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Chest Radiographic Appearance of Minimally Invasive Cardiac Implants and Support Devices: What the Radiologist Needs to Know

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A B S T R A C T

Minimally invasive implantable cardiac devices used in valve repair and replacement, cardiovascular support, and partial chamber and appendageal occlusion represent a burgeoning area of both bioengineering and clinical innovation. In addition to familiarizing the reader with the radiographic appearance of the most commonly utilized and encountered newer devices, this review will also address the relevant clinical and pathophysiological indications for usage and deployment as well as potentially encountered complications.

Introduction

Minimally invasive implantable cardiac devices used in valve repair and replacement, cardiovascular support, and partial chamber and appendageal occlusion represent a burgeoning area of both bioengineering and clinical innovation. In addition to familiarizing the reader with the radiographic appearance of the most commonly utilized and encountered newer devices, this review will also address the relevant clinical and pathophysiological indications for usage and deployment, as well as potentially encountered complications.

Radiographic Imaging Landmarks for Cardiac Valvular Position and Anatomy

Familiarity with radiographic landmarks of the chest, and particularly the heart, can assist in identifying and reporting cardiovascular support devices present on chest radiographs. By bisecting the cardiac silhouette with an imaginary line drawn perpendicular to the long axis of the heart on the frontal view and parallel to the long axis on the lateral view, a gross estimation of valvular position may be obtained (Figs 1-3). The aortic valve typically projects cephalad to the axis line on both views, appearing in profile on the frontal image and en face on the lateral view. In contrast, the mitral valve projects below the frontal and lateral reference axis line, appearing en face on the frontal view and in profile on the lateral image. The pulmonic valve is typically the most superiorly positioned cardiac valve in both projections, appearing in partial profile on each view. By comparison, the tricuspid valve is positioned most inferiorly on both images, appearing en face on the lateral view.[1-3] When radiographically visible, prosthetic valve leaflets may further assist in valve characterization by identifying regional flow directionality. However, due to physiological variations in cardiac size, axis, and position, as well as variations in radiographic projection, valvular identification based on radiographic position is relatively unreliable and reference to the clinical history should always be made.[2,3]

Transcatheter Valve Implants

Transcatheter Aortic Valve Replacement

Affecting approximately 7% of the population over the age of 65, degenerative aortic stenosis represents the most common restrictive valvular heart disease in the developed world and has an associated 2-year mortality of 50% when severe.[4] Valve replacement constitutes the only efficacious therapeutic option. First performed in 2002, transcatheter aortic valve replacement represents a growing alternative to open surgery in patients who are considered inoperable or at high surgical risk. Recently, multiple clinical trials have supported the expanded validity and efficacy of Transcatheter Aortic Valve Replacement (TAVR) in the intermediate surgical risk patient subset, as well as in more complex cases of failed bioprosthetic valves or bicuspid valvular stenosis.[4,5] Two approved valve models in wide usage with comparable performance metrics are the Medtronic CoreValve Revalving system (Medtronic Inc., Irivine, CA), utilizing a self-expanding nitinol mesh frame supporting a porcine pericardial trileaflet tissue prosthesis, and the Edwards SAPIEN XT and SAPIEN 3 valve replacement system (Edwards Lifesciences, Irivine, CA), constructed of balloon expandable steel mesh supporting an equine pericardial trileaflet valve (Figs 4 and 5). The SAPIEN device may be deployed via a transfemoral, transapical, transaxillary, or transaortic route, whereas the CoreValve construct has more limited deployability via femoral, axillary, or subclavian arterial approaches, offering the option of in situ recapture and repositioning.[4,6] To date, multiple longitudinal studies have demonstrated comparable short term 30-day,

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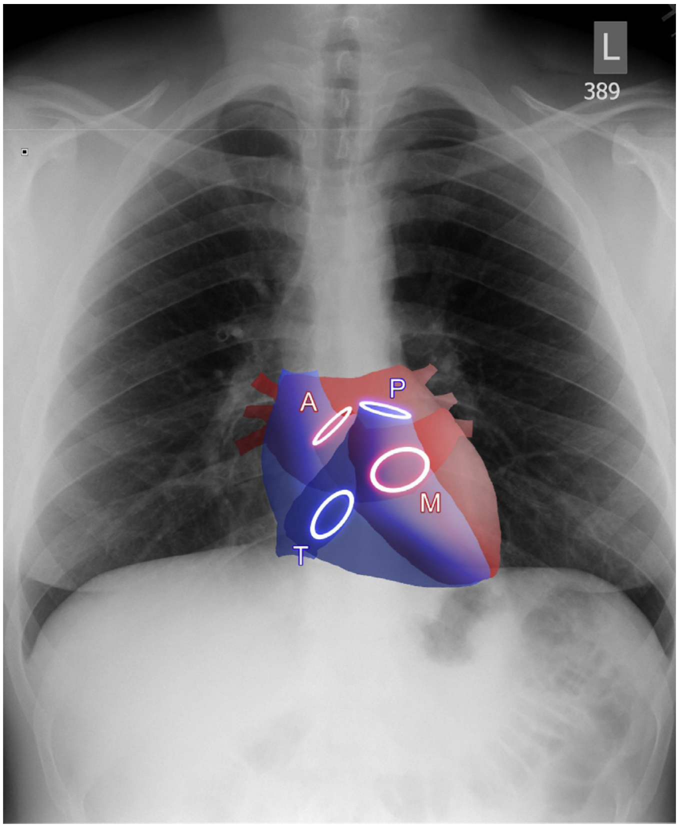

FIG 1. Posteroanterior radiograph of the chest demonstrates the expected valve positions superimposed upon the right and left cardiac chambers, shaded respectively in blue and red. The individual valves are denoted alphabetically, A—aortic valve, P—pulmonary valve, M—mitral valve, and T—tricuspid valve. (Color version of figure is available online.)

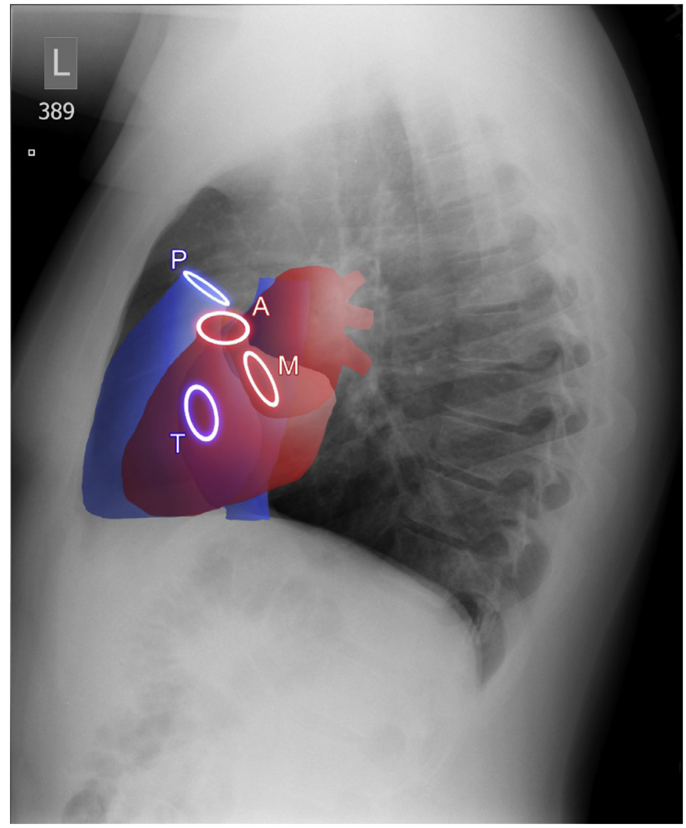

FIG 2. Lateral radiograph of the chest demonstrates the expected valve positions superimposed upon the right and left cardiac chambers, shaded respectively in blue and red. The individual valves are denoted alphabetically, A—aortic valve, P—pulmonary valve, M—mitral valve, and T—tricuspid valve. (Color version of figure is available online.)

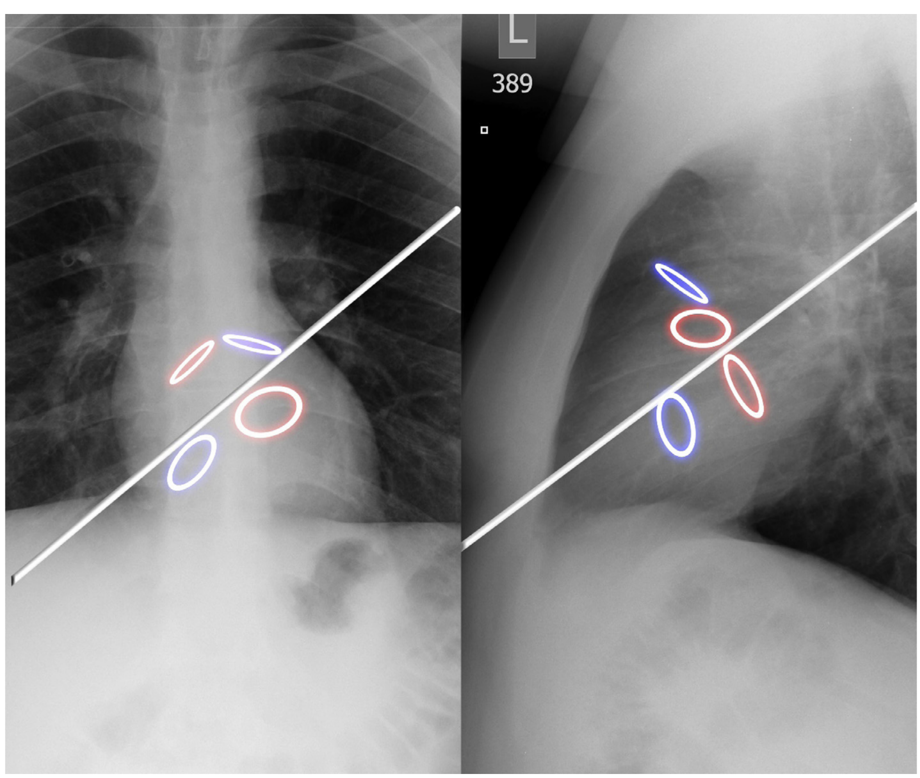

FIG 3. By bisecting the cardiac silhouette with a reference line drawn perpendicular to the long axis on a frontal view and parallel to the long axis on a lateral image, the respective valve positions can be extrapolated. AORTIC VALVE: When compared to the mitral valve, the aortic valve should be above the imaginary line, seen in profile on posteroanterior imaging and en face on lateral imaging. Flow is directed toward the aortic arch. MITRAL VALVE: When compared to the aortic valve, the mitral valve should be below the imaginary line. This is typically viewed en face on posteroanterior imaging and in profile on lateral imaging. Flow is directed toward the cardiac apex. PULMONIC VALVE: The pulmonic valve is typically the most superior of the cardiac valves. Flow is directed superiorly and posteriorly on lateral view. TRICUSPID VALVE: The tricuspid valve is located more anteriorly. It typically appears more en face on lateral view.

