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CT Imaging of Cardiac Trauma

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Abstract Cardiac injury can occur in the setting of blunt and penetrating trauma resulting in significantly adverse clinical outcomes. While the clinical presentation is variable and computed tomographic (CT) imaging is rarely performed to specifically evaluate for cardiac injury, the ability to recognize the findings of cardiac injury on CT examinations performed for thoracic trauma is essential to avoid misdiagnosis and direct potentially life-saving intervention. This article reviews the direct and indirect CT findings of cardiac injury.

Keywords Cardiac trauma · Blunt cardiac injury · Penetrating cardiac injury · Myocardial contusion · Myocardial rupture

Introduction

Cardiac trauma occurs in the setting of blunt or penetrating traumas and results in significantly adverse outcomes. The incidence of blunt cardiac injury is unknown with a wide range of reported incidences varying from as low as 20% when accounting for all blunt traumas to as high is 76% in the setting of blunt trauma with severe thoracic injury [1–3]. It has been estimated that 25% of deaths in the setting of blunt cardiac trauma are secondary to cardiac-related injuries [4]. Scenarios most closely associated with cardiac injury include motor vehicle collisions, falls, explosions, crush injuries, and cardiovascular resuscitation. There are several proposed mechanisms of cardiac injury from blunt trauma including direct precordial impact, crush injury from compression between the sternum and spine, deceleration or torsion, hydraulic effect, and blast injury [5]. Penetrating cardiac trauma has grave consequences as well, with survival rates reported between 19 and 73% [6••]. Common mechanisms of penetrating injury to the heart include stab wounds, gunshot wounds, and sternal fractures.

The clinical presentation of thoracic trauma is variable, and depends on the mechanism and magnitude of injury. Patients can present with nonspecific clinical symptoms including chest pain, dyspnea, and cardiac arrhythmia. Patients with minor injuries may be nearly asymptomatic, while more severe injury can present with a complex clinical picture. Physical examination may demonstrate a chest wall deformity or subcutaneous emphysema which in turn raises the possibility of cardiac injury [7]. Occasionally, findings on physical examination may be absent in patients with severe thoracic trauma. Adding to the confusion is that many patients with significant chest trauma, including sternal fractures, tend not to have any cardiac injury. While no clear diagnostic test exists, approaches to the workup of patients with concern for cardiac injury include an ECG evaluation and assessment of cardiac enzymes (troponin-I, CK-MB/CK ratio) [6••, 7]. In hemodynamically stable patients with a normal ECG and cardiac enzyme values, no further workup is required [5, 6••, 7]. In

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Fig. 1 55-year-old man involved in an MVC who presented with elevated troponins, increasing upon admission from 0.05 to 0.32 ng/mL. Initial MDCT transaxial images with intravenous contrast showed no evidence of cardiac injury. The patient was treated for a myocardial infarction, unrelated to cardiac injury

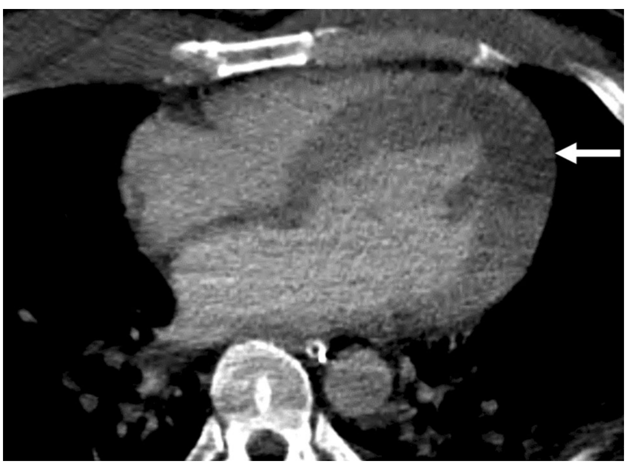


Fig. 2 40-year-old man who ran into a pole while playing basketball. Axial post-contrast MDCT image shows hyoenhancement of the left ventricular myocardium (white arrow) and papillary muscles. Echocardiography and coronary angiography confirmed left ventricular hypokinesis and findings compatible with myocardial contusion

