Pictorial Essay

Imaging of Cardiac Pacemakers

Stephen M. Bejvan[1], John H. Ephron[1], Julie E. Takasugi[2], J. David Godwin[1], Gust H. Bardy[3]

Cardiac pacemakers continue to evolve. The radiologist's role is in evaluating electrode position and lead integrity and in detecting complications as a result of implantation, such as pneumothorax.

Components

The pulse generator contains semiconductor chips and a lithium iodide battery. The pacing pulse is conducted through wires (leads) to electrodes (exposed metal conductors) positioned in the heart. The pulse goes through the myocardium and back to the generator to complete the circuit. In a unipolar system, the pulse is returned through the body, and in a bipolar system, through a second electrode and lead. Electrodes also function as the sensors that detect the cardiac rhythm and relay it to the generator.

Pulse Generator

Pulse generator housings are relatively radiolucent; the battery and semiconductor chips inside are visible. In a unipolar system, the posterior surface of the pulse generator that abuts the pectoral muscle is electrically insulated, and a small window in the housing allows the anterior surface to act as an electrode.

Leads

Leads (Fig. 1) are visible as continuous wires that extend to radiopaque electrodes in the heart. The polyurethane insulation is invisible. An atrial lead can have a J-shape for placement in the right atrial appendage (Fig. 1).

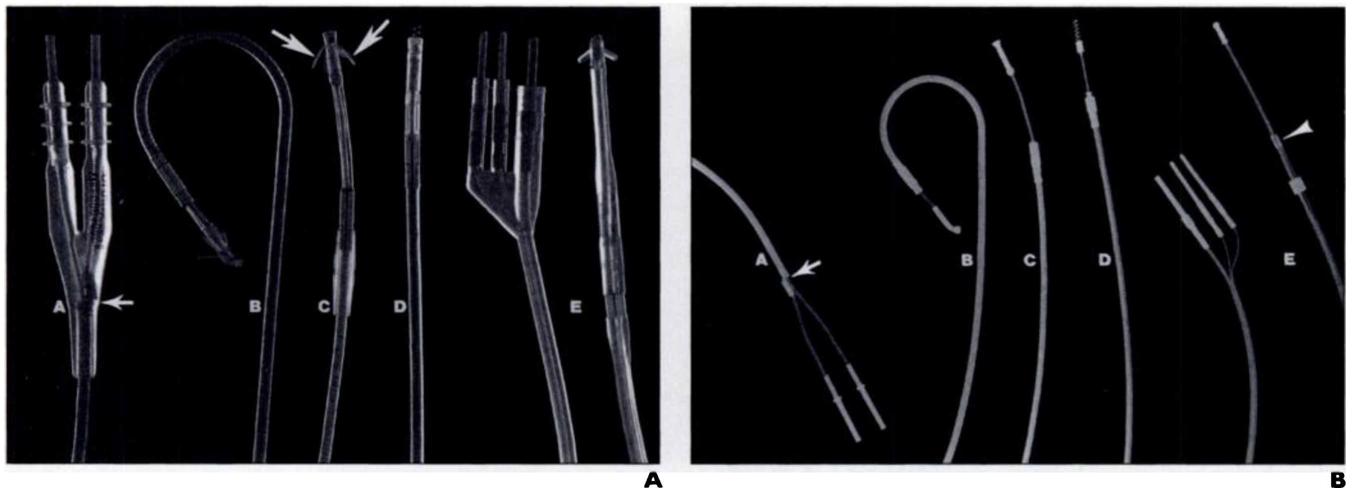


Fig. 1.—Photograph (**A**) and radiograph (**B**) of various pacemaker leads. A. Coaxial, bipolar lead (connector end). Note separation (*small arrow*, **A** and **B**) into component wires and connector pins. B. Coaxial, bipolar atrial lead. J-shape facilitates electrode placement into right atrial appendage. C. Coaxial, bipolar lead with passive fixation tip. Radiolucent ringlets (*large arrows*, **A**) catch in trabeculae and anchor electrode in heart. D. Coaxial, bipolar lead with active fixation tip. Screw is deployed beyond radiolucent sheath. E. Thermistor lead (Cook, Pacemaker, Leechberg, PA), a type of rate-adaptive lead. Bipolar lead incorporates temperature-sensitive electrode (*arrowhead*, **B**) that is positioned in heart and has "tripolar" configuration of connector pins. Thermistor lead is placed farthest from pulse generator.

Received February 20, 1997; accepted after revision April 29, 1997.

[1]Department of Radiology, University of Washington, 1959 N. E. Pacific Ave., Seattle, WA 98195.

[2]Department of Radiology 114, Seattle Veterans Administration Medical Center, 1660 S. Columbian Way, Seattle, WA 98108. Address correspondence to J. E. Takasugi.

[3]Department of Cardiology, University of Washington, Seattle, WA 98195.

AJR 1997;169:1371–1379 0361–803X/97/1695–1371 © American Roentgen Ray Society

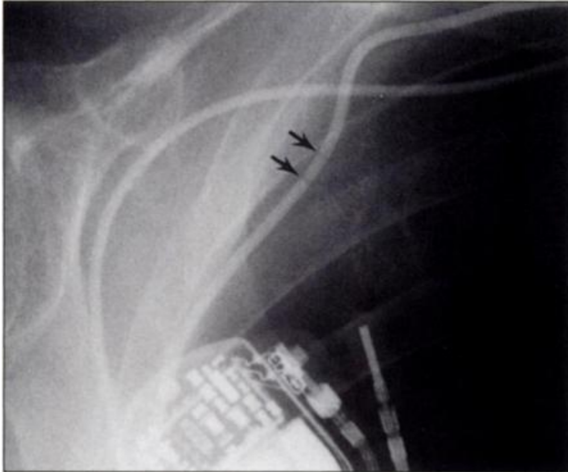


Fig. 2.—Pseudofracture. Posteroanterior radiograph shows impressions (*arrows*) on coaxial wire caused by tight anchoring sutures.

The proximal electrode of a bipolar lead is a metallic ring located 1–3 cm from the terminal electrode. The terminal electrode is in contact with the myocardium. Bipolar leads are almost always coaxial. Electrodes may have tips for active or passive fixation. Electrode tips for active fixation have a screw at the tip, and those for passive fixation have a blunt or "tined" tip (Fig. 1).