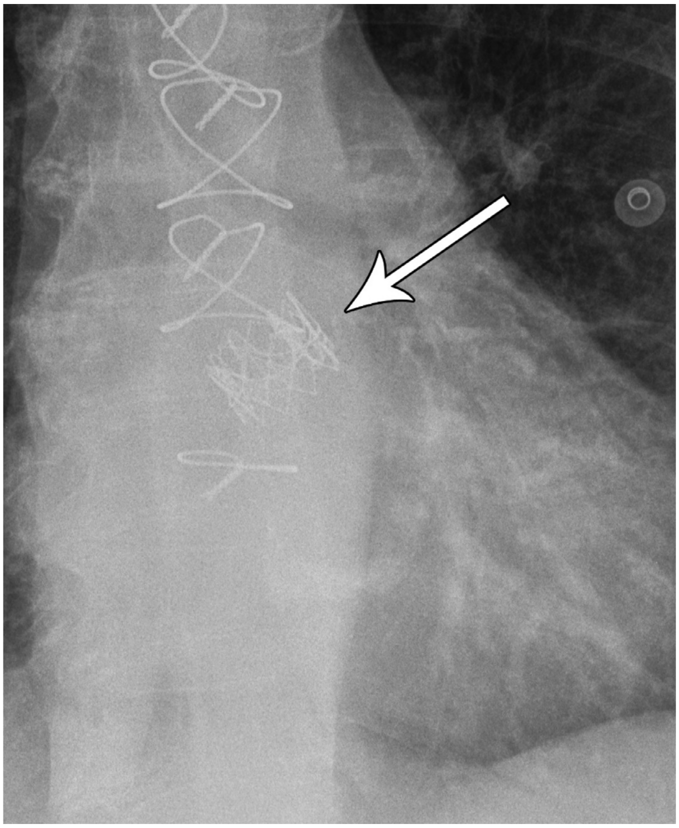

FIG 4. Anteroposterior magnified radiograph of the central cardiac silhouette demonstrates overlying sternal wire sutures and a tubular metallic device at the expected level of the aortic valve corresponding to a transcatheter Edwards Sapien aortic valve replacement (arrow). The valve should be in profile on posteroanterior imaging and more en face on lateral imaging, located just above the "imaginary line" and directed toward the expected location of the aortic root.

1-year and 5-year mortality rates in surgical and transcatheter valve replacement cohorts.[7]

Transcatheter Mitral Valve Repair/Replacement

Mitral regurgitation represents the most common type of valvular insufficiency, and may be either primary due to dysfunction of the intrinsic valve components, or, more commonly, secondary in the setting of ventricular dilation from ischemic cardiomyopathy.[8] Previously, treatment options were limited to open surgical mitral annular repair or valve replacement. Over the past 10 years, 4 percutaneous transcatheter techniques have evolved. The Evalve MitraClip system

FIG 5. A stock image of the Edwards Sapien XT 23 mm valve. (copyright Edwards Lifesciences Corporation, Irvine, CA).

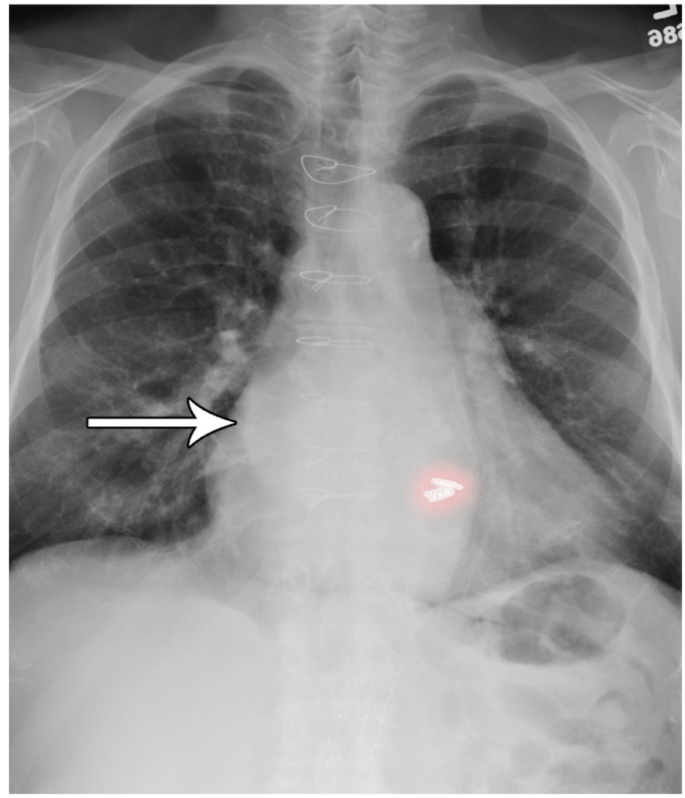

FIG 6. Posteroanterior radiograph demonstrate 2 MitraClips (shaded in red) projecting over the left heart in expected location of mitral valve. Left atrial enlargement (white arrow) is consistent with history of mitral regurgitation. (Color version of figure is available online.)

(Evalve Inc., Menlo Park, CA) utilizes a 4 mm cobalt-chromium clip placed via a trans-septal puncture to bridge and coapt the central aspects of the anterior and posterior mitral leaflets, creating a double orifice inlet valve to the left ventricle[8] (Figs 6-8). Overall complication rates are low with partial clip detachment occurring in 9% of individuals. Comparable 1 year end point results between surgical and transcatheter cohorts in left ventricular dimensions and volume, as well as improvement in New York Heart Association functional class ratings, have been shown in phase II clinical trials.[9]

Mitral annuloplasty, namely the reshaping and tightening of the annular ring surrounding the mitral valve to diminish incompetence due to left ventricular dilation, may be performed with either an open surgical or percutaneous approach. Transcatheter direct annuloplasty involves the implantation of a self-anchoring device directly into the mitral annulus below the valve plane, mimicking surgical annuloplasty. A number of devices are in commercial development with promising initial results.[8,10,11] Indirect annuloplasty involves the placement of a constraining device via the coronary sinus that parallels the posterior mitral valve annulus, creating static overlying tension to diminish the septal-lateral wall annular dimensions. Early models have utilized a proximally and distally anchored nitinol wire intra-sinus system to create positive ventricular remodeling with successful initial deployment in approximately two-thirds of patients with initial reduction of mitral regurgitation by at least one grade.[12,13,14,15]

Transcatheter mitral valve implantation constitutes another emerging percutaneous approach to the treatment of severe mitral insufficiency in high risk surgical patients. Various expandable metallic mesh construct devices similar in design to their aortic counterparts and deployable via a trans-septal or transapical approach are under development[16] (Figs 9-11). Feasibility of deployment has been demonstrated in the setting of pre-existing diseased bioprosthetic valves and annuloplasty rings.[17] The asymmetric, nonradial configuration of the annulus poses a unique challenge to transcatheter mitral

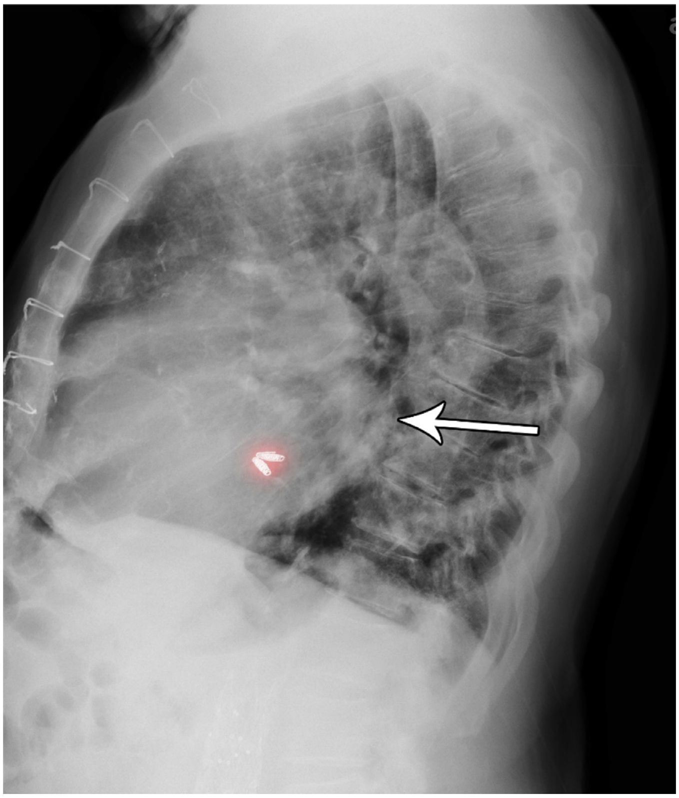

FIG 7. Lateral radiograph of the chest demonstrate 2 MitraClips (red) projecting over the left heart in expected location of mitral valve. Left atrial enlargement (white arrow) is consistent with history of mitral regurgitation. (Color version of figure is available online.)

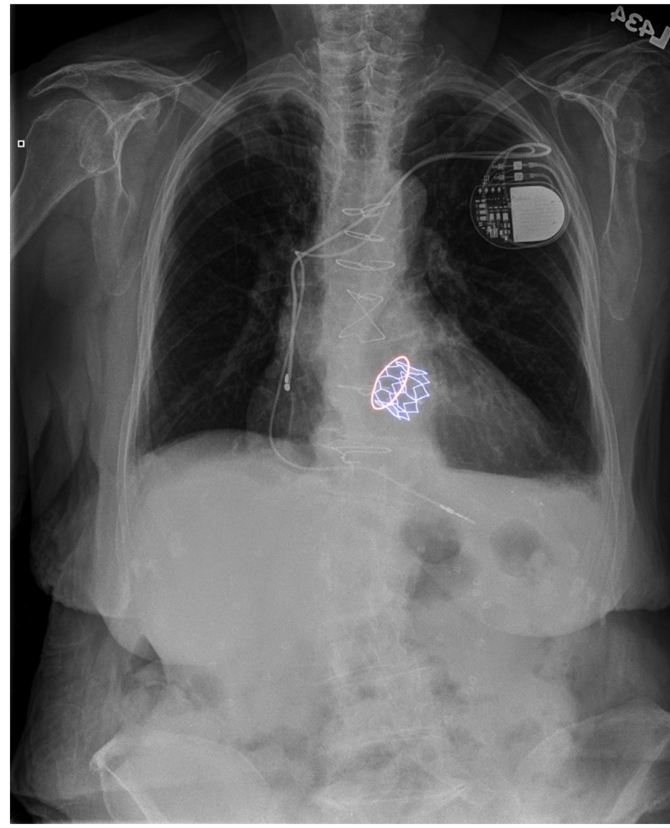

FIG 9. Frontal radiograph of the chest demonstrates a transcatheter mitral valve replacement (TMVR) projecting over failed bioprosthetic valve. Failed bioprosthetic valve is represented by red ring, TMVR represented by blue wire device. (Color version of figure is available online.)

FIG 8. Magnified radiographs of the cardiac silhouette in the frontal and lateral projection demonstrate small, tubular metallic devices projecting below the “invisible line,” in the typical location of the mitral valve. (Color version of figure is available online.)