patients with cardiac arrhythmia, hemodynamic stability, or elevated enzymes, further workup is often needed. Rarely is the radiologist requested to evaluate for cardiac trauma specifically, but recognition of findings of cardiac trauma on imaging examinations performed for thoracic trauma is essential to avoid misdiagnosis and to provide an explanation for the patient's clinical findings. Furthermore, prompt recognition of cardiac injury can result in life-saving intervention.

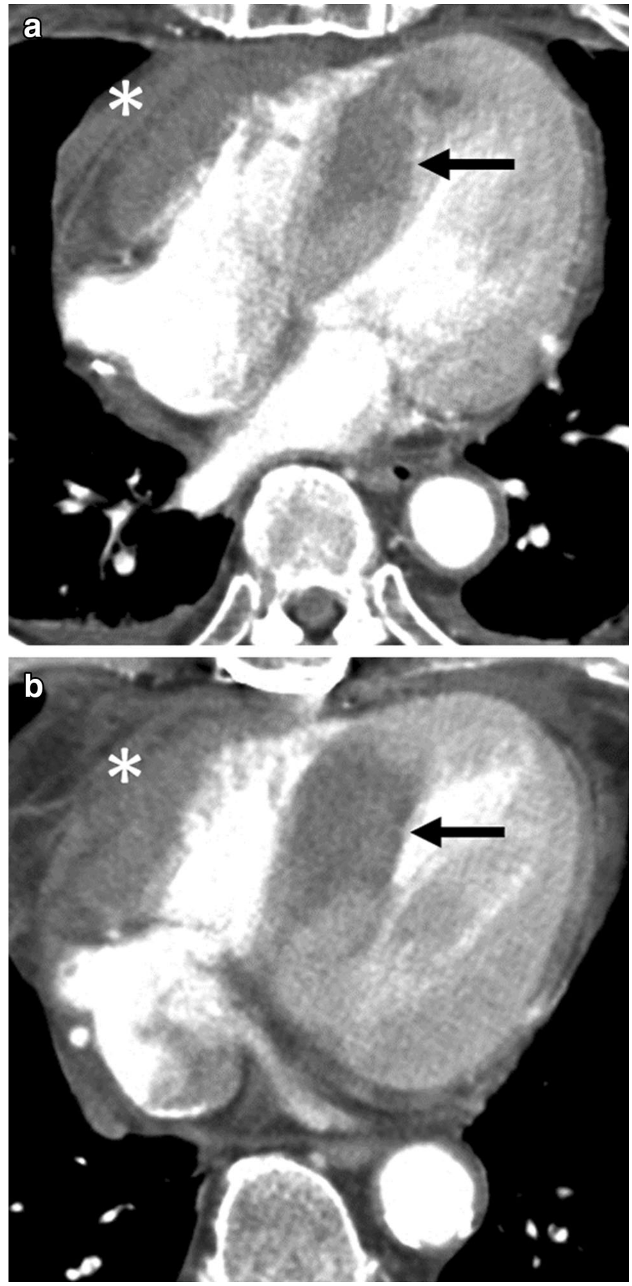


Fig. 3 **a** 62-year-old man involved in an MVC. MDCT transaxial images of the chest demonstrate decreased attenuation within the interventricular septum (black arrow) consistent with myocardial injury to this location. Hemopericardium (white asterisk), an indirect finding, is also seen adjacent to the thickened right ventricular free wall in this patient who also sustained a right ventricular free wall myocardial injury

Normal Anatomy and Imaging Technique

Although it is infrequent for a radiologist to be requested to specifically evaluate a patient for cardiac injury, findings of cardiac injury may be encountered on routine post trauma multidetector row-computed tomography (MDCT). MDCT

