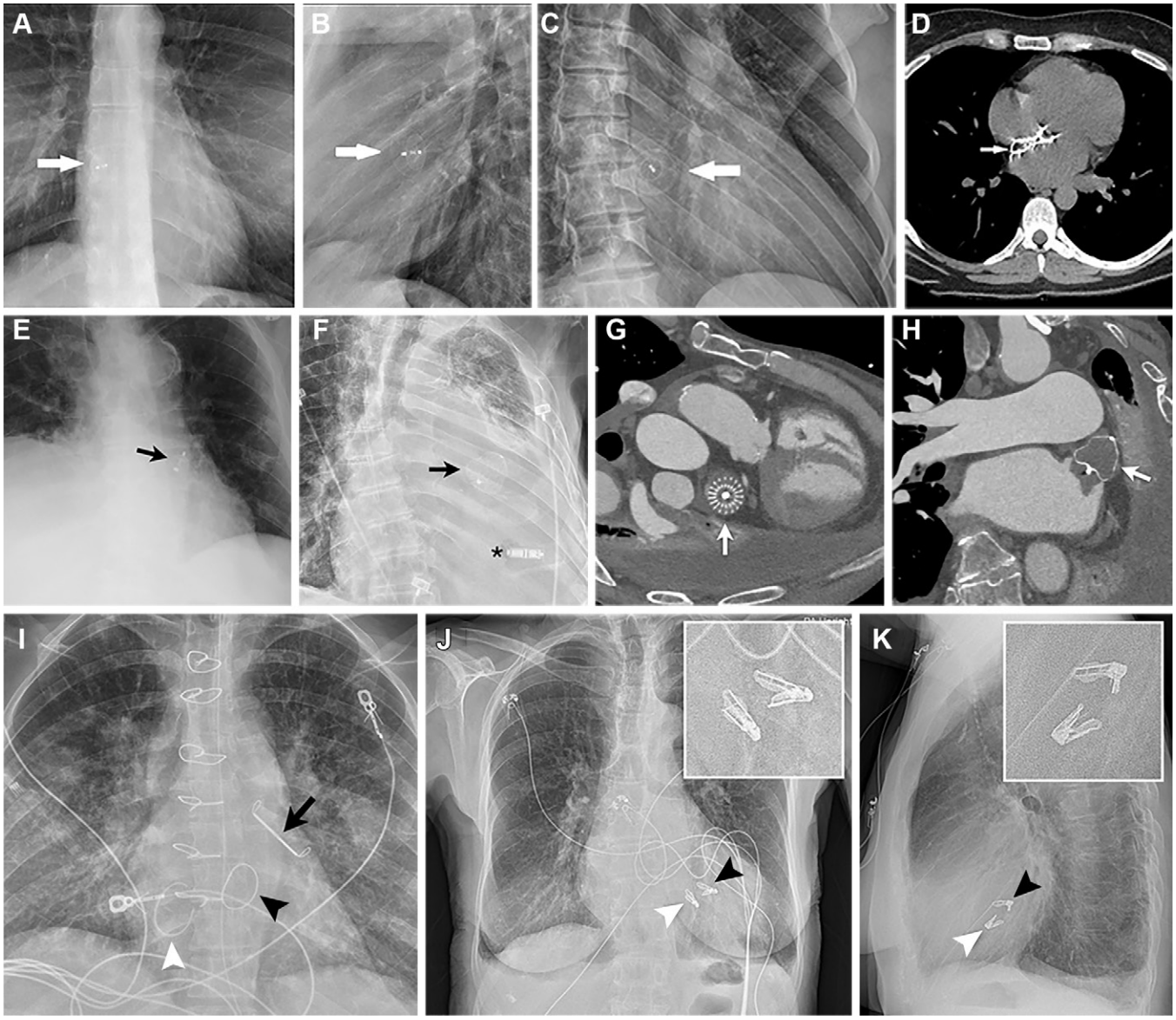

Figure 10: Cardiac repair devices. **(A)** Frontal, **(B)** lateral, and **(C)** oblique radiographs and **(D)** axial noncontrast chest CT image show an Amplatzer (Abbott) atrial septal occlusion device (arrow) that was placed via a percutaneous endovascular approach. The device traverses and seals the atrial septal defect with self-expanding disks positioned on either side of the septum within each atrium. The device is clearly visible on chest radiographs in the region of the atria, with the anatomy and device position better defined on the CT image. **(E)** Anteroposterior chest radiograph shows an Amplatzer Amulet (Abbott) left atrial appendage occlusion device (arrow). **(F)** Anteroposterior chest radiograph shows a Watchman (Boston Scientific) left atrial appendage occlusion device (arrow) in the normal anatomic position. The patient also has a leadless pacemaker (*). **(G, H)** Contrast-enhanced CT multiplanar reconstructions show the typical appearance of a Watchman device after deployment, with anticipated thrombosis (arrow). **(I)** Frontal chest radiograph after mitral valve replacement (white arrowhead) and tricuspid annuloplasty (black arrowhead) shows an AtriClip PRO2 (AtriCure) left atrial appendage epicardial occlusion clip (arrow) placed intraoperatively. **(J)** Posteroanterior and **(K)** lateral chest radiographs show appropriate superior (black arrowhead) and inferior (white arrowhead) positioning of MitraClip (Abbott) mitral valve clips in the anatomic position of the mitral valve. Insets show magnified clip details.