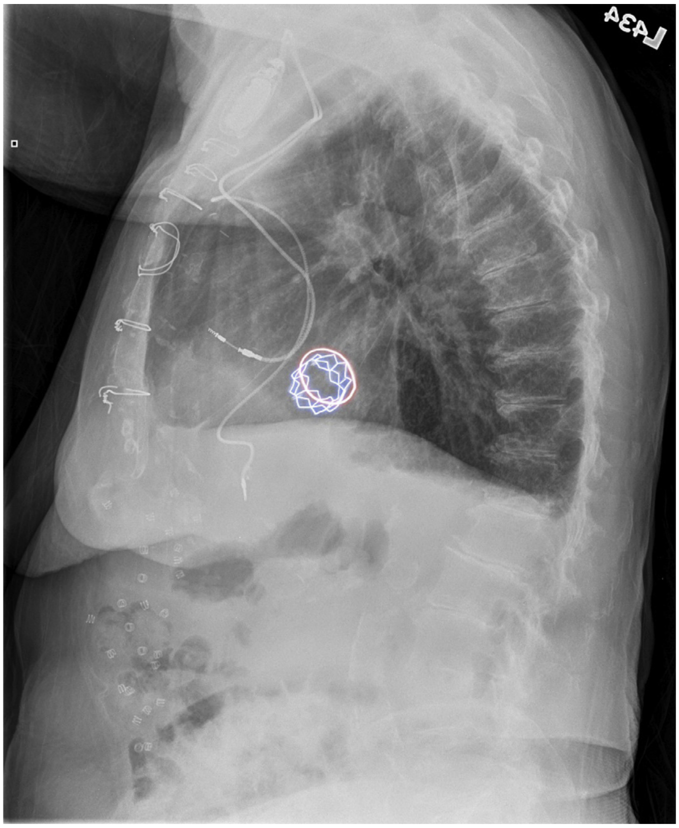

FIG 10. Lateral radiograph shows the transcatheter mitral valve replacement (TMVR) projecting over failed bioprosthetic valve. Failed bioprosthetic valve is represented by red ring, TMVR represented by blue wire device. (Color version of figure is available online.)

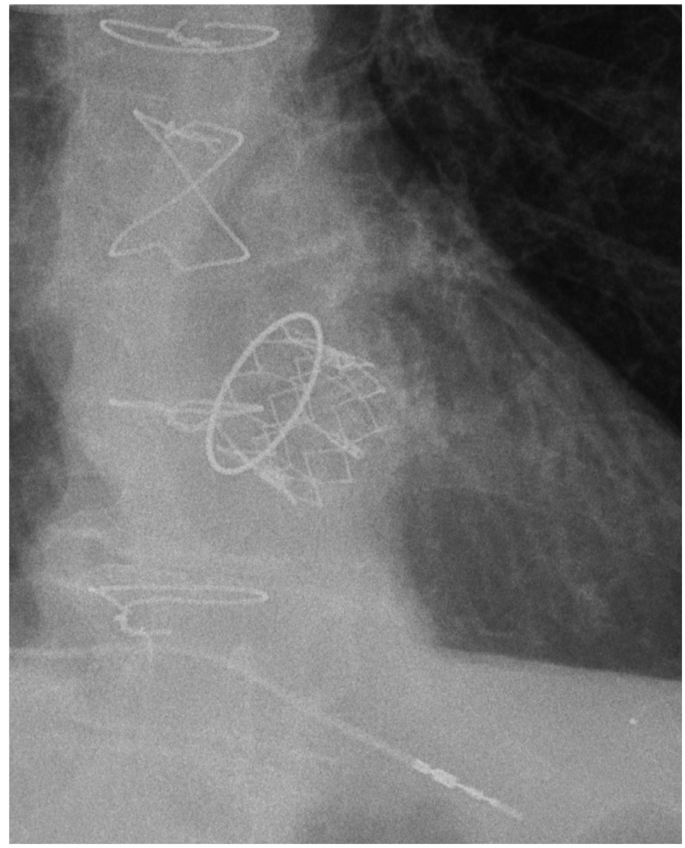

FIG 11. Magnified frontal radiographic image of the transcatheter mitral valve replacement (TMVR) demonstrates a metallic frame with angular geometry reflecting a transcatheter expandable valve construct. The valve is located just below the central reference line bisecting the cardiac silhouette on both frontal and lateral views corresponding to mitral positioning.

annular repair, potentially hindering the valve system anchorage and increasing the propensity for migration, paravalvular leaks, and left ventricular outflow tract obstruction.[18]

Caval Valve Implantation

Though less frequent than aortic or mitral insufficiency, moderate to severe tricuspid regurgitation affects an estimated 1.6 million people in the United States alone. Surgical repair risk is potentiated due to frequent hepatic and renal comorbidity.[19] Percutaneous valve implantation typically has been performed following failed surgical replacement. Due to the frequently capacious and often noncalcified nature of the native annulus, transcatheter valve sealing and anchoring is potentially problematic.[20] Intra-caval implantation of a unidirectional valve such as the Edwards Sapien valve system upstream of the right atrial inferior vena cava junction or potentially at both the superior and inferior vena caval atrial junctions represents an emerging therapeutic option[21] (Figs 12-14).

Minimally Invasive Occlusion Devices

Left Atrial Appendage Occlusion Device (Watchman)

Recurrent paroxysmal or persistent atrial fibrillation carries a 5% associated annual risk of stroke, typically embolic in nature and arising from thrombi that develop within stagnant blood within the left atrial appendage.[22] Though traditional treatment has centered on the use of antiplatelet and vitamin K antagonist-based anticoagulant therapy, a growing series of clinical trials and meta-analyses focusing on the Watchman device (Boston Scientific Corporation, Marlborough, MD) have supported the use of mechanical left atrial appendage exclusion in patients at risk for anticoagulation.[23] The Watchman, a nitinol umbrella-shaped device with a fibrinogenic polyethyl terephthalate cap, is placed in the left atrial appendage via a trans-septal puncture (Figs 15-17). Endothelialization occurs over 3-6 months and bridge antithrombotic therapy is recommended in the interval. Complete closure of the appendage with initial device deployment is achieved in approximately 80% of patients.[23] Gated cardiac contrast enhanced imaging has proven utility in assessing size and morphology of the left atrial appendage prior to device implantation as well as in the post procedural evaluation for migration, endothelialization, or peridevice leakage.[24]

Left Atrial Appendage Ligation (AtriClip)

In patients undergoing open cardiac procedures, the AtriClip LAA Occlusion System (AtriCure Inc, West Chester, OH) is a widely used and proven epicardial based occluder consisting of a self-closing nitinol clip with polyester covering[25] (Figs 18-20). Current outcome trials are focusing on clip usage as a stand-alone surgical alternative therapy with deployment via minimally invasive mediastinoscopy.[22]

Transcaval Access Occlusion Device

In patients with poor aortic vascular access due to advanced distal steno-occlusive vascular disease, transcaval access represents a viable alternative for percutaneous endovascular approach to the left cardiac region and proximal aorta, most commonly for transcatheter aortic valve replacement.[26] Access is achieved by transcaval puncture targeting a loop snare positioned in the aorta at a preselected,

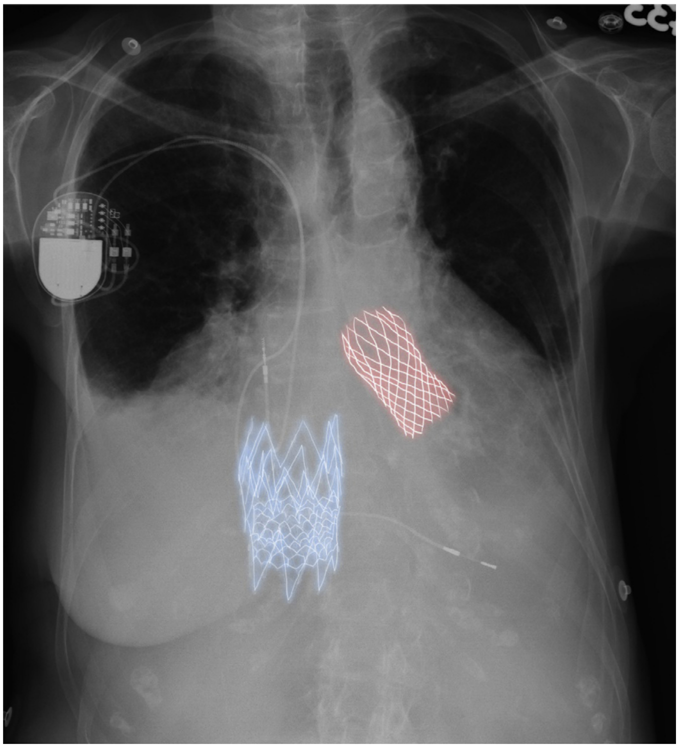

FIG 12. Posteroanterior radiograph of a patient who underwent placement of inferior vena caval valve implantation (CAVI) with IVC stent landing zone for severe tricuspid regurgitation. Transcatheter aortic valve replacement (TAVR) with Medtronic Corevalve (Medtronic, Dublin, IRL) was placed previously for severe aortic valve stenosis. The TAVR is superior and anterior (red), CAVI and IVC stent are inferior and posterior (blue). (Color version of figure is available online.)

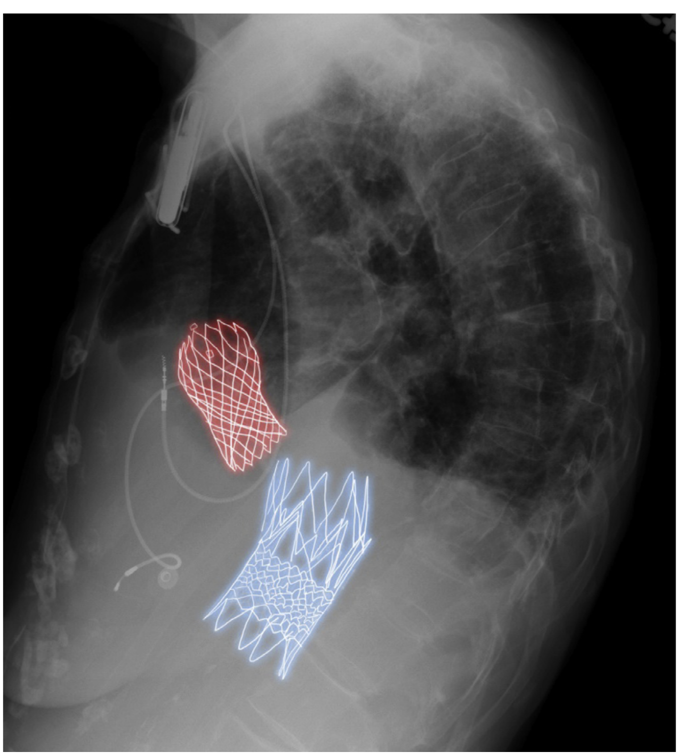

FIG 13. Lateral radiograph of same patient demonstrates the TAVR to be superior and anterior (red) with the CAVI and IVC stent inferior and posterior in position (blue). (Color version of figure is available online.)