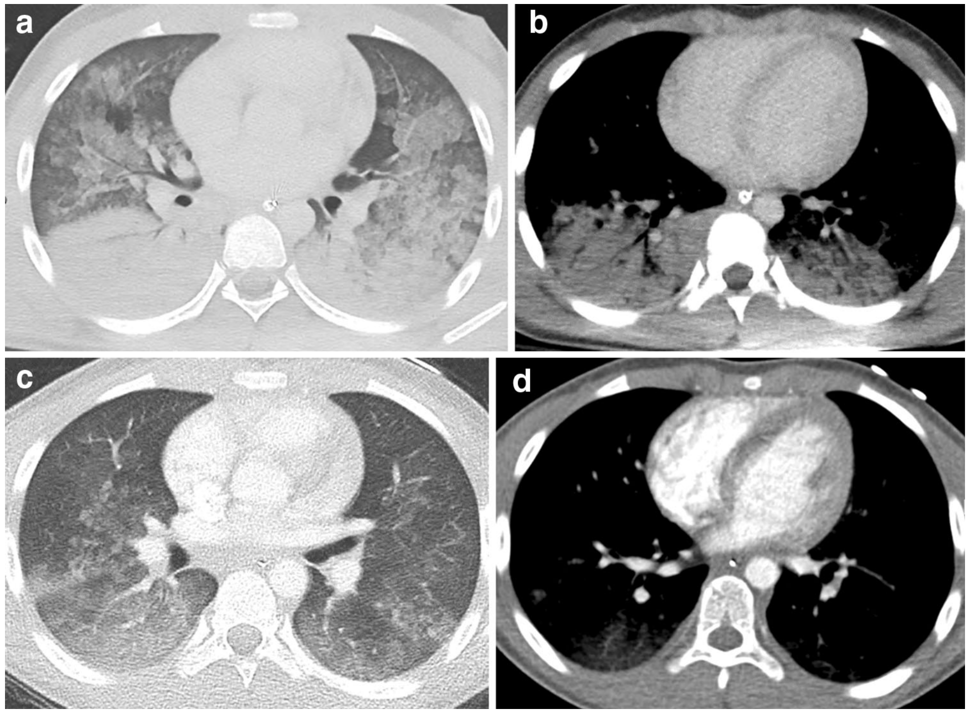


Fig. 4 45-year-old man involved in an MVC. MDCT transaxial images at the time of presentation (**a**, **b**) demonstrate ground glass consistent with pulmonary edema with left ventricular chamber enlargement. Follow-up MDCT imaging (**d**, **e**) 2 days later shows improved pulmonary edema and reduced size of the left ventricle suggesting improving findings of myocardial contusion

is currently the workhorse for evaluation of trauma in the emergent setting as it can be performed rapidly and can provide coverage of multiple regions of the body. MDCT has a high sensitivity for cardiac injury [8]. In cases of suspected cardiac trauma, ECG gating or high-pitch scan modes can be used to reduce both cardiac and motion artifacts [9, 10]. The MDCT protocol used at our institution is our routine trauma examination performed in a single phase with a fixed delay at 70 s with the arms raised above the patient's head. Images are obtained in a single pass from the thoracic inlet through the upper abdomen, using a standard 3-mm slice thickness reconstructed at 2-mm intervals, with the option to reconstruct at thinner slices.

While other modalities may be used in specific instances, they have important limitations. Chest radiography is a useful imaging tool in the initial assessment of patients who have sustained thoracic trauma, but is incapable of providing an in-depth evaluation of the heart [9]. Radiographs may demonstrate more commonly seen injuries such as rib or clavicular fractures, sternal fractures, pneumothorax, hemothorax, and lung contusion. Transthoracic echocardiography (TTE) is useful for evaluation of wall motion and structural abnormalities, but TTE can be technically challenging in the setting of significant chest trauma, especially in the setting of pneumomediastinum or pneumopericardium. Transesophageal echocardiography (TEE), while also useful, is limited by its invasive nature and may be difficult to perform in the setting of severe thoracic injury [9]. Although invasive, catheter angiography can be useful in assessing coronary artery injury, while also providing information about cardiac chamber size, myocardial function, and valve function. Cardiac magnetic resonance (MR) imaging, while providing a potential means for evaluation of the extent of myocardial injury, infarction, wall motion abnormalities, and valvular dysfunction, is not a practical tool in the setting of acute trauma given its long imaging times. In addition, both angiography and MR remove the patient from the emergency department and may delay other needed interventions.

