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PICTORIAL ESSAY

CT for evaluation of acute pericardial emergencies in the ED

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Abstract

Acute pericardial emergencies may present with acute chest pain. Although complete diagnosis and physiological effects of acute pericardial disease may require a combination of different imaging, CT plays a critical role in identifying the cause of chest pain in the ED. Many of these pericardial diseases can be fatal unless emergent treatment is obtained. The presentation can often be non-specific and symptoms can be overlapping with other diseases originating in the thorax or abdomen. Optimizing the CT scan is imperative when acute pericardial disease is suspected from clinical examination or preliminary imaging. The interpreting radiologist needs to be aware of the different entities which represent acute pericardial emergencies requiring urgent therapeutic intervention. Time is the essence, the clock is ticking, and every minute counts!

Keywords Pericardium · Pneumopericardium · Hemopericardium · Fistula · Pericardial perforation

Introduction

Pericardium can be affected by diseases from different etiologies (Fig. 1, flowchart). The presentation can often be non-specific and symptoms can be overlap with other diseases originating in the thorax or abdomen. Acute pericardial diseases are an important cause of morbidity and mortality in patients with cardiovascular diseases [1]. Imaging plays a key role in not just identifying the etiology but also in planning the therapeutic approach. Often these patients can present to the ED with chest pain and or dyspnea. Radiographs followed by ultrasound (US) or CT may be obtained for these indications. Additionally acute pericardial emergencies may be identified on a CT performed for other indications such as coronary artery disease, aortic dissection, pulmonary embolism, or pulmonary diseases etc. Although CT is highly versatile, optimizing the scan is important in order to accurately identify the underlying etiology and also for therapeutic planning. Most pericardial abnormalities can be diagnosed on non-ECG-gated CT of thorax. In selected patients, additional ECG-gated CT acquisition can be useful.

The interpreting radiologist needs to be aware of the entities which represent acute pericardial emergencies that may require urgent therapeutic intervention. Although cardiac US is considered a primary modality to identify pericardial diseases, its availability can be limited in the ED; it requires skilled operator and well-trained interpreter. US can often be limited in patients with poor acoustic windows, chest wall emphysema, or lung diseases. CT can prove to be important diagnostic modality in such patients. CT can also provide a roadmap for the treating interventionist or cardiothoracic surgeon. Surgical approach may require surgeons from more than one clinical service.

In this brief pictorial essay, we describe how an optimized CT in the ED can play a critical role in identifying, triaging, and providing a road map for optimal treatment of some of the most important pericardial emergencies (Table 1).

Anatomy

The pericardium is a three-layered conical fibroserous sac comprising an outer fibrous layer and inner serous double layers (parietal and visceral). The outer fibrous and parietal layers are

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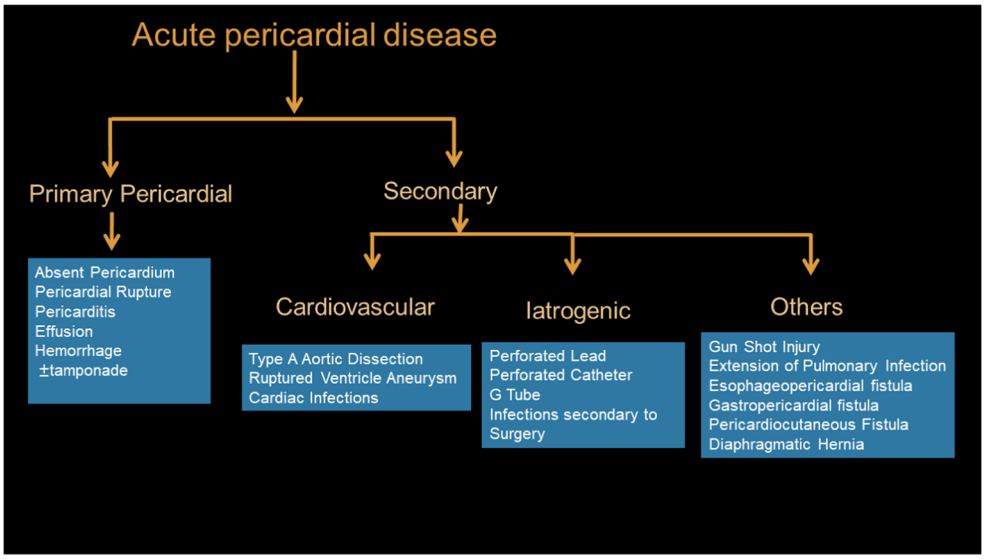

Fig. 1 Flowchart depicting the different causes of acute pericardial diseases that may require urgent intervention or surgery

fused, thus forming a potential space between these two fused layers and visceral pericardium which contains 5–50 cc of serous fluid. There are two cul-de-sac in the pericardium: *oblique sinus*, and the *transverse sinus* along with several pericardial recesses [2]. The pericardium regulates ventricular compliance, minimizes chamber dilation, and protects the heart.