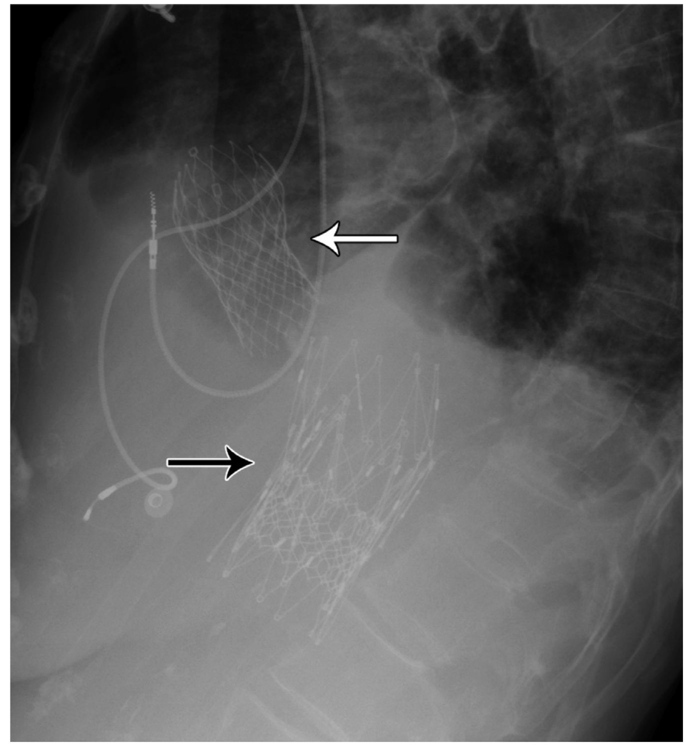

FIG 14. Magnified lateral image demonstrates overlapping wire structures reflecting CAVI within an IVC stent, projecting posterior and inferior to cardiac silhouette (black arrow), with more anterosuperior TAVR noted (white arrow).

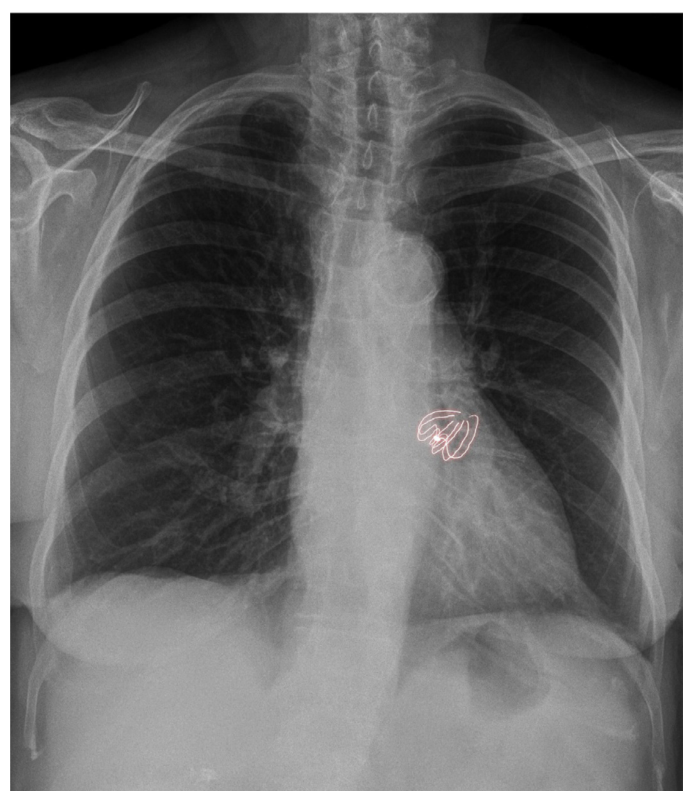

FIG 15. Anteroposterior radiograph of the chest demonstrates a Watchman left atrial occlusion device outlined in red corresponding to the expected location of the left atrial appendage. (Color version of figure is available online.)

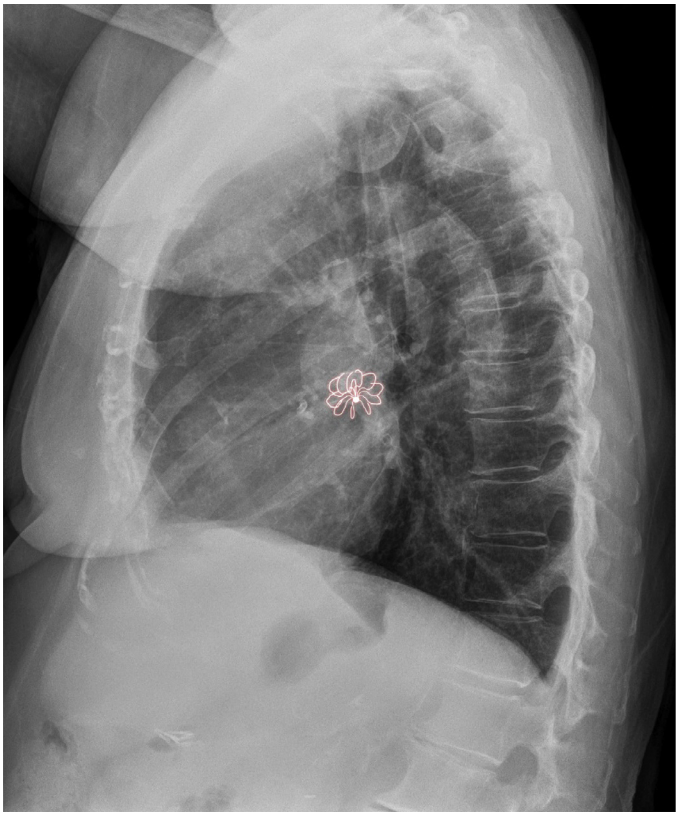

FIG 16. Lateral chest radiograph demonstrates an in situ Watchman occluder device outlined in red within the left atrial appendage region. (Color version of figure is available online.)

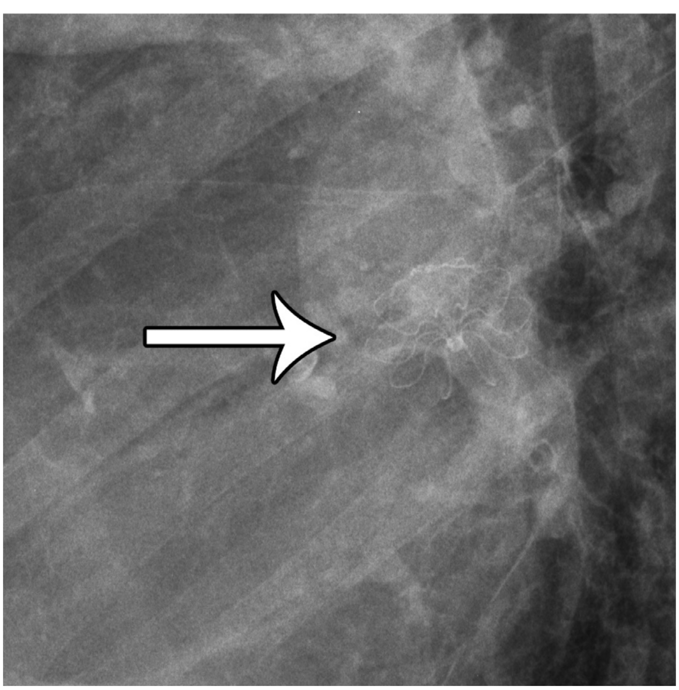

FIG 17. Magnified lateral radiograph demonstrates an in situ Watchman device at the level of the left atrial appendage (white arrow). As the metallic frame and anchors are thin, visualization may be difficult, particularly on anterior view. In such cases the central knob may be the only component visualized.

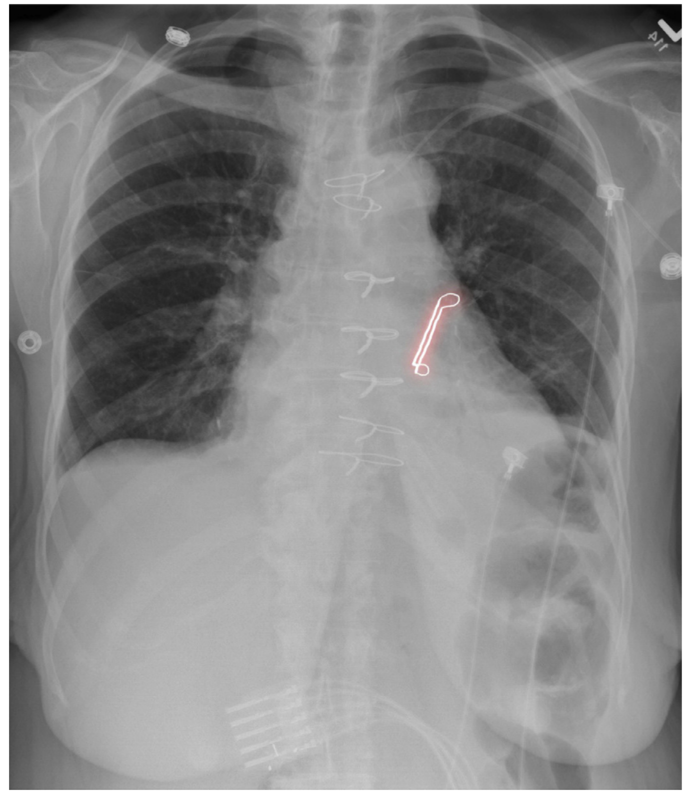

FIG 18. Posteroanterior radiograph of the chest demonstrates an AtriClip device (red) projecting over the left heart corresponding to the expected location of the left atrial appendage. (AtriCure, Mason, OH). (Color version of figure is available online.)

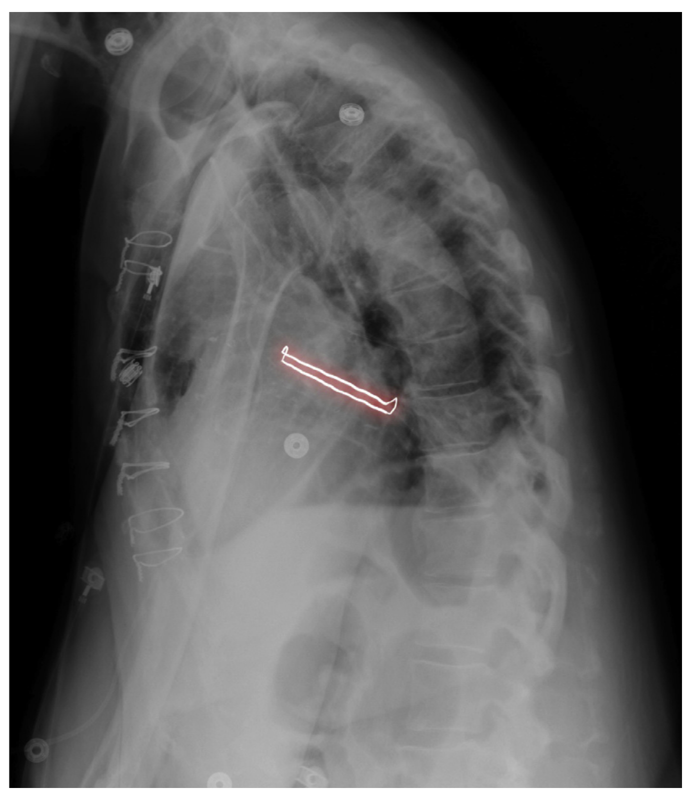

FIG 19. Lateral radiograph of the chest demonstrates an AtriClip device (red) projecting over the left heart corresponding to the expected location of the left atrial appendage. (AtriCure, Mason, OH). (Color version of figure is available online.)