In the evaluation of aortic and vascular injuries, many reports have pointed to direct and indirect signs of injury. We propose a similar approach to the evaluation of suspected cardiac injury. Direct signs of cardiac injury include decreased myocardial attenuation (typically best appreciated in the portal venous phase), active extravasation of contrast, or a focal outpouching/defect in the myocardium. Indirect signs of cardiac injury include pulmonary edema, cardiac chamber enlargement, pneumopericardium, hemopericardium, and wound path/trajectory.

The right heart, specifically the right ventricle, is the most common location of cardiac injury in blunt and penetrating trauma [4, 5, 6••]. In blunt trauma, this is likely secondary to the close proximity of the right heart to impacts along the anterior chest wall. In penetrating trauma, the right heart is also most vulnerable given its anterior location in the thoracic cavity [4]. Of the patients who experience cardiac injury, only a small percentage make it to the emergency department alive. Awareness of the common locations of cardiac injury and recognition of

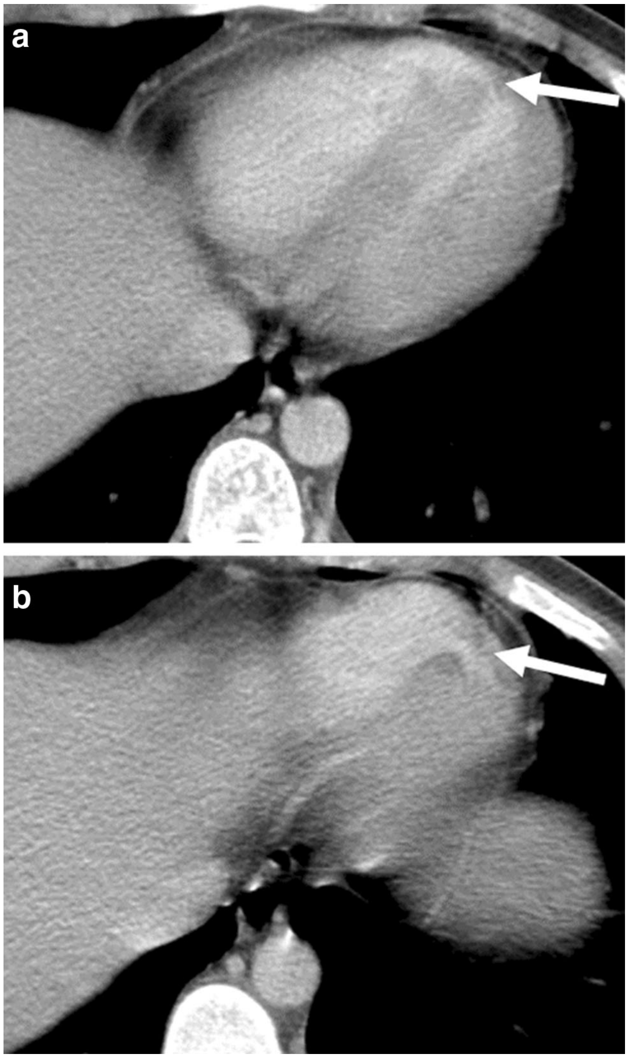


Fig. 5 **a**, **b** 36-year-old man involved in an MVC. MDCT transaxial images with intravenous contrast demonstrate a post-traumatic ventricular septal defect near the apex (white arrow). The findings were confirmed during surgery at the time of repair

the direct and indirect findings of cardiac injury can allow for rapid diagnosis at the time of the initial MDCT. Furthermore, when there is high clinical suspicion for a cardiac abnormality, and a lack of imaging findings to suggest trauma, attention can be directed to an alternative diagnosis (Fig. 1).