CT protocol

While a CT of thorax may be obtained without intravenous (i.v.) contrast, during a breath hold, administration of i.v. contrast increases senstivity for certain pericardial diseases. Newer CT scanners with dual source or wide detector array also allow for a free breathing high-pitch acquisition useful in unconscious or intubated patients, who cannot obey verbal commands. The timing of image acquisition after administration of intravenous contrast is equally important. Arterial phase is useful to identify vascular origin of pericardial emergency, while a venous phase can be useful to evaluate suspected pericarditis. ECG gating (prospective) can be used to decrease cardiac motion artifacts and is recommended when evaluating cardiac pathology such as myocardial perforation. Retrospective ECG gating is useful when evaluation of cardiac function or pericardial constriction. Oral contrast is useful when a bowel pathology such as esophageal or gastric perforation is suspected.

Acute pericardial diseases

Congenital pericardial absence (Fig. 2) results from abnormal early regression of the common cardinal vein, resulting in incomplete formation of the pleuropericardial membrane. Partial absence of the pericardium which is limited to the left pericardium is more common than complete absence of pericardium which is extremely rare [3, 4]. On several instances, this entity may be acquired following percutaneous cardiac interventions or lung transplantation. Pericardial tears in blunt trauma most commonly occur along the left pleuropericardium parallel to the phrenic nerve [5]. Findings on CT include leftward mediastinal shift, herniation of lung parenchyma into the aortopulmonary window (due to lack of superior pericardial recess), or between the base of heart and diaphragm, enlargement of the right heart chambers and left atrial appendage. Although the majority of patients are asymptomatic, complications include herniation of cardiac structures such as the left atrial appendage through the defect resulting in torsion and ischemic necrosis. In these conditions, pericardioplasty with mesh placement is the recommended management [6, 7].

Pericardial effusion is defined as the accumulation of more than 50 ml of fluid in the pericardial sac. Criteria for quantifying it by echocardiography is based on identification of fluid throughout the cardiac cycle, (in both systole and diastole). Pericardial effusion is semi-quantitatively quantified on echocardiography by measuring the separation between parietal and visceral pericardium in end-diastole as trivial (seen only in systole), small (less than 1 cm), moderate (1–2 cm), and large (more than 2 cm) [8]. On CT simple or transudative effusions, measure less than 10 HU's and an exudative pericardial effusion measures between 20 and 40 HU. Hemorrhagic pericardial effusion is better characterized on unenhanced CT and measures between 40 and 60 HU. Hemopericardium can be seen in the setting of left ventricular free wall rupture after myocardial infarction, ventricular or coronary aneurysmal rupture, postsurgical, trauma, and malignancy (Fig. 3) [9].

Pericardial tamponade is defined as the accumulation of pericardial fluid under pressure. The amount of fluid required to compromise diastolic ventricular filling is dependent on how fast the fluid accumulates rather than the amount or characteristics of fluid itself [9, 10]. In the acute setting for example in a patient with type A aortic dissection with rupture into the pericardium, only 150–

Table 1 Table depicting different causes of acute cardiac pericardial disease, optimal CT technique, key imaging findings, and treatment