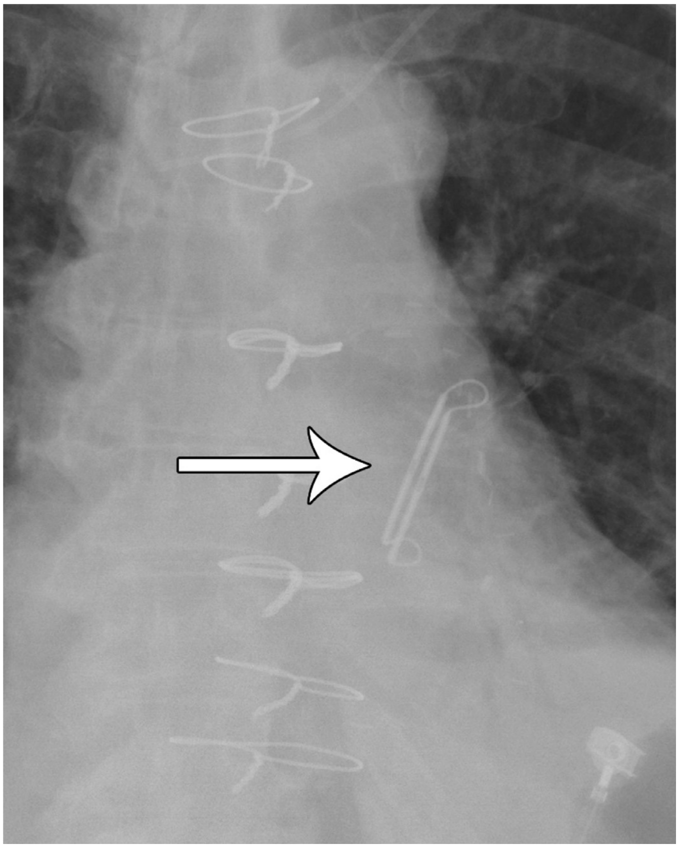

FIG 20. Magnifed frontal view of the central cardiac silhouette demonstrates a metallic linear construct corresponding to an AtriClip device projecting over the left heart in the expected location of the left atrial appendage ostium. The 2 parallel metallic bars reflect approximation of opposing clip surfaces after closure (white arrow).

typically infrarenal atheromatous-free level. After final device deployment, periprocedural heparin anticoagulation is reversed and a nitinol cardiac occluder, typically Amplatzer Duct Occluder or Ventricular Septal Defect Occluder (St. Jude Medical, St. Paul, MN) is used to close the aorto-caval port.[27] In a recent published case series detailing experience with 99 patients, major, life-threatening transcaval hemorrhage occurred in 12 of 99 cases and covered aortic stent bailout deployment was necessitated in 8 patients. Successful aorto-caval fistula closure was documented in nearly 75% of patients at 30 day follow-up angiography.[27] By comparison, rates of life-threatening periprocedural hemorrhage at time of direct transthoracic and transfemoral TAVR are 22.6% and 6.7% respectively.[28] Though typically placed at an infra-renal mid lumbar level, occluder devices may be discernible on postprocedural chest radiographs with sufficient upper abdominal coverage as small tubular radio-opaque foci overlying the mid lumbar level (Figs 21 and 22). Both Amplatzer Duct and Septal Occluders are variations on shape-memory, self-expanding devices consisting of nitinol wire mesh with a central waist and 2 opposing polyester imbued retention disks.[29,30]

Transapical Access Occlusion Device

Transapical access through the left ventricle myocardium represents a viable option for transcatheter aortic or mitral valve replacement and other structural heart procedures in patients with severe aortic and peripheral vascular disease. Initially, access followed a left anterolateral mini-thoracotomy, though increasingly, direct percutaneous access has been employed with lower profile delivery systems.[30] For occlusion of the access site following device deployment, Amplatzer muscular septal or ductal occluder devices or vascular plugs have been utilized, though a variety of other emerging devices are at various stages of testing and development[31,32] (Figs 23-25). Currently transapical access accounts for approximately 20% of overall TAVRs performed annually. Overall up to twofold increased mortality rates have been noted in meta-analyses of transapical outcome

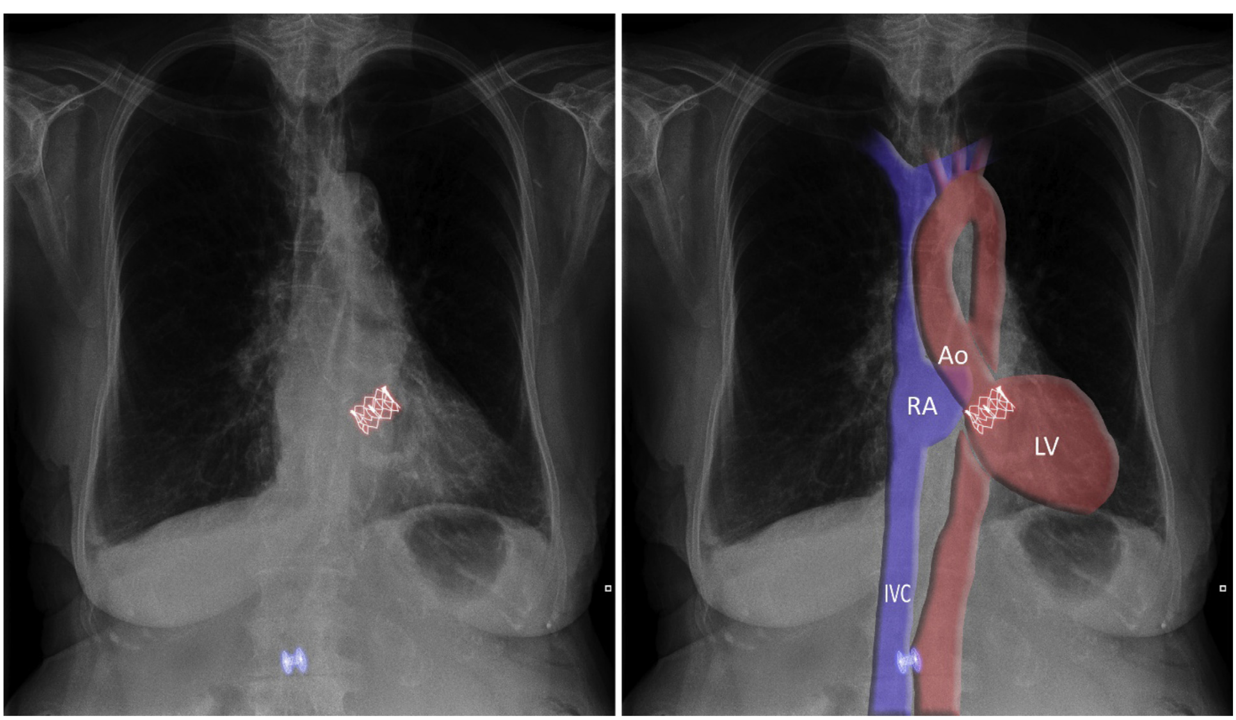

FIG 21. A caval occlusion device is seen outlined in blue at the site of transcaval puncture into the aorta. Proximally, a deployed TAVR is seen outlined in red. A schematic outlining approximate routes of the aorta and vena cava is also provided (Ao—aorta, LV—left ventricle, RA—right atrium, IVC—inferior vena cava). The site of caval-aortic access is typically infrarenal, limiting probability that the occlusion device will be seen on chest radiograph. However, higher access (as in this case) may be attempted depending on extent of calcified aortic plaque. (Color version of figure is available online.)

FIG 22. A stock image of an Amplatzer ventricular septal defect (VSD) occluder, as used for transcaval closure (copyright St. Jude Medical, Saint Paul, MN).

compared to transfemoral traditional valve access procedures, with greater than 15-fold rise in post procedural cardiac troponin levels identified as an independent risk predictor. The data significance, however, is in general mitigated by the range, extent, and severity of varying comorbidities in the transapical patient cohort.[33]

Ventricular Septal Occlusion Device

Among the most common congenital cardiac malformations, ventricular septal defects account for approximately 20% of all developmental deformities, with over 70% located in the region of the membranous septum.[34] Though surgical closure has been the historical gold standard of treatment, associated complications are not insubstantial with complications due to residual leakage occurring in up to 2% of patients and iatrogenic atrioventricular block occurring in up to 8% of cases.[35] Percutaneous closure of membranous defects in particular was initially stymied due to geometric limitations given the proximity to the adjacent valve plane and concomitant issues with residual shunting and poor device sealage. In this regard, the Amplatzer membranous occluder was designed with partially asymmetric disk morphology to better allow for flush deployment along the septal surface, in contrast to the uniform rounded symmetry of the muscular occluders and vascular plug constructs[36] (Figs 26 and 27). Recent modifications have included thinner nitinol wire mesh, decreasing rigidity, and improving pliability, as well as redesigned deliberate concavity of the left ventricular surface cup, allowing for improved retention and stability. Meta-analyses have shown mean successful rates of closure of 97%-98.5%.[37] Complications include device embolization, transient hemolysis, aortic regurgitation and conduction disturbances. Complete heart block necessitating permanent pacer placement occurs on average in 2.6% of cases and is greatest in perimembranous defect closure.[37]

In addition to the repair of congenital muscular and membranous septal defects, percutaneous closure plays a growing role in the treatment of acquired defects following trans-septal myocardial infarction, a patient cohort in whom open repair carries associated mortality rates of up to 90% due to often severe coexistent cardiac compromise and high rates of cardiogenic shock with multiorgan system compromise.[38] Mortality rates for emergent percutaneous repair in the first week following infarction remain quite high on average, up to 60%,

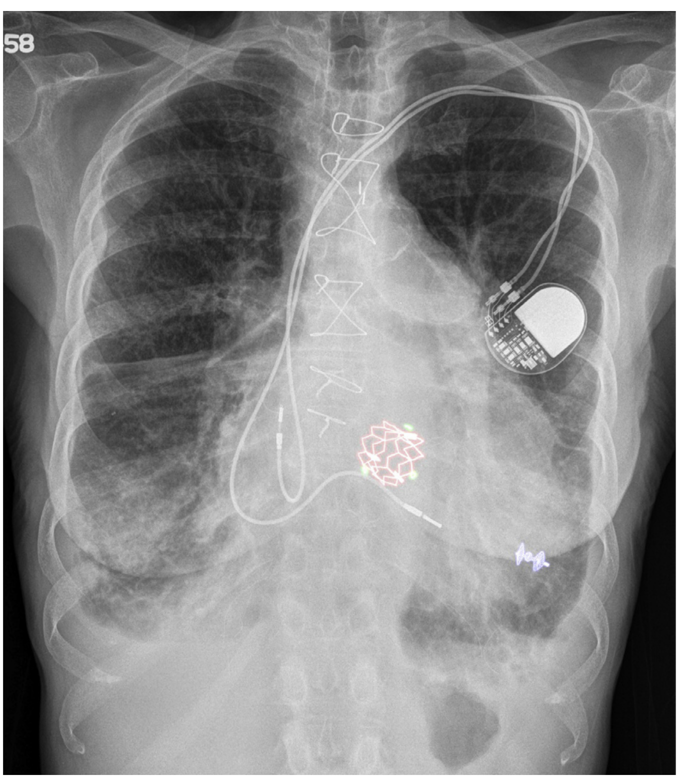

FIG 23. Posteroanterior radiograph of the chest shows a transcatheter mitral valve replacement (TMVR) (red) and a transapical occlusion device (blue). A previously placed mitral valve prosthesis is demonstrated by green dots at the mitral valve replacement. Patient had undergone surgical bioprosthetic mitral and aortic valve placement 15 years prior, followed by a transapical/transeptal mitral valve-in-valve replacement for recurrent severe mitral regurgitation. (Color version of figure is available online.)