A coaxial bipolar lead may falsely appear fractured at the origin of the coaxial winding, but this pseudofracture [1] is caused by normal separation of the lead into its two component wires (Fig. 1). A different pseudofracture occurs when the anchoring sutures are so tight that they deform the outer coaxial wire (Fig. 2) [1, 2]. This deformity does not affect conduction, but if the suture cuts into the insulation it could short circuit the pacing pulse.

Lead Placement

Transvenous electrodes are placed using fluoroscopic and electrophysiologic guidance. The electrode is positioned in the right atrium or right ventricle. The lead should have a direct course to the heart and be neither taut nor redundant (Fig. 3).

An atrial electrode is usually placed in the atrial appendage but is sometimes placed in the body of the atrium or along the septum (Fig. 3), if the pacing threshold is favorable. A ventricular electrode is usually placed in the right ventricular apex (Fig. 3) but is sometimes placed in the coronary sinus (Fig. 4). An unusual location may be chosen for electrode placement depending on the pacing threshold (Fig. 5) or to avoid pacing the diaphragm.

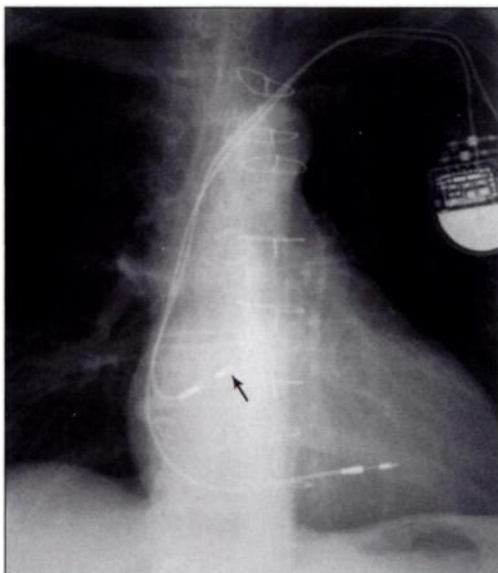
Lead and Electrode Malposition

Leads can enter the left ventricle through a septal defect or a surgically created shunt or by inadvertent arterial puncture (Fig. 6). A lead in the left ventricle can cause systemic thromboembolism.

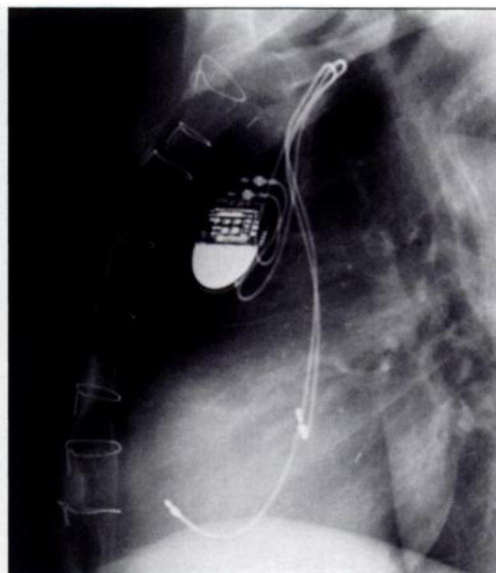
On frontal images, a lead entering the middle cardiac vein (Fig. 7) may be indistinguishable from one entering the right ventricle [3]; however, on lateral images, a lead in the middle cardiac vein takes a more posterior and inferior course (Fig. 8). A lead intended for the coronary sinus may appear to be correctly positioned on a frontal radiograph but actually be in the right ventricular outflow tract (Fig. 9). On a lateral image, the lead curves posteriorly if in the coronary sinus and anteriorly if in the outflow tract.

Complications

Initial chest radiographs help establish baseline position and exclude immediate complications. In one series, complications included electrode malposition (6%), taut or redundant lead (5%), pneumothorax (3%), pleural effu-



A



B

Fig. 3.—Unusual electrode position. Posteroanterior (**A**) and lateral (**B**) radiographs show intentional fixation of right atrial lead to interatrial septum (*arrow*, **A**) using active fixation electrode. Unusual electrode position may be chosen if pacing threshold is favorable. Note expected course of lead with electrode positioned in apex of right ventricle. Lead is not taut or redundant. Note expected anterior course of lead on lateral radiograph (compare with Fig. 8).

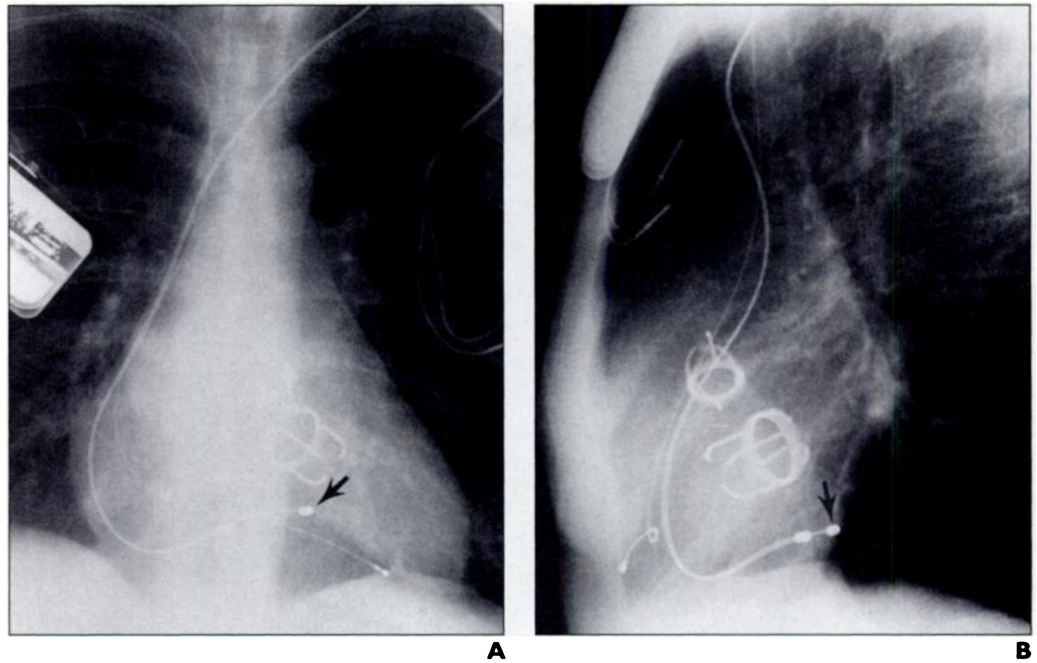


Fig. 4.—Coronary sinus pacing. Posteroanterior (**A**) and lateral (**B**) radiographs show disconnected bipolar lead (*arrow*) in coronary sinus. Coronary sinus position is indicated by posterior course of lead on lateral view. Active electrode is positioned in right ventricular apex.