	CT technique	Imaging finding	Treatment
Absent pericardium	Can be identified on non-ECG-gated CT. ECG-gated images can be useful to identify focal herniation of cardiac chambers.	Left mediastinal shift. Herniation of lung between aorta and pulmonary artery. Enlargement of the right heart	Asymptomatic: no treatment. Emergent pericardioplasty in patients with valve insufficiency, herniation with compression of coronary arteries or torsion
Tamponade	Can be identified on non-ECG-gated CT. Retrospective ECG gating useful to identify hemodynamic significance and cardiac function	Flat RV free wall. SVC/thoracic aortic ratio ≥ 1. IVC/abdominal aortic ratio > 2. Distention of the IVC	Pericardiocentesis* Pericardial window may be needed for recurrent effusions
Hemorrhage	Can be identified on non-ECG-gated CT. Initial non-contrast followed by post contrast to identify etiology	Fluid attenuation of > 40–60 HU	Pericardiocentesis*
Pericardiocutaneous fistula	Can be identified on non-ECG-gated CT	Identification of a fistulous tract from pericardium leading to the skin	Surgical repair
Gastropericardial fistula	Non-ECG-gated CT with oral contrast	Identification of a fistula from pericardium to stomach	Surgical repair
Esophageal pericardial fistula	Initial non-contrast CT. If needed, water-soluble oral followed by intravenous contrast-enhanced CT to identify the fistula (limit *Z* axis coverage and use lower kVp and mAs setting to reduce radiation dose or use a dual energy scan.)	Identification of a fistula from esophagus to the pericardium. Air in the left atrium, oblique sinus adjacent to esophageal hematoma	Surgical repair
Lead perforation	Non-ECG-gated CT. Prospective ECG-gated CT useful in subtle perforation	Identification of a catheter tip in the pericardium	Extraction of a chronically perforated functioning lead is not necessary. Transcatheter retrieval for infected leads with contained perforation. Surgical repair for larger defects or patients with hemodynamic instability
GSW/knife	Initial non-contrast CT. Contrast-enhanced CT useful to identify cardiac injury, pseudoaneurysm, perforation	Identification of a projectile in the pericardium. Tear in pericardium	Depends upon hemodynamic status of the patient. Surgical repair may be needed.
Iatrogenic	Can be identified on non-ECG-gated CT. Initial non-contrast followed by post contrast to identify etiology	Identification of the device/catheter in the pericardium. Tear in myocardium or pericardium	Removal of device, G-Tube etc. Surgical repair may be necessary.

*In penetrating or blunt injury, surgery is recommended as pericardiocentesis may remove the "tamponade" effect of collected blood on traumatized cardiac chambers with subsequent circulatory collapse

200 ml of hemorrhagic fluid can lead to tamponade. In the chronic setting as the fluid accumulates gradually, increased compliance due to the elastic fibers can allow up to 1000 ml of fluid (20 times the normal physiologic amount) without hemodynamic decompensation [11]. Diagnostic criteria on CT (Fig. 4) include the following: flattened heart sign (flattening of the RV free wall with right atrial indentation), SVC/thoracic aortic ratio equal or greater than 1, IVC/abdominal aortic ratio greater than 2, and distention of the IVC and azygous arch. Reflux of contrast into the IVC, hepatic veins and azygous vein can also be seen [6, 9].

Penetrating cardiovascular injury can be caused by firearms or less commonly by knife and other objects [12]. It has a very high mortality with overall survival of less than 20% [13]. Right ventricle being more anteriorly placed cardiac chamber is often the site of entry. Prognosis is worse when the left ventricle is injured [14]. The bullet can traverse the mediastinum injuring vessels and other organs. The projectile can lodge in the pericardium, atria, or the ventricles (Fig. 5). Bullet fragments can also embolize distally.

Intrapericardial diaphragmatic hernia are rare [15]. These can be congenital [16] or may arise as a complication of diaphragmatic rupture from blunt trauma, which results from sudden rise in intra-abdominal pressure. The presentation can be immediate or may be delayed by more than 20 years. Often asymptomatic,