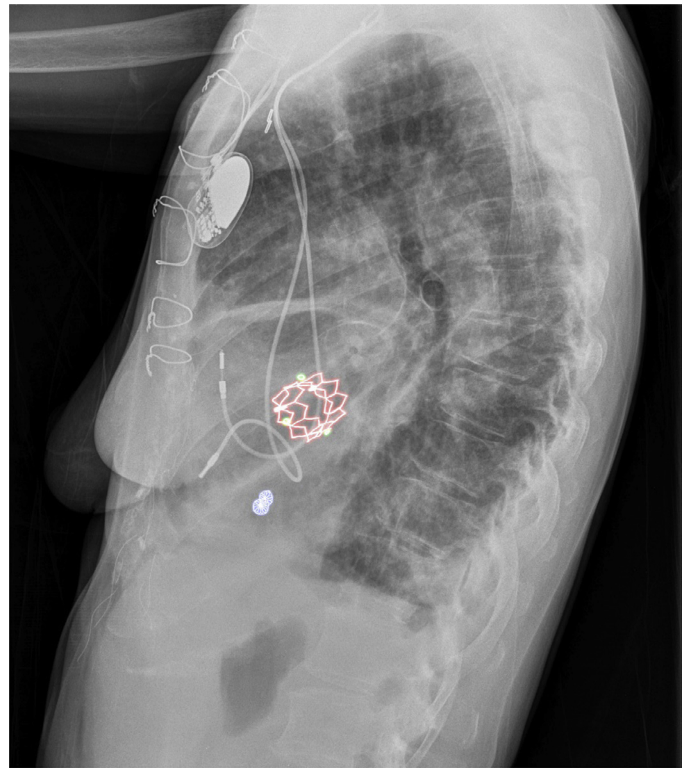

FIG 24. Lateral radiograph of the chest shows a transcatheter mitral valve replacement (TMVR) (red) and a transapical occlusion device (blue). A previously placed mitral valve prosthesis is demonstrated by green dots at the mitral valve replacement. Patient had undergone surgical bioprosthetic mitral and aortic valve placement 15 years prior, followed by a transapical/transeptal mitral valve-in-valve replacement for recurrent severe mitral regurgitation. (Color version of figure is available online.)

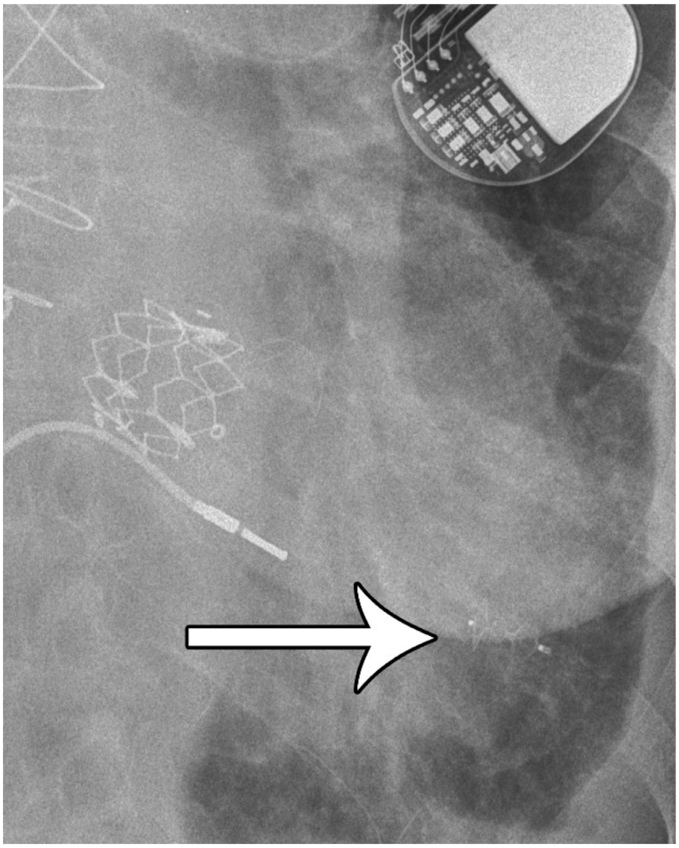

FIG 25. A frontal magnified image of the cardiac silhouette demonstrates a small trans-apical occlusion device projecting over the cardiac apex (white arrow). The concomitant presence of a transcatheter valve replacement provides supporting evidence of its etiology.

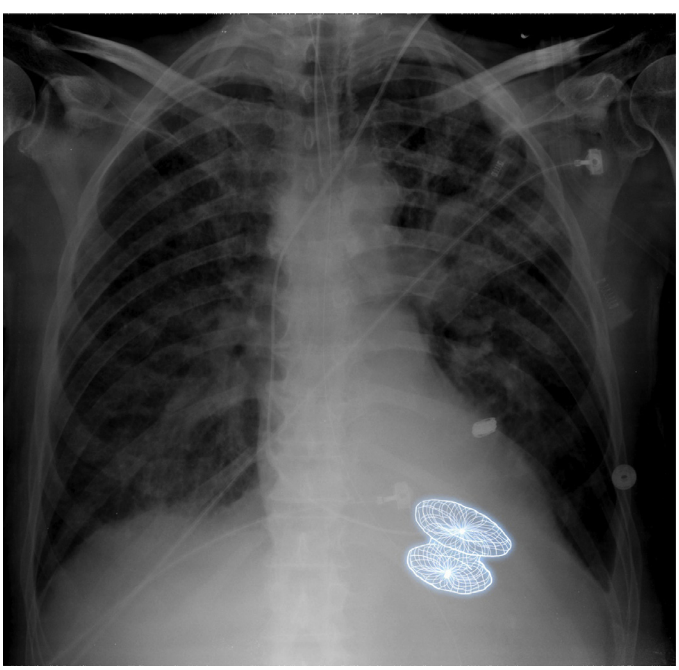

FIG 26. Anteroposterior radiograph of the chest reveals 34 mm Amplatzer VSD occluder device (blue) following deployment (St. Jude Medical, Saint Paul, MN). Patient had developed a postinfarction mid-septal ventricular septal defect (VSD) with left to right shunt and severe pulmonary hypertension. (Color version of figure is available online.)

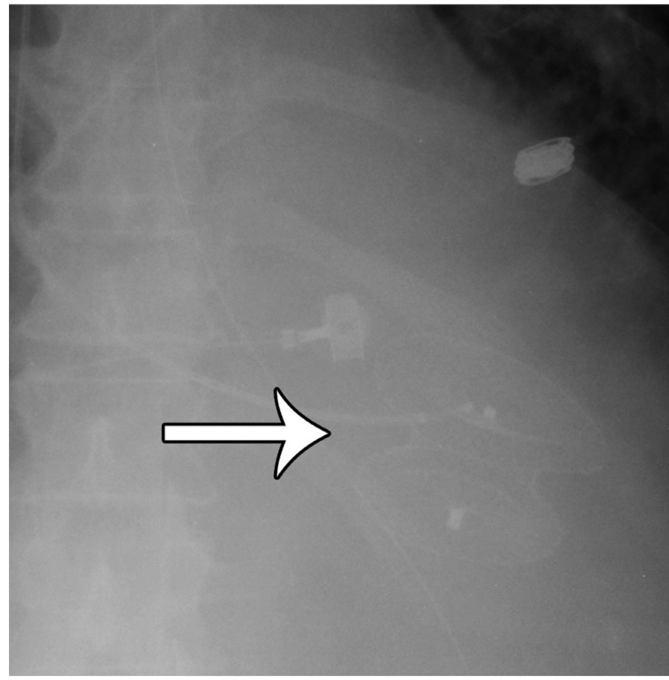

FIG 27. Magnified frontal image of the cardiac silhouette demonstrates ventricular septal occluder device projecting close to the cardiac apex (white arrow) in contradistinction to an atrial septal defect (ASD) or patent foramen ovale (PFO) occluder device.

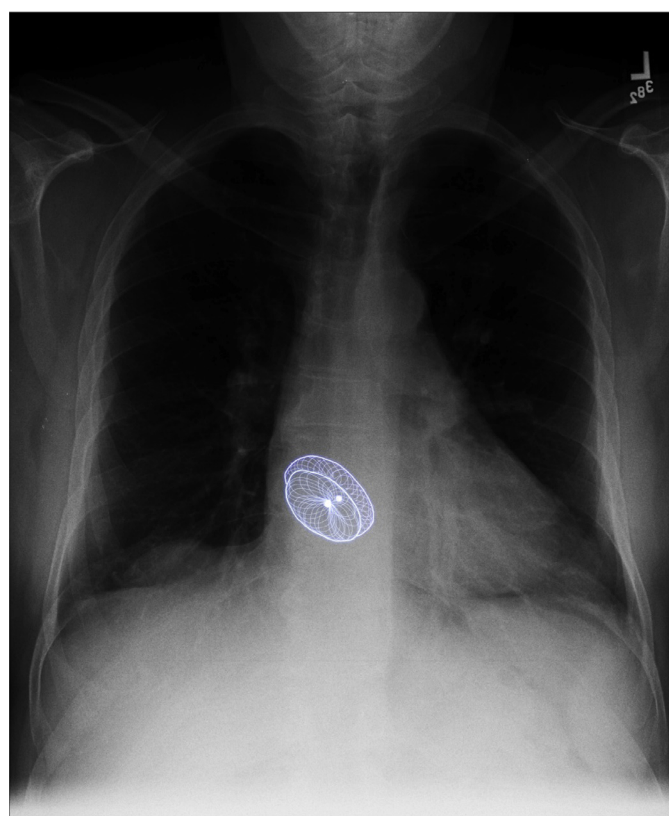

FIG 28. Posteroanterior radiograph demonstrates an ASD occluder (blue) projecting over the base of the heart. Patient had undergone placement of Amplatzer septal occluder (St. Jude Medical, Saint Paul, MN) for a large atrial septal defect. (Color version of figure is available online.)