device appears as a linear density in the region of the left atrial appendage with looped nitinol springs at each end (Fig 10I).

Mitral Valve Clips

Patients with mitral valve regurgitation may be eligible for a minimally invasive endovascular procedure that places clips securing the anterior and posterior leaflets to minimize valve redundancy, improve valve closure, and restore normal blood flow across the valve (41,42). MitraClip (Abbott) is one such commercially available device, implanted with fluoroscopic and three-dimensional transesophageal echocardiographic guidance. Typically, two clips are placed, one superiorly and the other inferiorly, to narrow the mitral valve and maintain a symmetric central opening. At chest radiography, the clips project in the mitral valve region, with the clip apexes directed toward the LV because the devices are deployed from the left atrium (Fig 10J, 10K).

Complications associated with mitral valve clips, such as bleeding, infection, and mitral valve stenosis, are primarily procedure-related (41,42). Reported device-related complications include leaflet perforation, clip migration or embolization, and single leaflet device attachment, where the clip attaches to only one of the valve leaflets (anterior or posterior) (41). These complications typically occur during deployment but may not be appreciated until after the procedure. Radiologists should therefore be diligent in noting any change in the appearance and location of clips at chest radiography.

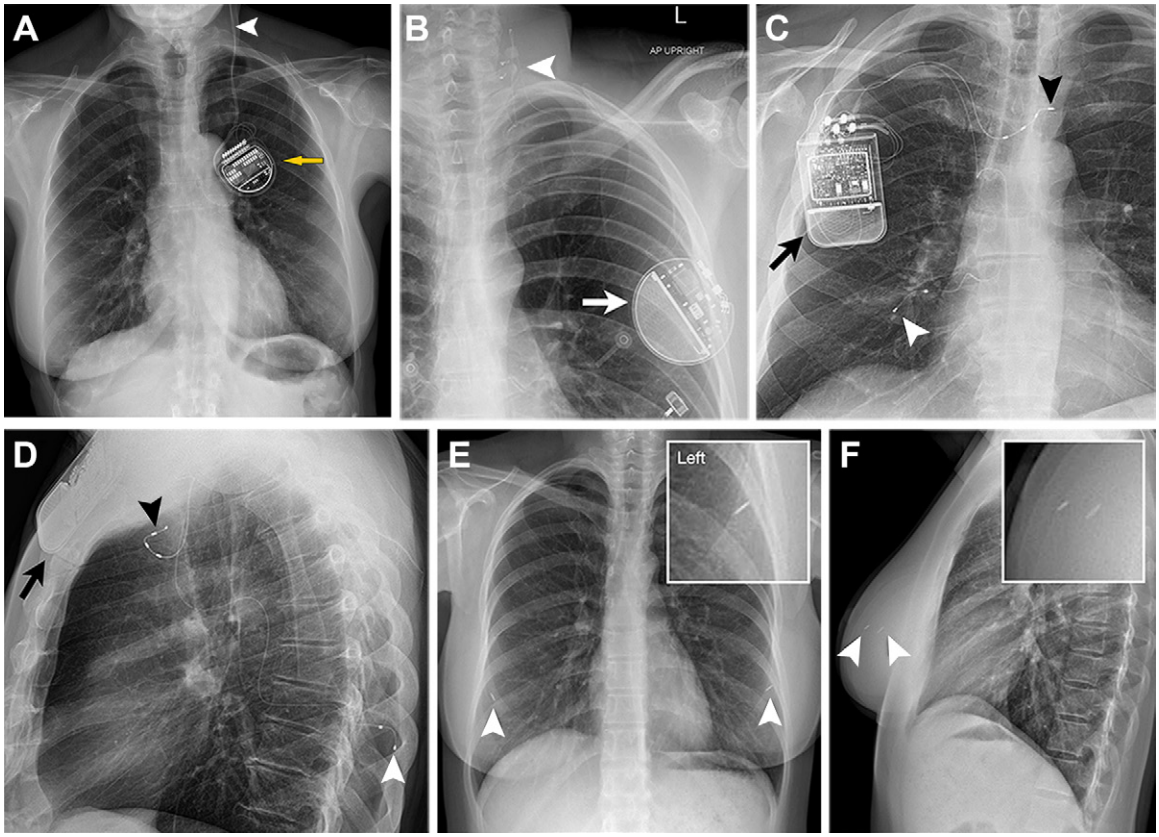

Figure 11: Noncardiac devices. **(A)** Deep brain stimulator. Posteroanterior chest radiograph shows the implanted device generator (arrow) in the left infraclavicular region. The electrodes (arrowhead), projecting cranially beyond the field of view, are implanted intracranially in the subthalamic nuclei. **(B)** Vagal nerve stimulator. Anteroposterior chest radiograph shows that the pulse generator (arrow) is in a similar location as for a deep brain stimulator; however, the electrode wires (arrowhead) ascend cranially to end in the midneck, wrapping around the left vagus nerve. **(C, D)** Phrenic nerve stimulator. **(C)** Posteroanterior and **(D)** lateral chest radiographs of the remedē System (Zoll) show the normal placement of the implanted generator (arrow) within the anterior subcutaneous tissues and the respiratory sensing lead in the azygos vein extending into a posterior intercostal branch (white arrowhead). The stimulation lead (black arrowhead) is in the region of the left brachiocephalic vein at the pericardiophrenic venous confluence. **(E, F)** Breast implant radiofrequency markers. **(E)** Frontal and **(F)** lateral chest radiographs demonstrate bilateral radiofrequency markers (arrowheads) measuring 2–3 mm within each breast implant shell (see insets for detail). These markers allow electronic identification of the implant brand, model, and volume.

Noncardiac Devices

Some medical devices have imaging features similar to implantable cardiac-related support apparatuses. Familiarity with these devices can facilitate accurate identification at imaging and minimize diagnostic errors.

Deep Brain Stimulators