Imaging Findings

Blunt Injury

Blunt cardiac injuries can be classified in two categories: myocardial concussion and myocardial contusion. Myocardial concussion is defined as having a wall motion abnormality without evidence of anatomic or cellular injury. Myocardial contusion is defined as having an anatomic injury which presents with elevated cardiac enzymes or tissue injury diagnosed at surgery or autopsy. Other less commonly encountered cardiac injuries which may occur in the setting of blunt trauma include pericardial inury/rupture, myocardial rupture, papillary muscle injury, atrial or ventricular septal defect, valvular injury, or coronary artery injury.

Myocardial Contusion

In blunt trauma, the incidence of myocardial contusion is unknown with a wide reported range from 10 to 75% [1]. Autopsy and clinical series of patients who have died from cardiac trauma demonstrated contusions in 14–100% of patients [1, 5, 11]. Myocardial contusion involves hemorrhage and necrosis within the myocardium and has a nonspecific clinical presentation ranging. While no set

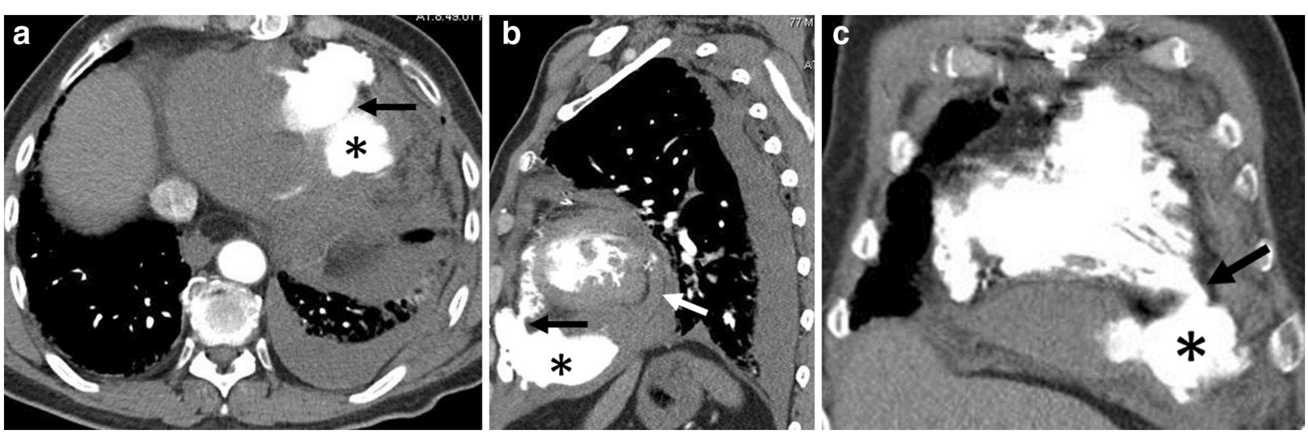


Fig. 6 **a–c** 37-year-old involved in an MVC. MDCT transaxial (**a**), sagittal (**b**), and coronal (**c**) images with intravenous contrast show complete disruption of the right ventricular myocardium (black arrows) with extravasation of contrast (black asterisks) outside of the cardiac chamber and extensive hemopericardium (white arrows). The findings were confirmed at autopsy