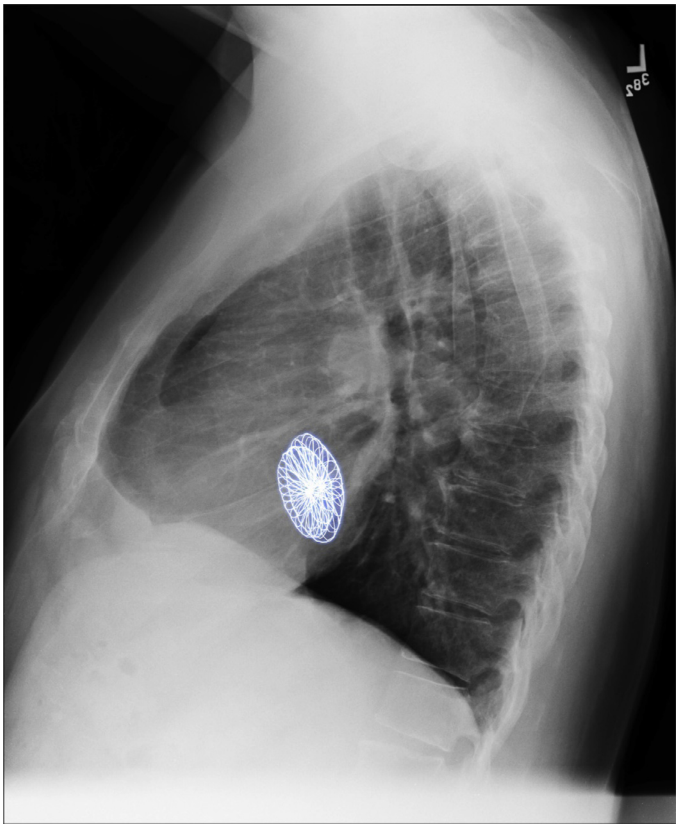

FIG 29. Lateral radiograph demonstrates an ASD occluder (blue) projecting over the base of the heart. Patient had underwent placement of Amplatzer septal occluder (St. Jude Medical, Saint Paul, MN) for a large atrial septal defect. (Color version of figure is available online.)

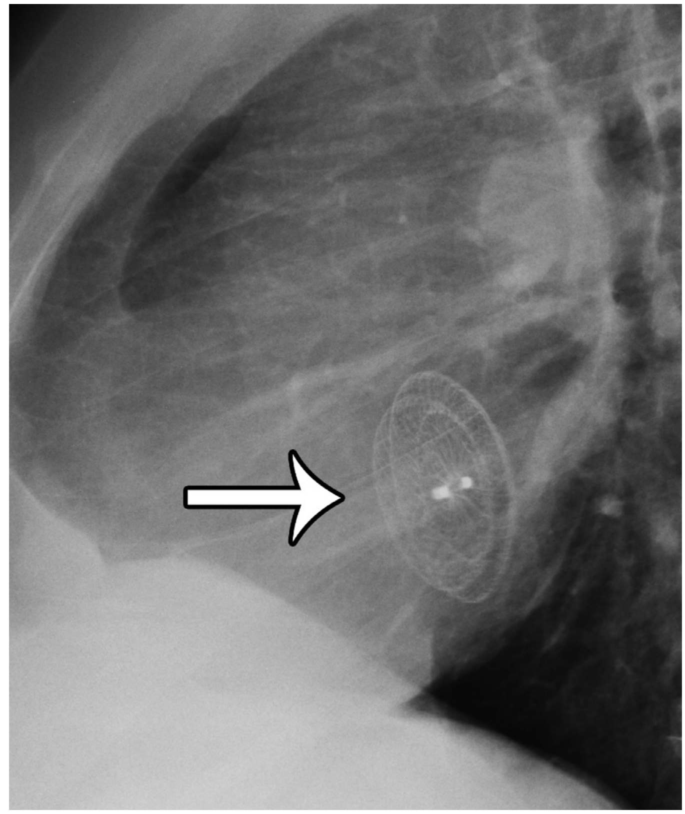

FIG 30. Magnified lateral view demonstrates an Amplatzer septal occluder projecting centrally at the level of the interatrial septum (white arrow). The occlusion device is typically larger than a patent foramen ovale (PFO) occluder and projects closer to the cardiac base in comparison to a ventricular septal defect (VSD) occluder device.

though improved from surgical series. Mortality rates drop precipitously to approximately 30% in those patients able to undergo elective repair at least 15 days postinfarct.[39]

Atrial Septal Defect and Transseptal Access Occlusion Device

Accounting for approximately 7% of all congenital heart disease, atrial septal defects (ASD) are commonly discovered in both the pediatric and adult population and, similar to all left-right shunts, can lead to right-sided cardiac failure, arrhythmias, and pulmonary hypertension if untreated.[40] When feasible, transcatheter ASD closure, most commonly performed with the Amplatzer septal occluder (St. Jude Medical, St. Paul, MN), has become the treatment of choice[30] (Figs 28-30). Defects occur in one of 4 potential locations, most commonly as an ostium secundum defect at the level of the fossa ovalis. Secondary types include ostium primum, sinus venosus, and coronary sinus defects, the majority of which typically undergo surgical repair with the anecdotal exception of coronary sinus defects.[30] Repair of defects measuring up to 38 mm may be achievable, though larger lesions pose technical challenges and carry heightened rates of periprocedural complications, in particular delayed adjacent cardiac erosion due to mechanical device impingement.[30,41] In the adult population, especially those with left ventricular coexistent diastolic dysfunction, ASD closure is associated with variably increased rates of periprocedural congestive heart failure due to increased preload following shunt closure.[42] In those patients with coexistent atrial fibrillation, catheter ablation has shown proven utility, with device deployment typically performed 3 months after durable sinus rhythm is established.[30]

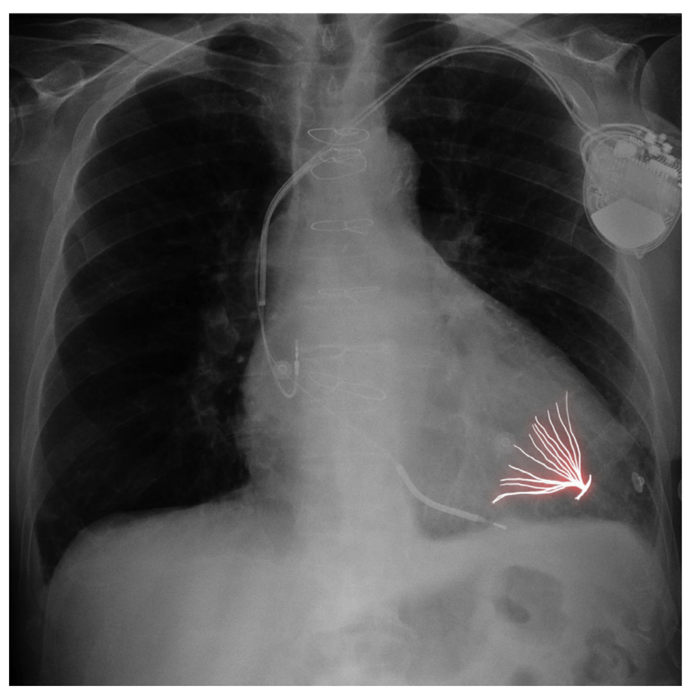

FIG 31. Anteroposterior radiograph of the chest shows parachute device (red) projecting over the left ventricle, with radiopaque "foot" directed toward the cardiac apex. Patient underwent placement of left ventricular partitioning device for ischemic cardiomyopathy. (Color version of figure is available online.)

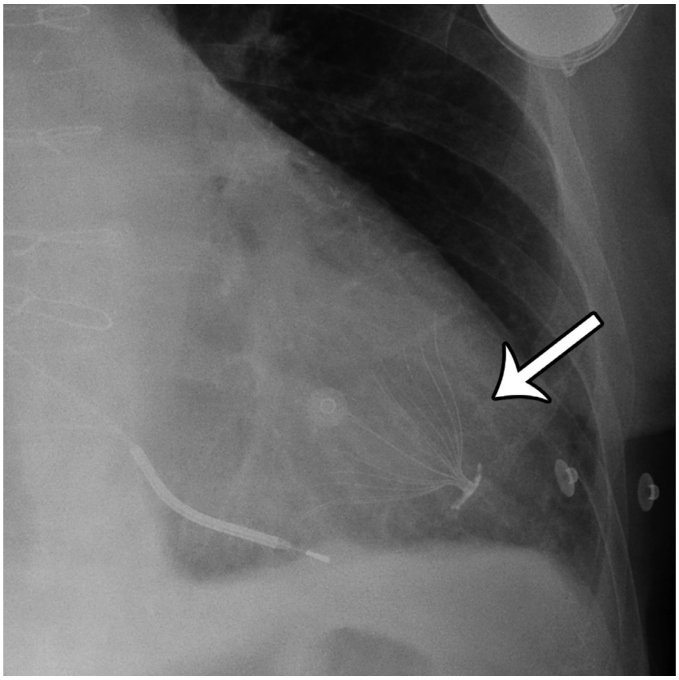

FIG 32. Frontal magnified radiograph of the left ventricular apex demonstrates a parachute device in situ (white arrow). The radiopaque foot is directed toward the cardiac apex while the radiopaque frame radiates toward the cardiac base, roughly approximating the intraluminal contour of the left ventricle.

Left Ventricular Partitioning Device (Parachute)

In patients with cardiac failure and severely reduced left ventricular ejection fraction due to aneurysmal dilation of the left ventricular apex following transmyocardial infarction, a percutaneously placed ventricular partition device, known as the Parachute device (CardioKinetic Inc, Menlo Park, CA), has shown utility in improving cardiac hemodynamics and functional status.[43] Designed like an inverted umbrella, consisting of a nitinol frame with fabric overlay, the device rests in the cardiac apex, creating a static distal subchamber within the left ventricle (Figs 31-33). Exclusion of the noncontractile portion of the myocardium results in volume and pressure unloading of the left ventricle and improved contractile efficiency with up to 38% increase in ejection fraction.[43,44] Successful initial deployment is achieved in up to 87% of patients with pooled major and minor complication rates from meta-analysis data of 9% on average, including puncture site hematoma, aortic and mitral valve damage, dislodgement, and arrhythmia.[43,45,46]

FIG 33. A stock image of the PARACHUTE implant, as placed in the preceding patient (copyright Cardiokinetix, Menlo Park, CA).