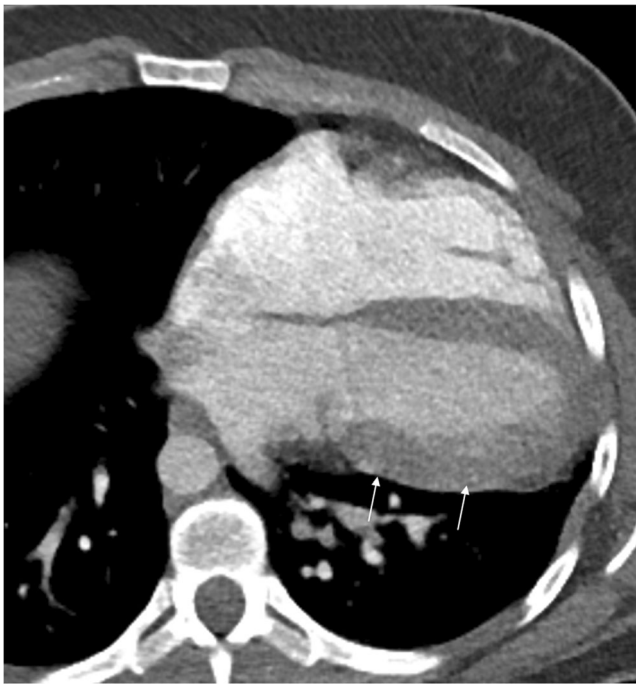

Fig. 2 Preoperative non-ECG-gated axial contrast-enhanced CT in a 24-year-old patient presenting with an intrapulmonary bronchogenic cyst identifies complete absence of pericardium (white arrows indicating normal location of pericardium), instead undulating left ventricle epicardium is present with mediastinal shift towards left. At the time of surgical resection of the bronchogenic cyst, complete absence of pericardium was confirmed. Complete absence of the pericardium may be associated with developmental anomalies of the lung (particularly left upper lobe) including bronchogenic cyst and sequestration

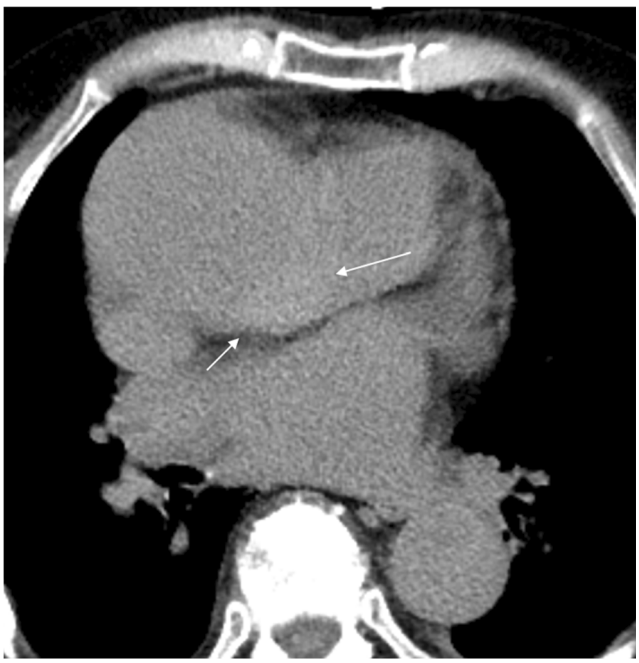

Fig. 3 Axial non-contrast non-ECG-gated CTA in a patient presented with acute chest pain identifies high attenuation in the transverse sinus (white arrows). With attenuation of more than 45 HU, this is concerning for pericardial hemorrhage. Contrast-enhanced CTA (not shown) identified an ascending thoracic aortic aneurysm with type A dissection

Fig. 4 Axial non-ECG-gated contrast-enhanced CT in a patient presenting to the ED with chest pain and past history of mitral valve replacement identifies a high-attenuation pericardial effusion (white arrows) causing extrinsic compression on right atrium and right ventricle. On an ECG-gated CTA diastolic flattening of right ventricular free wall, prolonged systolic notching of right atrial wall and in the presence of large effusion, swinging of the heart within the pericardial sac can be identified

these can also present with symptoms from bowel obstruction or cardiac dysfunction. Clinical examination may reveal bowel sounds in the thorax, absent point of maximal cardiac impulse, etc. Herniated viscera may include stomach (Fig. 6), colon, liver (Fig. 7), or a combination of these.

Fistula can develop between the pericardium and skin, esophagus, gastrointestinal tract, lung, or liver. Gastropericardial fistula is characterized by communication between the stomach and pericardium (Fig. 8). This is a surgical emergency as it can result in cardiac tamponade and sepsis [17]. These fistulas can be seen in patients with prior history of gastroesophageal surgery or from peptic ulceration in a hiatus hernia. On CT, the presence of water-soluble oral contrast in the pericardium along with the fistula's communication with esophagus or stomach can be identified.