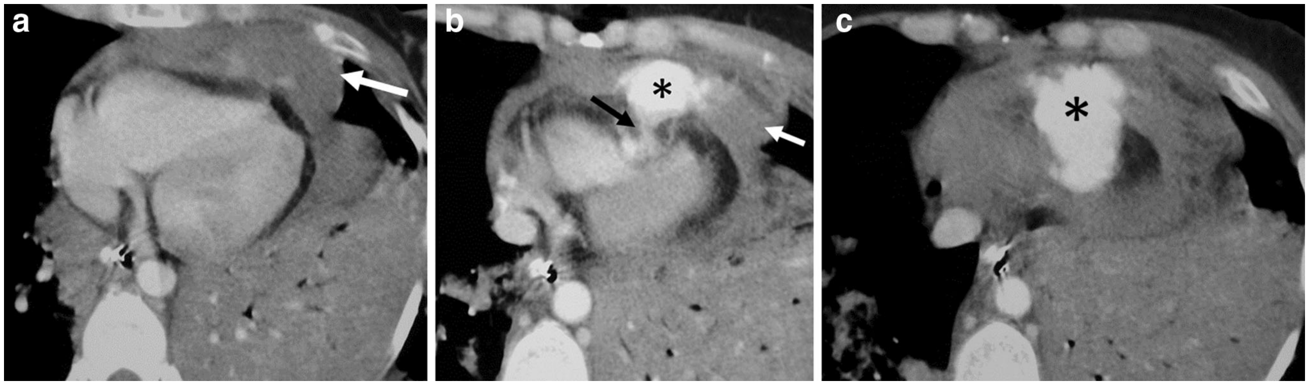


Fig. 7 a–c 44-year-old involved in an MVC. MDCT transaxial images with intravenous contrast show complete disruption of the right ventricular myocardium (black arrows) with extravasation of contrast (white asterisks) outside of the cardiac chamber and extensive hemopericardium (white arrows). The findings were confirmed at autopsy

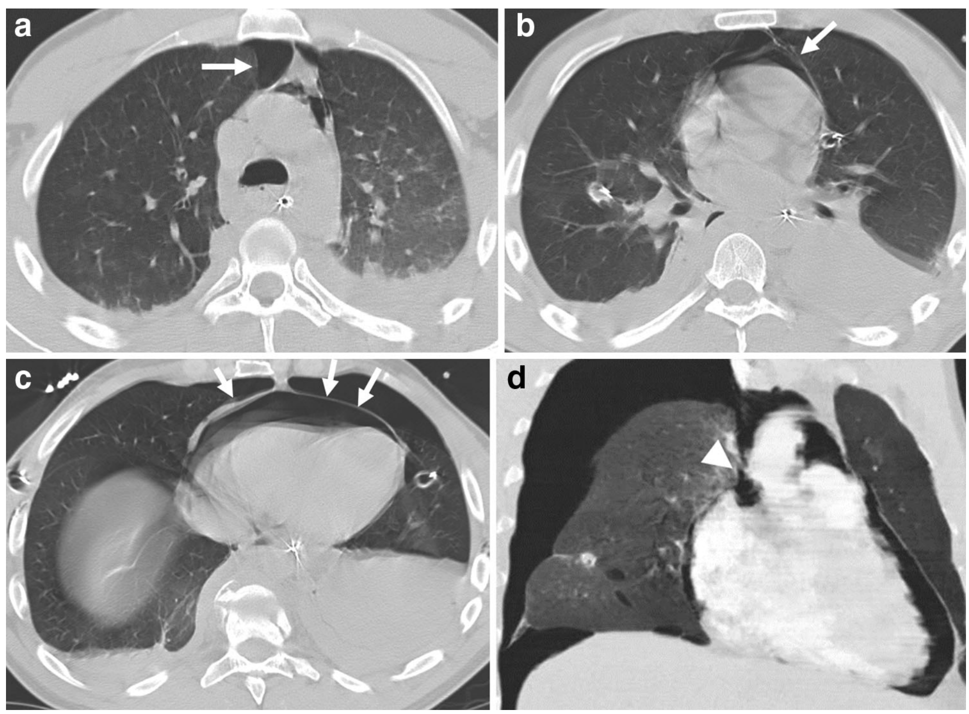


Fig. 8 27-year-old patient's status post MVC. MDCT transaxial (**a–c**) and coronal images (**d**) demonstrate extensive pneumopericardium (white arrows) which tracks along the great vessels. A suspected pericardial tear is seen along the right side of the percairdium just superior to the right atrium (white arrowhead)