Deep brain stimulation devices are used in patients with uncontrollable movement disorders, such as Parkinson disease and dystonia syndromes, and in severe cases of essential tremor (43). Although they do not cure the underlying condition, their use helps with symptom management. At chest radiography, the pulse generator projects within the subcutaneous chest wall, similar to an ICD; however, the leads are directed cranially, track into the neck, and extend outside the field of view (Fig 11A). The lead tips terminate intracranially in the region of the subthalamic nuclei. Correct identification is essential for MRI planning, as these devices require specific procedural precautions (43).

Vagal Nerve Stimulators

Vagal nerve stimulators are primarily used for managing intractable epilepsy and treatment-resistant depression (44). On chest radiographs, the device, which includes a pulse generator and lead, is typically implanted on the left side. The generator is located in the infraclavicular subcutaneous soft tissues, and the lead ascends to the midleft neck, where it wraps around the left vagus nerve (Fig 11B). This distinctive positioning helps differentiate vagal nerve stimulators from other devices like pacemakers and those used for deep brain stimulation. Newer models are often MRI conditional, but older devices may not be safe for MRI (44).

Phrenic Nerve Stimulators

Phrenic nerve stimulators are indicated to treat chronic obstructive sleep apnea (45). The remedē System (Zoll) is an implantable device used to treat central sleep apnea by restoring a normal breathing pattern during sleep. The generator of this device is placed in the right chest wall, with a single stimulation lead deployed in either the left pericardiophrenic vein or the right brachiocephalic vein. A sensing lead is placed into the azygos vein to detect respiration (Fig 11C, 11D) (44). The unique anatomic positioning of the leads differentiates phrenic nerve stimulators from deep brain and vagal nerve stimulators and implantable cardiac devices.

Breast Implant Radiofrequency Markers

Some manufacturers, such as Motiva, include microtransponders in breast implants, which are seen as small linear 2–3-mm densities

projected on the breasts (Fig 11E, 11F). These can mimic surgical clips or even pulmonary artery pressure monitors on the frontal chest radiograph; however, the lateral projection will clearly denote placement within the breast tissues. The transponder emits a wireless radiofrequency identification signal that can be detected with an external reader, providing information on the implant make, model, year, and volume. It is important to identify these implant markers due to their MR-conditional status and the imaging implications of radiofrequency-associated signal intensity artifacts (46).

Conclusion

Correct identification of cardiac medical devices at chest radiography is crucial for timely diagnosis, identifying complications, and directing patient care. Radiologists must fundamentally understand diverse cardiac and other devices, recognize their normal appearance and location, and identify common complications that may result in device failure and potential patient harm. This review focused on implantable cardiac and other similar devices routinely encountered on chest radiographs in practice. Recognizing that specific devices may vary based on cardiologist or surgeon preferences, radiologists are encouraged to be engaged with referring clinicians and clinical colleagues to better understand the specific devices in use at their institutions, including the indications and any special reporting criteria. By understanding the purpose, imaging appearance, and considerations of implantable devices, radiologists can better support clinical teams in effective patient care.

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