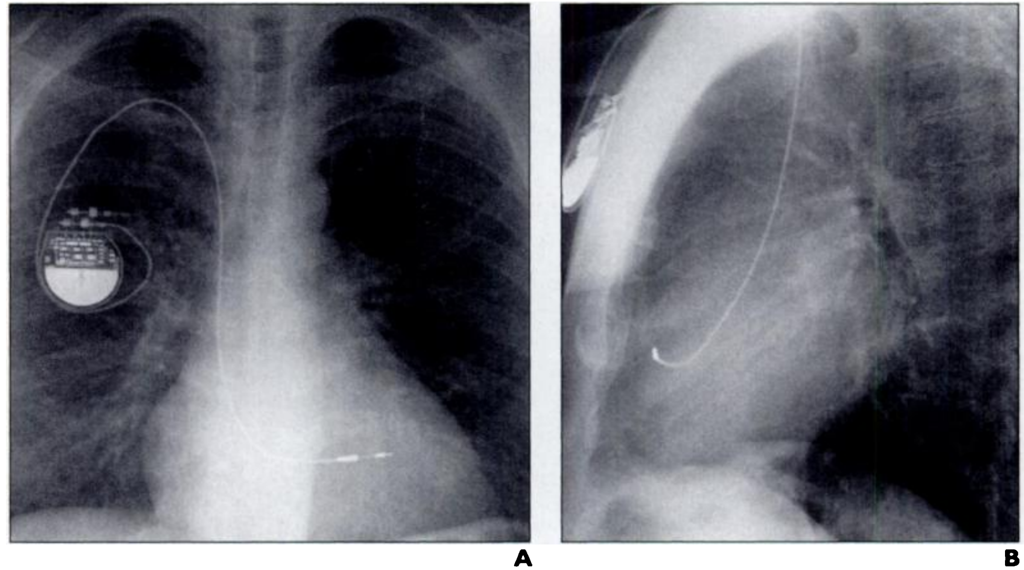


Fig. 5.—Unusual electrode position. Posteroanterior (**A**) and lateral (**B**) radiographs shows screw-tipped lead anchored along interventricular septum below right ventricular outflow tract. An unusual position may be chosen if threshold is favorable or to avoid diaphragmatic pacing.

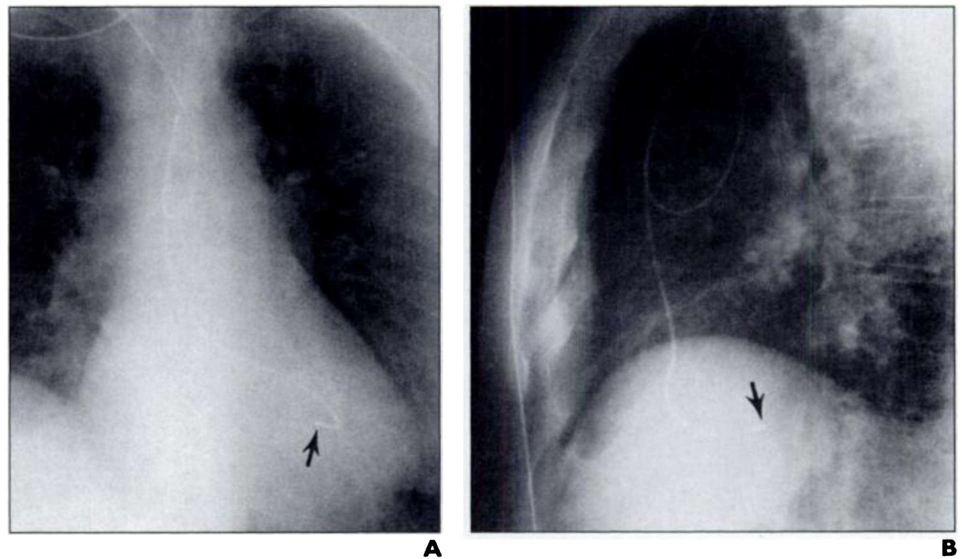


Fig. 6.—Malpositioned lead. Posteroanterior (**A**) and lateral (**B**) radiographs show inadvertent intraarterial placement of temporary pacing lead with electrode (*arrow*) in left ventricle. Note coil in ascending aorta.