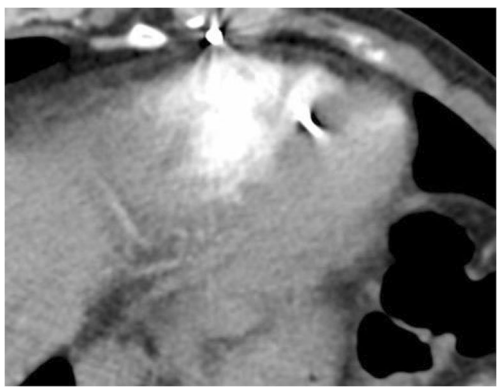

Fig. 5 Axial contrast-enhanced CT in a patient with acute chest and abdomen pain presenting to the ED after gunshot injury identifies round metallic projectiles in the pericardium and right ventricle

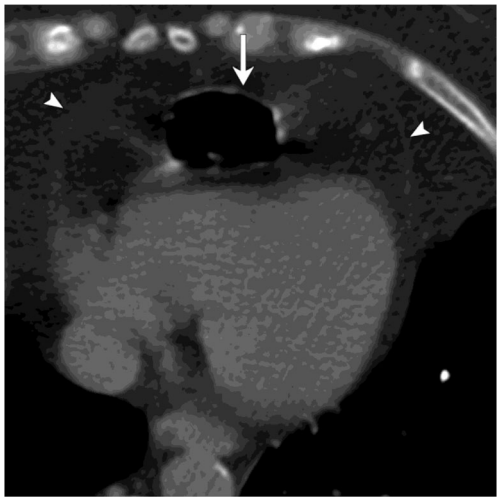

Fig. 6 Axial non-contrast CT in a 35-year-old patient with recent history of blunt abdominal injury demonstrates the presence of stomach (white arrow) in the pericardium (arrowheads) abutting the right ventricle. This finding is consistent with posttraumatic intrapericardial diaphragmatic herniation of stomach (movie 1)

Surgery involves emergent pericardial decompression, resection of fistula, and repair of any associated hernia.

Pericardiocutaneous fistula (Fig. 9) is a rare complication of cardiac surgery [18]. It has also been described after transapical approach for transcatheter aortic valve replacement [19] and from infections [20]. These patients may develop draining sinuses on skin. CT or MRI can demonstrate the communication between the skin and pericardium. Treatment may require surgical resection with repair of the pericardial defect often by an omental patch.

Left atrial ablation is increasingly being used to treat refractory atrial arrhythmias. A potential complication of this

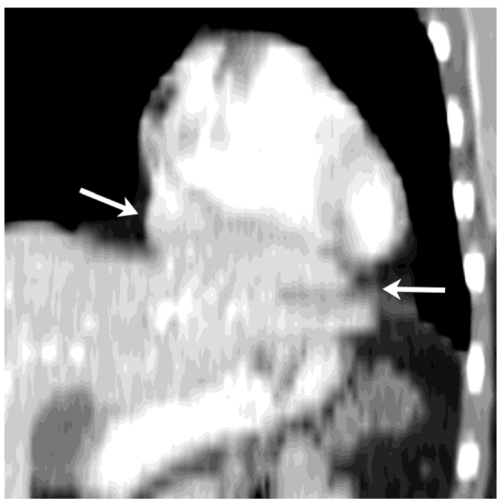

Fig. 7 Coronal post contrast CT in a 60-year-old patient with recent history of motor vehicle accident identifies portion of left lobe of liver protruding into the pericardial cavity abutting the right ventricle (white arrows). The presence of hepatic vessels extending across the diaphragm is useful in differentiating this hepatic herniation from other pericardial masses and tumors

Fig. 8 Axial CT in a patient with prior esophageal cancer post esophagectomy and gastric interposition graft placement presenting to the ED with new onset chest pain identifies presence of oral contrast in the pericardium through focal defect (arrowhead) in the gastric graft. This finding is suggestive of gastropericardial fistula (movie 2)

procedure involves thermal injury of the esophageal mucosa [21]. These can present as asymptomatic esophageal lesions, esophageal hemorrhage (Fig. 10) with *esophagopericardial fistula* and in rare cases with atrioesophageal fistula. On CT, air can be identified in the pericardium and sometimes also in the left atrium. In the case of atrioesophageal fistula, a one-way valve is created with leakage of esophageal contents into the left atrium [22]. Early surgical repair is essential. Endoscopic interventions should be avoided as they increase the risk for air emboli. Interposing tissue between the repaired esophagus and the LA decreases postoperative complications. Infection from the lung or adjacent mediastinal structures can also extend into the pericardium (Fig. 11). This can lead to rapid spread of infection to myocardium and cardiac valves. In immune compromised patients, these may require surgical resection and drainage using minimally invasive video-assisted thoracic surgery.