Minimally Invasive Cardiac Support Devices

Implantable Pulmonary Artery Pressure Sensor (CardioMEMS)

Implanted within the main pulmonary artery endothelium at the time of right heart catheterization, the CardioMEMS heart sensor (St. Jude Medical, Sylmar, CA) is a wireless radiofrequency pressure sensor that is electromagnetically coupled with an external antenna, which can be positioned at the body surface[47] (Figs 34-37). In the recent multicenter prospective CHAMPION trial, the CardioMEMS sensor showed proven utility in reducing hospitalizations for heart failure exacerbations by guiding the adjustment of medications based on pulmonary pressure monitoring compared with medical management based on clinical signs and symptoms alone.[47,48]

Implantable Loop Recorder

A small subcutaneous device for continuous electrocardiographic monitoring, the implantable loop recorder has proven useful in a variety of clinical scenarios, including in the diagnosis of syncope of indeterminate etiology, in episodic symptomatic palpitations, in the detection of transient, or occult atrial fibrillation, and in the work up of cryptogenic stroke.[49] Loop recorders are subcutaneously implanted in the left parasternal region under local anesthesia and can record events by 2 methods—manual activation in case of perceived symptomatology and automatic triggering when arrhythmias satisfy

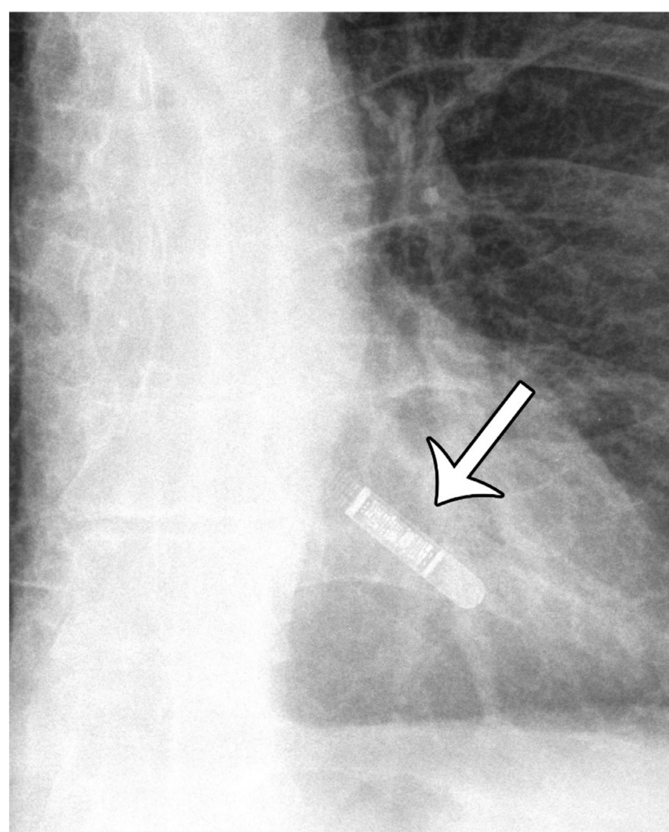

FIG 34. A frontal magnified projection of the central cardiac silhouette demonstrates a tubular electronic device corresponding to an implantable loop recorder (white arrow) projecting over the heart.

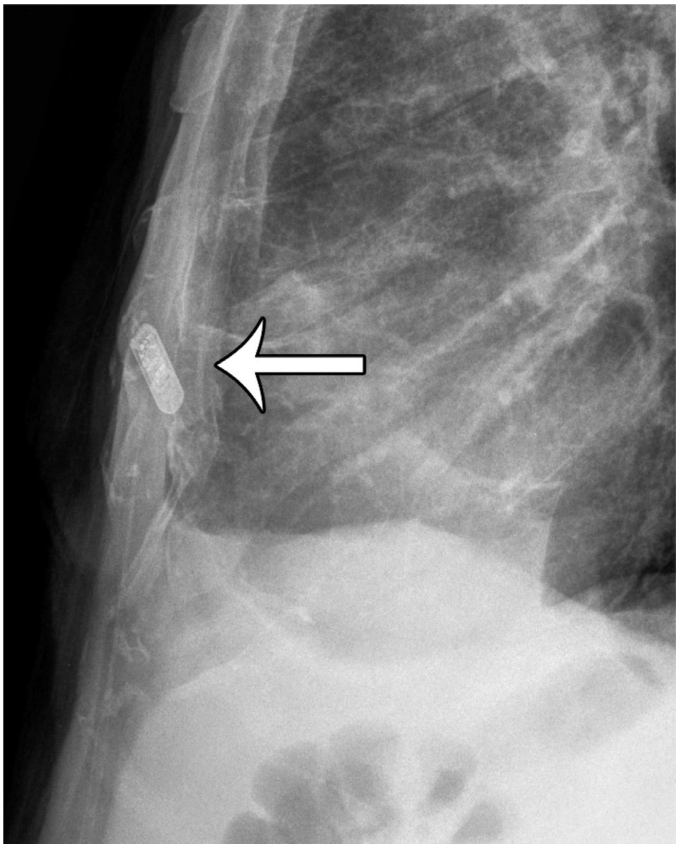

FIG 35. A lateral magnified projection of the central cardiac silhouette demonstrates the implantable loop recorder (white arrow) to be within the anterior chest wall.

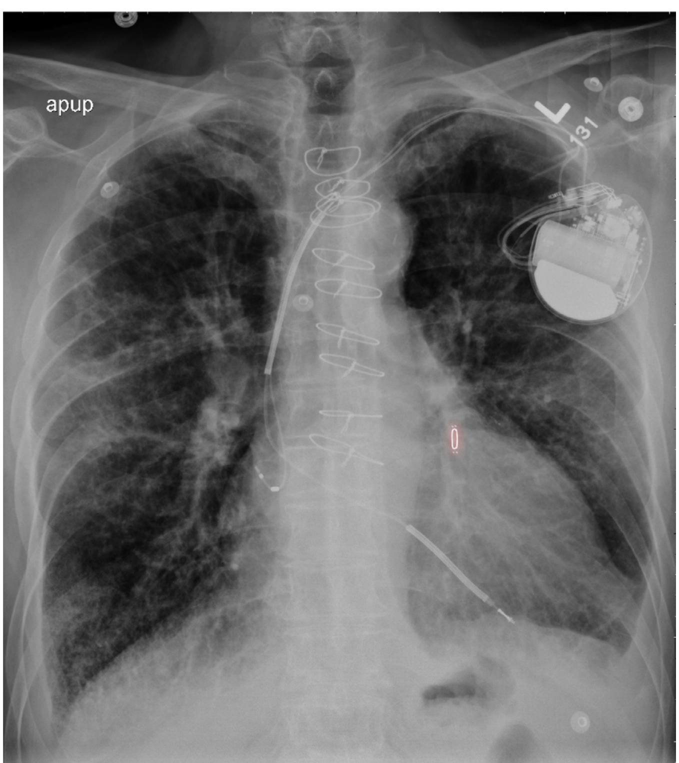

FIG 36. Posteroanterior radiograph shows small CardioMEMS device (red) projecting inferior to the left hilum, in expected location of left pulmonary artery. Patient had a history of ischemic cardiomyopathy and occluded coronary artery bypass grafts. (Color version of figure is available online.)

FIG 37. Lateral radiograph shows small CardioMEMS device (red) projecting posterior to the left hilum, in expected location of left pulmonary artery. (Color version of figure is available online.)

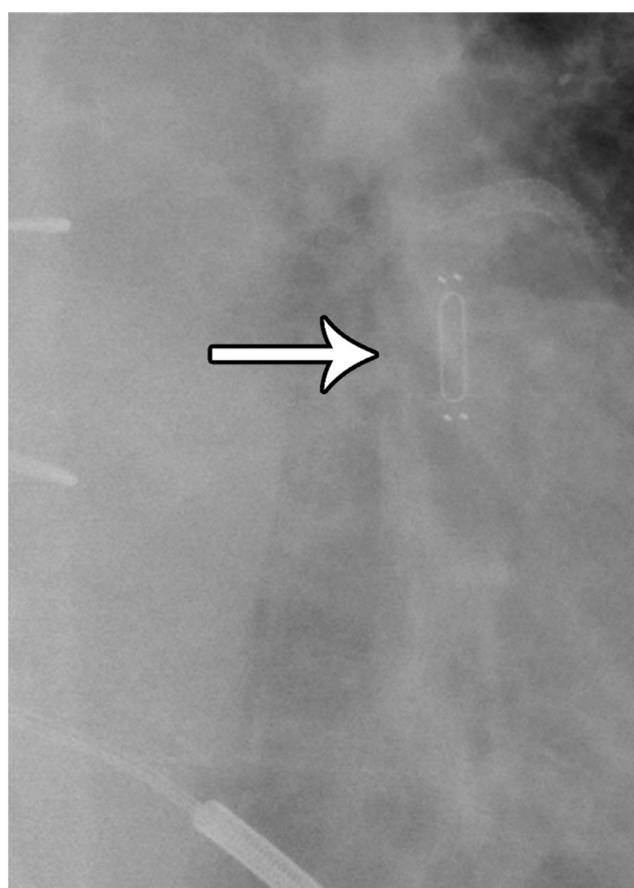

FIG 38. Magnified frontal view of the left cardiac region better demonstrates the appearance of the implantable CardioMems pulmonary artery pressure monitor as a tubular metallic construct with twin end wire loops (white arrow).

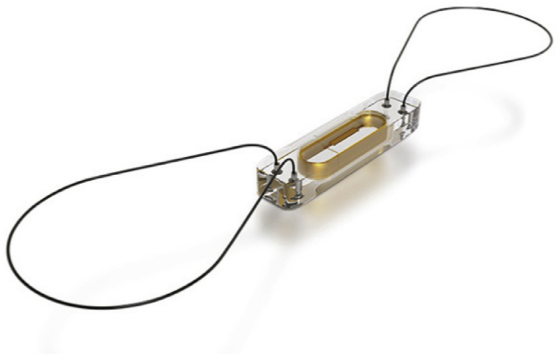

FIG 39. A stock image of the CardioMEMS implant, as placed in the preceding patient (copyright St. Jude Medical, Saint Paul, MN).

preprogrammed criteria. Commonly employed models include the Medtronic Reveal (Medtronic, MN) and the St. Jude Confirm (St Jude Medical, St Paul, MN) (Figs 38 and 39). In the RUP study, implantable loop recorders proved efficacious when compared with the use of a conventional strategies in the work-up of unexplained syncope (24-hour Holter recording, a 4-week period of ambulatory ECG monitoring with an external recorder, and electrophysiological study). This study also demonstrated the superiority of the ILR approach for establishing a final clinical diagnosis with a conclusive rate of 73% versus 21% in the conventional group.[50]

Conclusion

Percutaneously implanted cardiac devices for structural shunt and valve repair, appendageal and partial chamber occlusion, and in situ cardiac monitoring represent an ever-growing area of technical and clinical innovation. Familiarity with device design, radiographic appearance, and intended clinical usage will give additive value to the radiological report and enhance the role of diagnostic radiologists as clinical colleagues in the collective care and management of these oftentimes clinically challenging patients.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1067/j.cpradiol.2018.05.006.

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