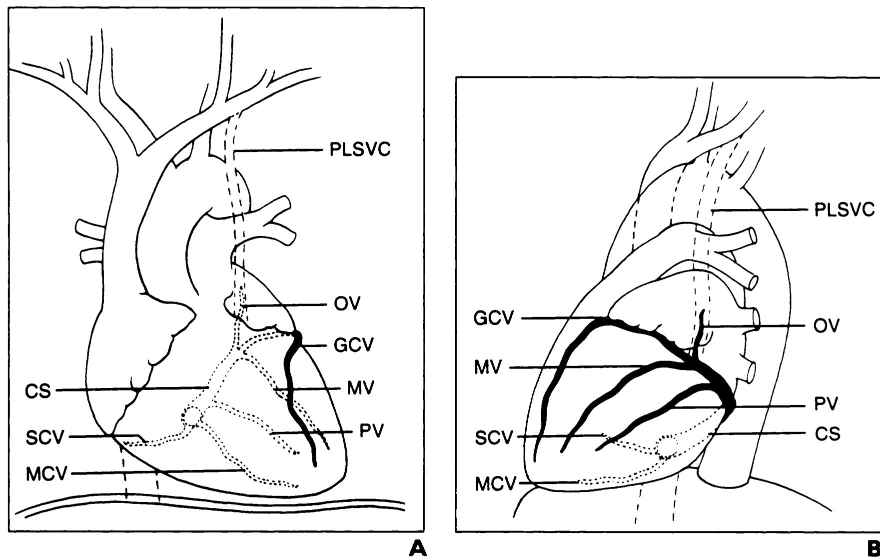


Fig. 7.—Frontal (**A**) and lateral (**B**) diagrams of the heart show location of cardiac veins. Coronary sinus (CS) arises from union of great cardiac vein (GCV) and oblique vein of left atrium (OV) in left atrioventricular groove. Middle cardiac vein (MCV) lies in posterior interventricular sulcus, and small cardiac vein (SCV) lies in right atrioventricular sulcus. Marginal vein (MV) and posterior ventricular vein (PV) drain into great cardiac vein or coronary sinus. PLSVC = persistent left-sided superior vena cava. (Reproduced with permission from [2])

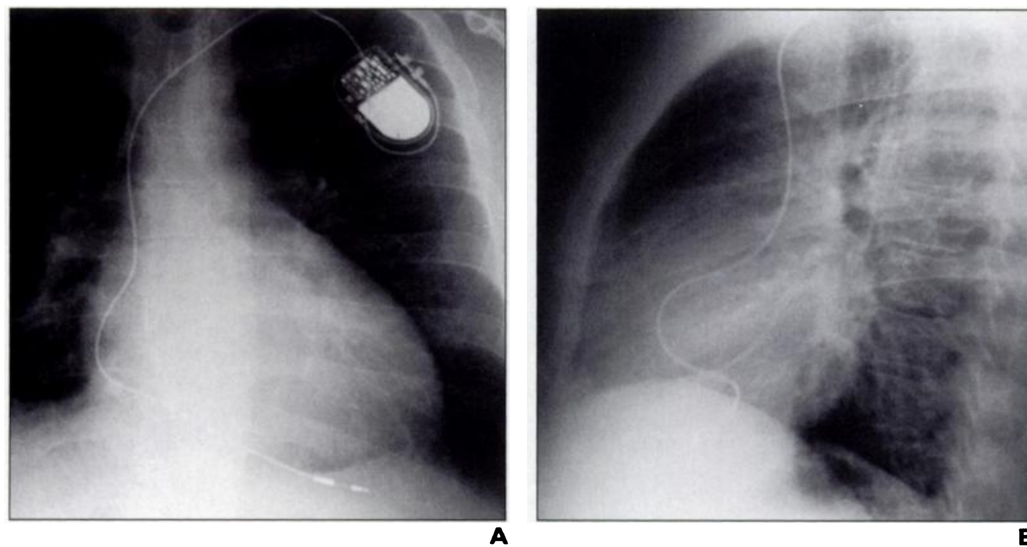


Fig. 8.—Malpositioned lead. Posteroanterior (**A**) and lateral (**B**) radiographs show lead in middle cardiac vein that was confirmed at autopsy.

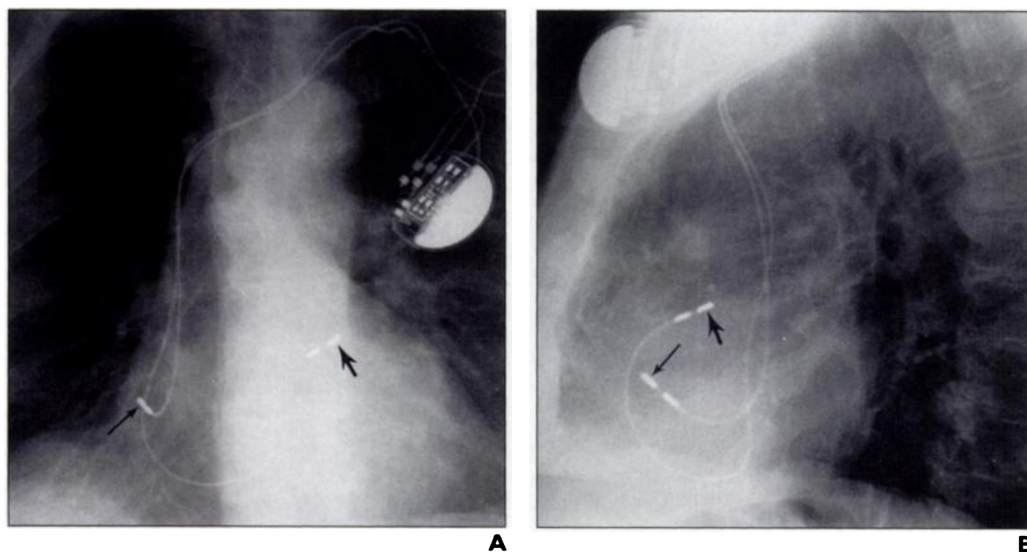


Fig. 9.—Malpositioned lead. Posteroanterior (**A**) and lateral (**B**) radiographs show bipolar right ventricular lead (*large arrow*) malpositioned in right ventricular outflow tract. Lead could be falsely interpreted as entering coronary sinus if only frontal radiograph was obtained. Atrial lead (*small arrow*) is in body of right atrium.

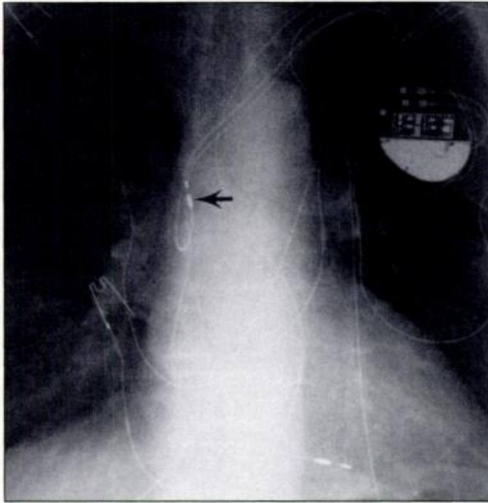


Fig. 10.—Dislodged electrode. Radiograph shows J-curved atrial lead with dislodged electrode (*arrow*) in superior vena cava.