criteria exist, myocardial contusion should be suspected in the setting of substantial chest trauma with an abnormal EKG, hypotension, and/or elevated cardiac enzymes [12•]. Identification of substantial thoracic injuries on MDCT such as multiple rib fractures, sternal fracture, pulmonary contusion, mediastinal hematoma, hemopericardium, great vessel injury, and solid organ injury should raise the suspicion for myocardial injury. It should be noted, however, that myocardial injury may occur in isolation. MDCT may show decreased enhancement of the myocardium, but this finding is not sensitive [12•]. Decreased enhancement of the myocardium is best seen on portal venous phase images (70–75 s delay after contrast administration), may be missed on an early arterial phase (< 60 s post contrast), and can be accentuated with a narrow window (Fig. 2). While decreased attenuation of the myocardium is a direct sign of cardiac injury, other indirect signs of cardiac injury may also be present including pulmonary edema and ventricular enlargement due to ischemia (Figs. 3, 4).

Myocardial Rupture

Myocardial rupture is a rare finding seen on MDCT in patients sustaining blunt cardiac injury as a majority of patients with rupture expire in the field. The most common location of chamber rupture is the right ventricle, followed by the right atrium, left ventricle, and left atrium [5]. Clinically, patients may present with profound hypotension and

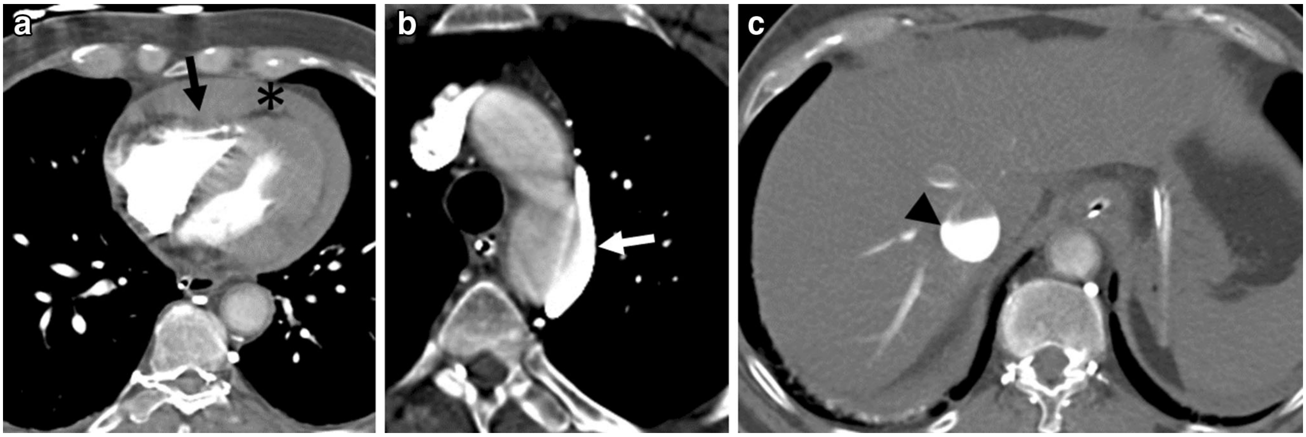
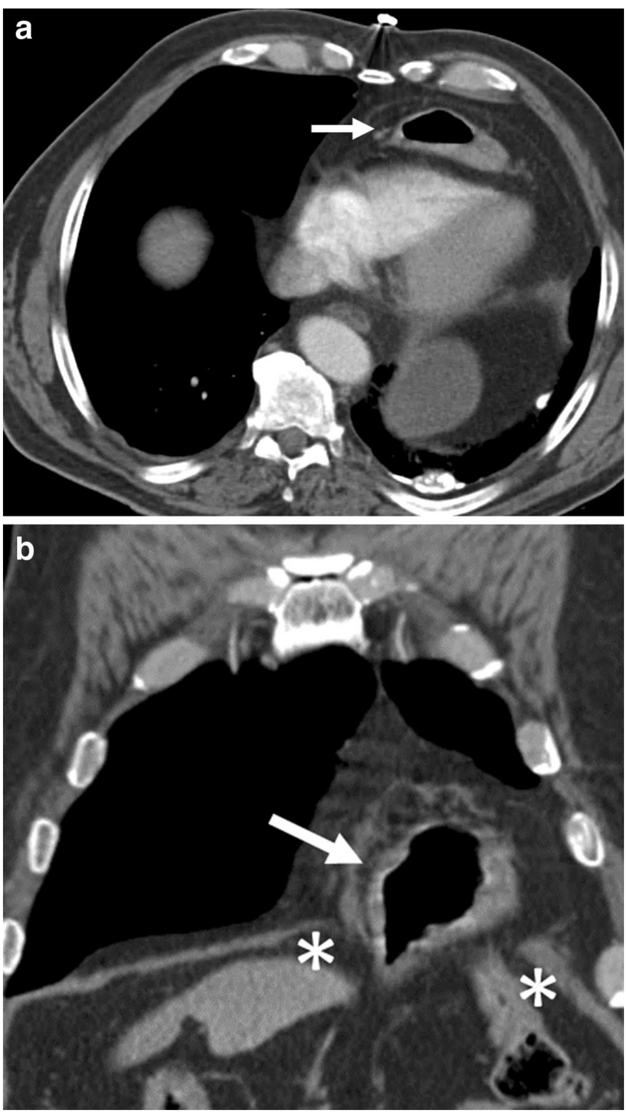