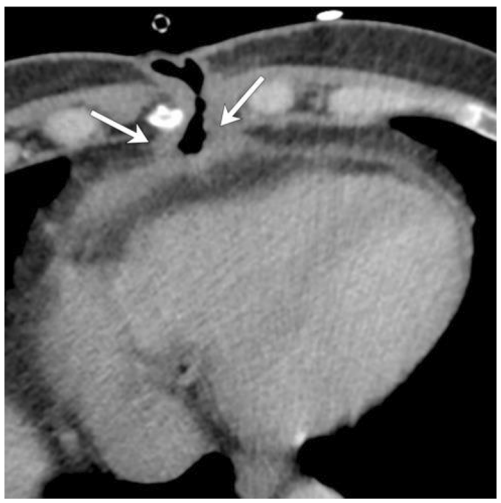

Fig. 9 Venous phase axial contrast-enhanced CTA in a patient with recent surgical aortic valve replacement and new onset fluid discharge from the sternal wound identifies the presence of a fistula tract communicating with the overlying skin. This finding is concerning for a pericardiocutaneous fistula (movie 3)

Fig. 10 Axial non-contrast-enhanced CT in a patient who had recently undergone left atrial ablation for atrial fibrillation presenting to the ED with new onset chest pain. High attenuation seen in the esophagus consistent with esophageal hematoma (white arrow). In addition, focal specks of air are also present in the oblique sinus of pericardium (arrowhead). These findings are suggestive of esophageal injury with resultant esophagopericardial fistula (movie 4)

Acute pericardial disease may also be seen from *iatrogenic* injury. Pericardiocentesis can lead to inadvertent puncture of ventricles (Fig. 12). Port catheters are commonly used for central access. Lead tip of the port catheter can perforate the relatively thin-walled right atrium (Fig. 13). Pacemakers and implantable cardiac devices are commonly used to treat arrhythmias and congestive heart failure. Pacemaker lead perforation can be seen in up to 15% of patients and is often asymptomatic [23] but can lead to pneumopericardium, hemopericardium, or hemothorax (Fig. 14). Atrial lead perforation is more common than ventricle lead perforation. In rare instances, malposition of other devices such as gastrostomy tube, thoracostomy tubes can occur. Inadvertent transthoracic placement of the gastrostomy tube can occur (Fig. 15) which can lead to formation of direct communication between the stomach and pericardium.

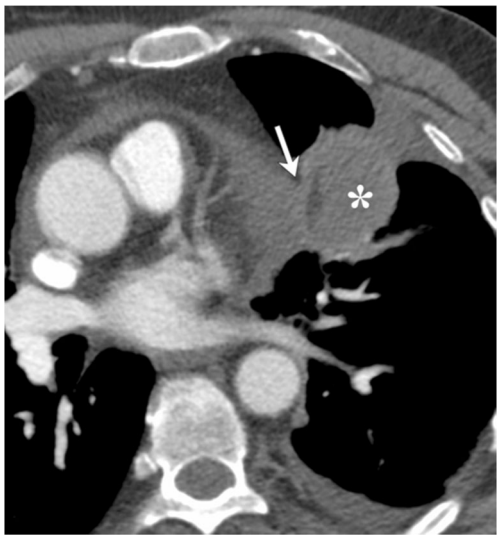

Fig. 11 Non-ECG-gated contrast-enhanced CT in an immunosuppressed patient with recent bone marrow transplant and new onset chest pain and heaviness presenting to the ED demonstrate a well-defined fluid collection along with consolidation in lingual lingula (asterisk) consistent with a lung abscess. In addition, there is a left pericardial effusion (white arrow) which is contiguous with this abscess and concerning for pericardial infection. This patient failed conventional treatment; FNA was suggestive of fungal infection but the patient did not respond well to conventional antifungal therapy also. Minimally invasive thoracic surgery was performed with resection which confirmed pericardial fungal infection (movie 5)

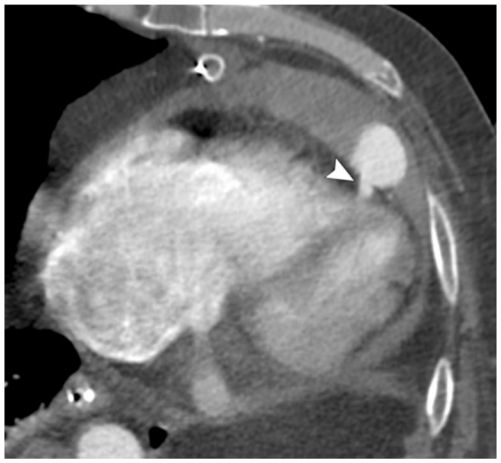

Fig. 12 Seventy-one-year-old patient presenting with increasing chest pain after pericardiocentesis for pericardial effusion. Non-ECG-gated axial contrast-enhanced CT demonstrates focal contrast outpouching emanating from the right ventricle (arrowhead) extending into the pericardium. This finding is consistent with right ventricle pseudoaneurysm with hemopericardium