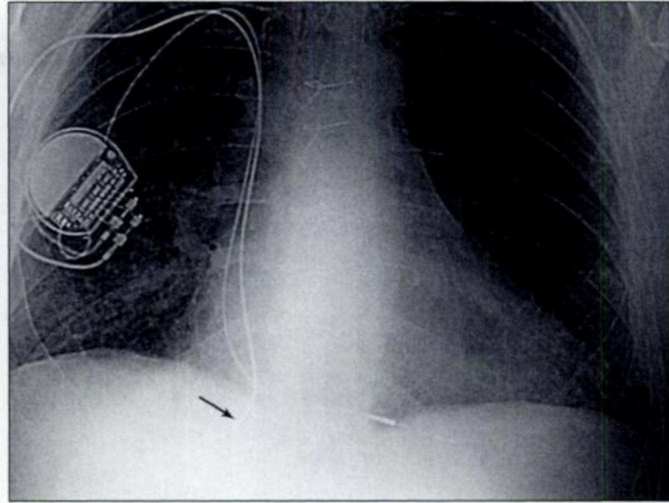


Fig. 11.—Dislodged electrode. Anteroposterior radiograph shows that atrial electrode (*arrow*) has migrated to inferior vena cava.

sion (1%), wire fracture (1%), fluid level in the pulse generator pouch, and rotation of the generator [4]. At our institution, the immediate postimplantation radiograph is supplemented with upright posteroanterior and lateral images 1 day later. The upright image helps detect pneumothorax, and the lateral image verifies electrode position.

Electrode Dislodgment or Migration

The electrode is usually secured by entrapment of its tip by the trabeculae of the right ventricle. Permanent fixation requires a fibrous adhesion to form at the tip, which takes weeks to mature; accordingly, 50% of electrode dislodgments occur in the first 2 weeks [1]. Using an active fixation tip helps avoid dislodgment. A loose atrial electrode can migrate into the vena cava (Figs. 10 and 11). A loose ventricular electrode can migrate into the ventricular outflow tract or along the ventricular septum.

Redundancy of a lead predisposes dislodgment of the electrode [1]. Another predisposing factor is conscious or subconscious manipulation of the pulse generator within its subcutaneous pouch (twiddler's syndrome), which can twist or wind the leads (Fig. 12) and dislodge the electrodes. Traction on the lead can also be caused by excess motion of the pulse generator in a pouch that is too big (Fig. 13).

Myocardial Perforation

Myocardial perforation (Fig. 14) can occur as an early or late complication after lead placement and can cause hemopericardium and tamponade. At our institution, the incidence of perforation is about 0.5%. Partial penetration of the myocardium is inferred if the electrode is within 3 mm of epicardial fat on posteroanterior or lateral images; perforation is inferred if the electrode extends into epicardial fat [1].

Lead Fracture

Lead fracture is usually caused by repetitive flexion. The most common sites of fracture are the segment between the first rib and clavicle (Fig. 15), the loop in the subcutaneous tissue near the pulse generator (Fig. 16), and the point of venous entry [1]. Fracture usually results in complete failure of the lead, but if the insulation remains intact around the break, there may be intermittent electrical contact and function.

Some lead fractures are not seen on radiographs, particularly fractures concealed behind the pulse generator and fractures in which the insulation maintains apposition of the fractured ends.

Circuit Failure Not Caused by Lead Fracture

One cause of circuit failure is a loose connection between the lead and the pulse generator. Another cause is residual air in the subcutaneous pouch right after implantation; the air insulates the active surface of the unipolar generator from the subcutaneous tissues. A third cause is rotation of the pulse generator in the subcutaneous pouch, bringing the active surface of the pulse generator in contact with the pectoral muscle, sometimes stimulating the muscle. This rotation can be recognized by the counterclockwise exit of the pacing leads from the generator [5]. Most pacemakers implanted before 1995 were designed to be placed with the lead(s) exiting clockwise. New models di-

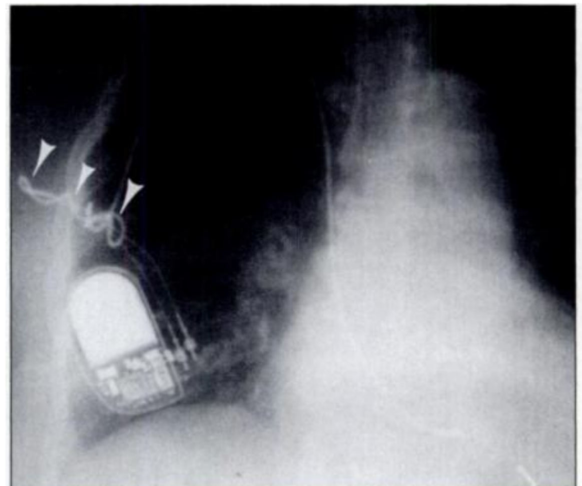


Fig. 12.—Twiddler's syndrome. Radiograph shows lead twisted (*arrowheads*) in subcutaneous pouch as a result of conscious or subconscious manipulation of pulse generator by patient. Twiddling may cause lead fracture or electrode dislodgment.

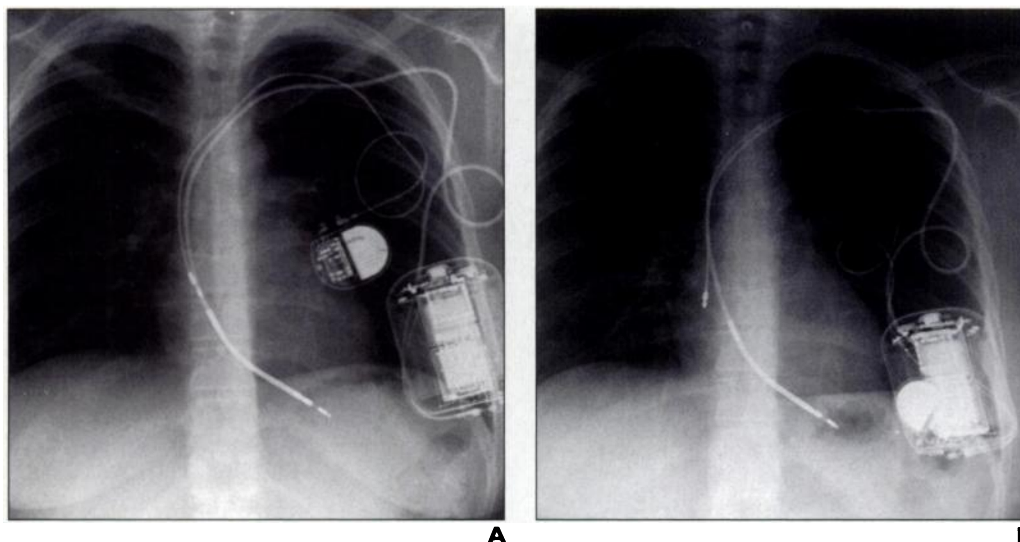


Fig. 13.—Slippage of pacemaker pulse generator.
A, Posteroanterior radiograph of patient with pacemaker combined with implanted defibrillator.
B, Several months later, pacemaker pulse generator slipped downward to overlap defibrillator generator. Traction on lead may predispose to electrode dislodgment.

rect the leads toward the venous entry; thus, a pacemaker implanted on the left side of the chest may have leads exiting counterclockwise. Circuit failure can also be caused by a loss of battery power. However, battery reserve can no longer be evaluated radiographically, only electrically.

Exit Block

An exit block is defined as an increase in pacing threshold despite an intact pacing system. The usual cause is fibrosis at the electrode tip. The role of the radiologist in evaluating exit block is to exclude a mechanical cause for the increased threshold, such as electrode dislodgment or myocardial perforation.

Infection

Any foreign body, including a pacemaker, predisposes to infection, most commonly with *Staphylococcus* organisms. Infection of the subcutaneous pouch is manifested on radiographs as soft-tissue swelling or a fluid level and can lead to abscess and breakdown of the pouch. Spread of infection along the leads can cause thrombosis, endocarditis, septicemia, or exit block.

Tricuspid Valve Insufficiency

Adhesions between the lead and the valve leaflets can cause tricuspid insufficiency. The extraction of a lead can lacerate a leaflet. Some authors recommend that no more than three leads be placed across the tricuspid valve [6]; therefore, old leads should be removed when new ones are placed.

Venous Thrombosis

Thrombi form immediately around the leads after placement and undergo endothelialization and organize in a few months, forming a thin sheath around the lead. Thromboembolism is rarely apparent clinically because emboli are usually small. Superior vena cava syndrome is a rare complication; when it occurs immediately after pacemaker insertion, it may respond to thrombolytic therapy or anticoagulation. However, when it occurs late (weeks to months later), the thrombus is usually organized [1] and resection may be required.

Ionizing Radiation

Pacemakers are not damaged by diagnostic radiography, but therapeutic doses may adversely affect pacemaker function. If the pulse generator cannot be excluded from the radiation port, a radiation-resistant generator may be selected. Even if the generator is outside the port, shielding is advisable.

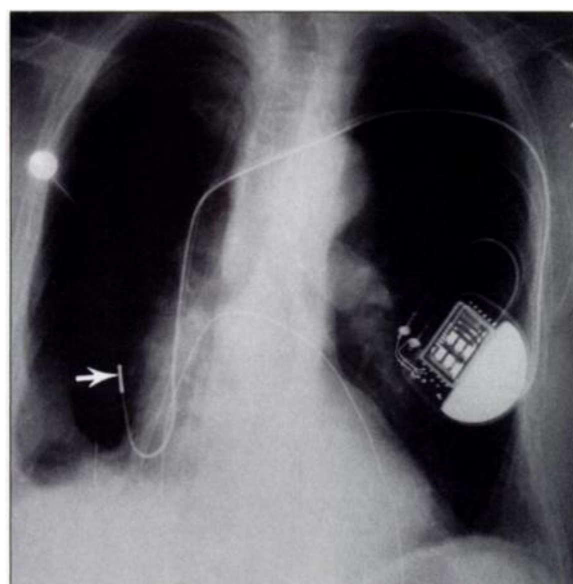
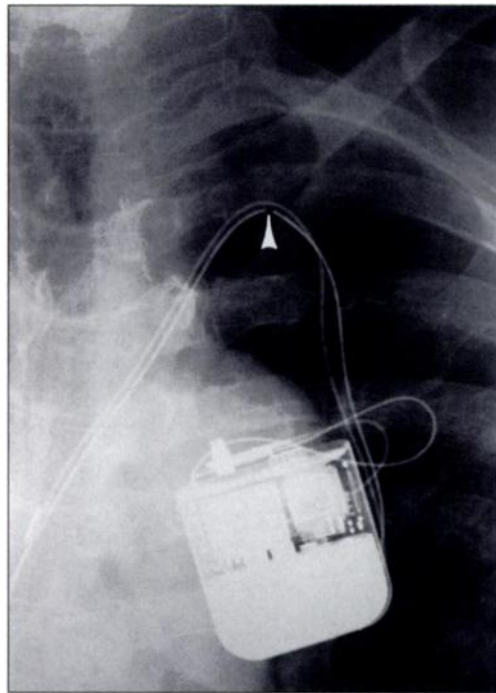


Fig. 14.—Myocardial perforation. Chest radiograph after right atrial perforation. Electrode (*arrow*) is outside cardiac contour. CT confirmed extracardiac position.

Extraction of Leads

Indications for the removal of pacemaker leads are infection, fracture, dislodgment, and recall by the manufacturer.