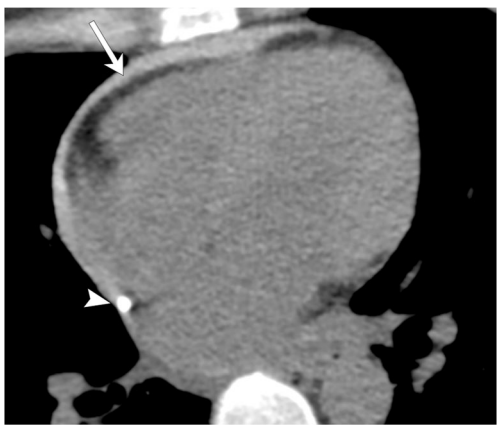

Fig. 13 Non-contrast-enhanced axial prospectively ECG-gated CT performed immediately after port catheter placement identifies the port catheter tip in the pericardium (arrowhead) which is beyond the epicardial fat. High-attenuation pericardial fluid (white arrow) is due to the intravenous from the contrast injected at the time of through the port catheter (movie 6)

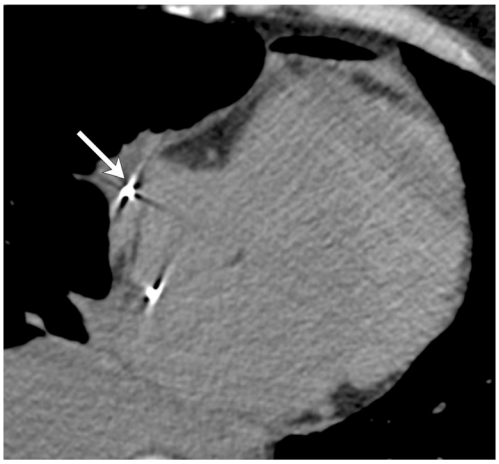

Fig. 14 Axial non-contrast prospectively ECG-gated CT performed in a patient with recent pacemaker lead placement and new onset chest pain. The right atrial lead is identified outside the atrium; tip is beyond the epicardial fat. In addition, the lead extended into the right pleural cavity with right hydropneumothorax (movie 7). These findings are consistent with perforated pacemaker lead

Conclusion

Pericardial emergencies can have high morbidity and mortality. CT imaging is central in the evaluation of these patients and recognition of abnormalities is important for timely management. In many cases the CT may be obtained suspecting a non pericardial disease. The radiologist plays a crucial role in ensuring that the CT study is correctly protocoled and acquired. Familiarity with potential complications of certain diseases or procedures can prove life-saving in this patient population.

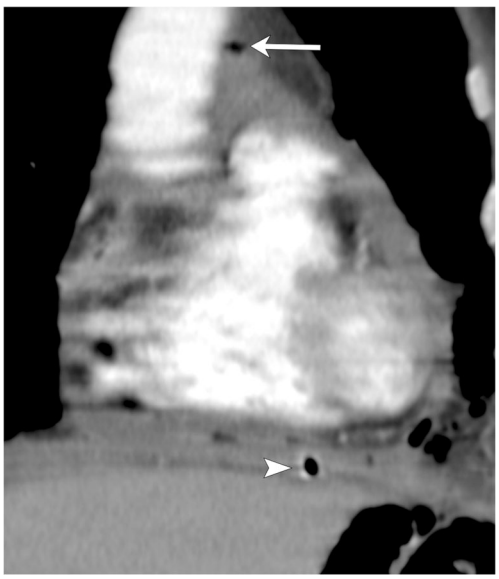

Fig. 15 Coronal image from a contrast-enhanced axial chest and abdominal CT in a patient with new onset chest pain after recent percutaneous gastrostomy tube placement identifies the G-Tube traversing the pericardium (arrowhead), diaphragm before extending into the stomach (movie 8). In addition, pneumopericardium is also present (arrow)

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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