A lead can be removed surgically or percutaneously. Smith et al. [6] successfully extracted 99 of 104 leads percutaneously. Three patients (5%) had major complications: right atrial tear in one and hemorrhage in two. A lead may fracture during extraction, leaving



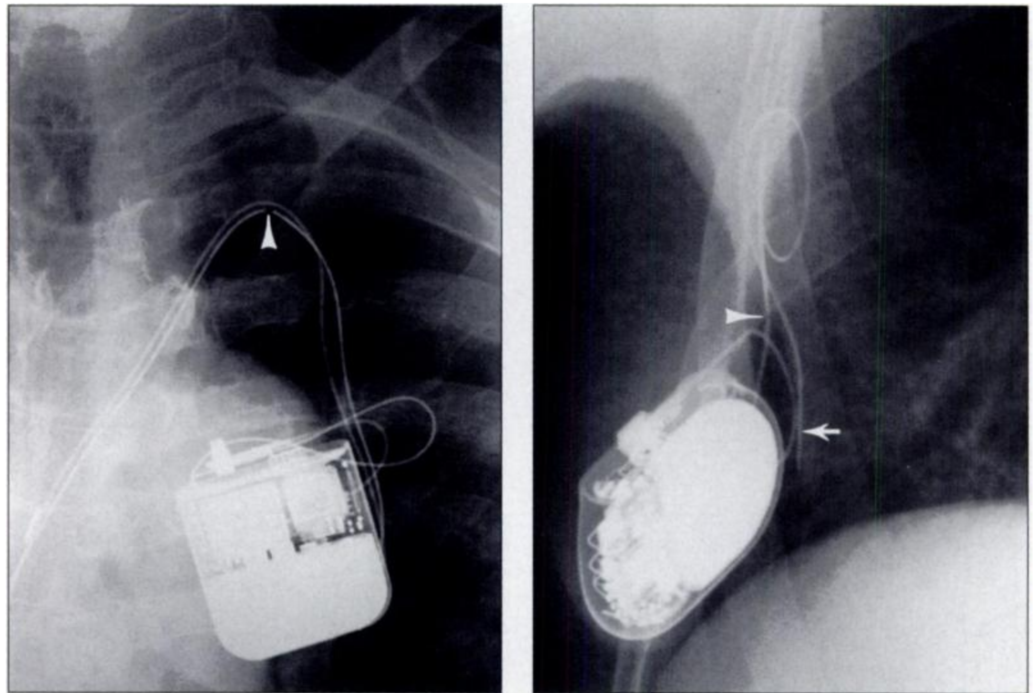


Fig. 15.—Lead fracture. Close-up posteroanterior radiograph shows lead fracture (*arrowhead*) in typical location, between first rib and clavicle.

Fig. 16.—Lead fracture. Posteroanterior radiograph shows lead fractured (*arrowhead*) near pulse generator. Disconnected lead (*arrow*) is also present.

electrodes embedded in the myocardium (Fig. 17) or in a brachiocephalic or subclavian vein. A lead fragment can embolize to a pulmonary artery (Fig. 18).

Special Patients

Children

In general, smaller and more durable transvenous leads have supplanted epicardial leads, even in infants and in some patients with complex structural heart disease that may require nonstandard placement. Small-caliber unipolar leads are preferred for children. However, uni-

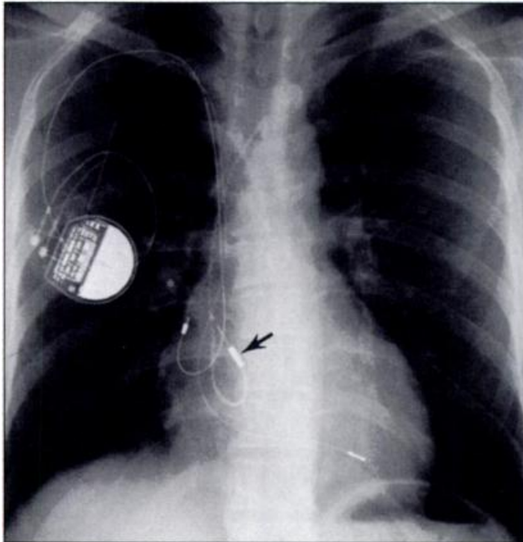


Fig. 17.—Fracture of lead during extraction. Chest radiograph after attempted extraction of bipolar atrial lead that fractured during procedure; fragment (*arrow*) remains in left brachiocephalic vein, superior vena cava, and right atrium. Unipolar right atrial and right ventricular leads are present.

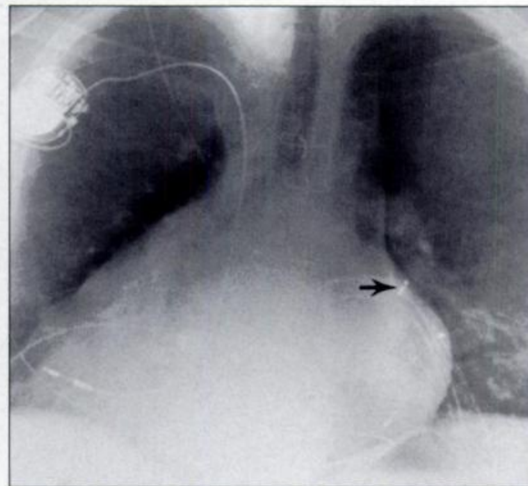


Fig. 18.—Embolization of electrode. Posteroanterior radiograph in patient with dextroversion and congenitally corrected transposition of great arteries. Electrode (*arrow*) from fractured lead has embolized to left pulmonary artery.

polar leads can cause extracardiac pacing (e.g., diaphragmatic pacing), which can be avoided by placing the electrode higher than usual in the right ventricle. The leads are often left deliberately long (Fig. 19) to allow for body growth.

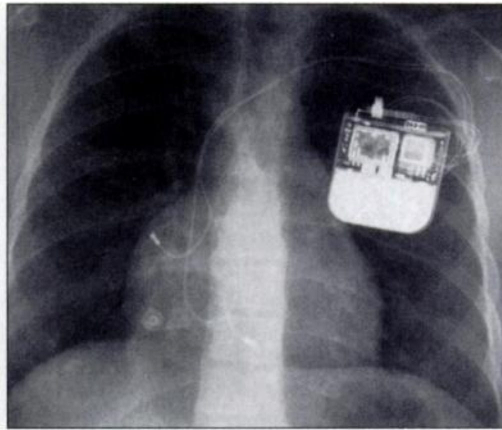
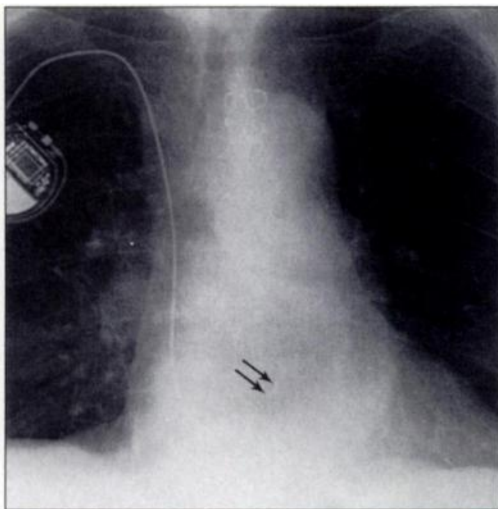


Fig. 19.—Intentional redundancy of lead in child with Ebstein's anomaly. Posteroanterior radiograph after implantation at age 11 years; ventricular lead is redundant to allow for body growth.

Cardiac Transplant Recipients

Because the donor sinoatrial node and conduction system usually function normally, only 2–15% of cardiac transplant recipients require permanent pacing [7]. Sinoatrial node dysfunction is the most common reason for long-term pacing; it can be a result of rejection, ischemia caused by



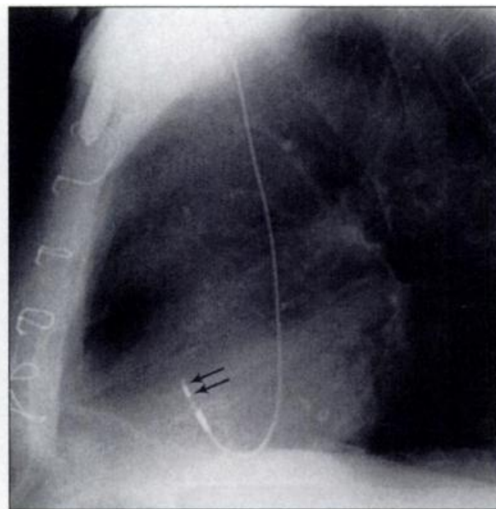
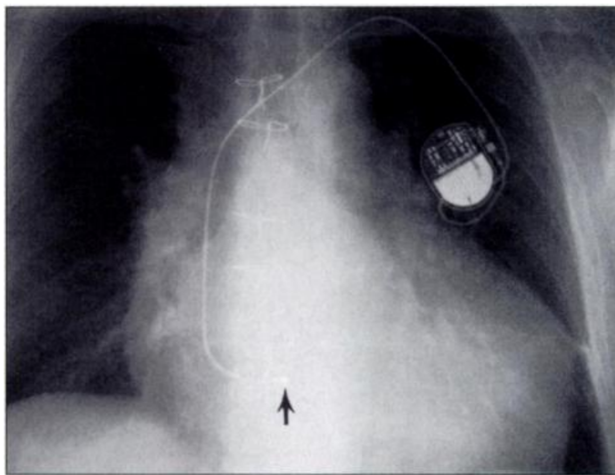


Fig. 20.—Unusual electrode position. Posteroanterior (**A**) and lateral (**B**) radiographs in patient with cardiac transplant. Electrode (*arrows*) must be positioned in donor atrium for impulses to be conducted properly.



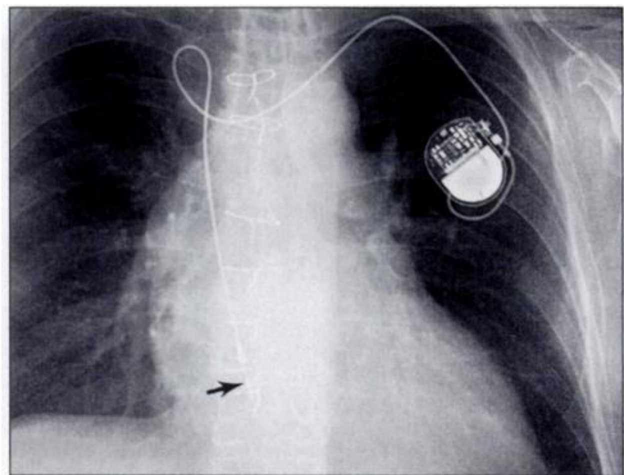


Fig. 21.—Electrode dislodgment caused by endomyocardial biopsy. Cardiac transplant recipient before (**A**) and after (**B**) transvenous cardiac biopsy. Screw-tipped electrode (*arrow*) has been dislodged after biopsy, and lead is coiled in right brachiocephalic vein.

the operation, or aberrant blood supply to the node [7].

A typical pacing system uses atrial leads. Because the native atrium (including the appendage) is isolated electrically from the donor's atrium, the electrode is placed low in the donor's atrium (Fig. 20) or along the interatrial septum.

A transplant recipient may undergo percutaneous endomyocardial biopsy to detect rejection. This carries a risk of electrode dislodgment (Fig. 21).

Conclusion

Pacemaker technology has advanced dramatically over the last decade. Knowledgeable radiologic assessment of the pacemaker and its attendant complications is essential.

Acknowledgments

We would like to acknowledge Eden Palmer in the Department of Medical Media at the Seattle Veterans Affairs Medical Center for her assistance with photography.

References

1. Steiner RM, Tegtmeyer CT. The radiology of cardiac pacemakers. In: Morse D, Steiner RM, Parsonnet V, eds. *A guide to cardiac pacemakers*. Philadelphia: Davis, **1983**:63–91
2. Takasugi JE, Godwin JD, Bardy GH. The implantable pacemaker-cardioverterdefibrillator: radiographic aspects. RadioGraphics **1994**;14:1275–1290
3. Hewitt MJ, Chen JTT, Ravin CE, Gallagher JJ. Coronary sinus atrial pacing: radiographic considerations. *AJR* **1981**;136:323–328
4. Grier D, Cook PG, Hartnell GG. Chest radiographs after permanent pacing. Are they really necessary? *Clin Rad* **1990**:42:244–249
5. Karis JP, Ravin CE. Counterclockwise exit of cardiac pacemaker leads: sign of pulse-generator flip. *Radiology* **1990**;174:711–712
6. Smith CW, Messenger JC, Schaner SP, Renner JW. Cardiac pacemaker electrodes: improved methods of extraction. *Radiology* **1994**;193: 739–742
7. Payne ME, Murray KD, Watson KM, et al. Permanent pacing in heart transplant recipients: underlying causes and long-term results. *J Heart Lung Trans* **1991**;10:738–742