Fig. 9 **a**–**c** 22-year-old patient involved in an MVC. Axial MDCT images demonstrate extensive hemopericardium (black asterisk) and notching of the right ventricular free wall (black arrow). Additional findings of cardiac tamponade include contrast within the superior intercostal vein, a collateral pathway (white arrow), as well as reflux of contrast into the dilated inferior vena cava with a fluid–fluid level (black arrowhead)



◀**Fig. 10** **a**, **b** 31-year-old patient involved in an MVC. Axial (**a**) and coronal (**b**) MDCT images with intravenous contrast demonstrate herniation of bowel into the pericardial sac (white arrow) secondary to a central tendon defect (white asterisks). This patient was taken to the operating room for reduction and repair of the defect

findings of tamponade. On MDCT, findings may be limited to the myocardium and demonstrate a focal aneurysm or post-traumatic ventricular septal defect, a direct finding of myocardial injury (Fig. 5a, b). Other direct findings include complete disruption of the myocardium and extravasation of intravenous contrast outside the heart (Figs. 6a–c, 7a–c). Indirect imaging findings associated with myocardial rupture include hemopericardium and tamponade. Given the grave consequences of myocardial rupture, early diagnosis is essential to ensure prompt repair.

Pericardial Injury/Rupture

Impact to the anterior chest wall or an acute increase in intraabdominal pressure can result in pericardial injury. The pericardium can rupture along either the diaphragmatic or pleural surfaces. Clinical presentation is variable ranging from hemodynamic instability to cardiac arrest. Rupture of the pericardium has a mortality ranging from 30 to 64% [13]. Pneumopericardium in the setting of blunt thoracic trauma should raise the suspicion for pericardial injury. Pericardial rupture with resultant pneumopericardium can easily be identified on MDCT with gas outlining the heart contained by the pericardial reflections at the root of the great vessels (Fig. 8a–d). Distinguishing pneumopericardium from pneumomediastinum relies on identifying strands of fat within pneumomediastinum but not pneumopericardium, as the gas in pneumopericardium is

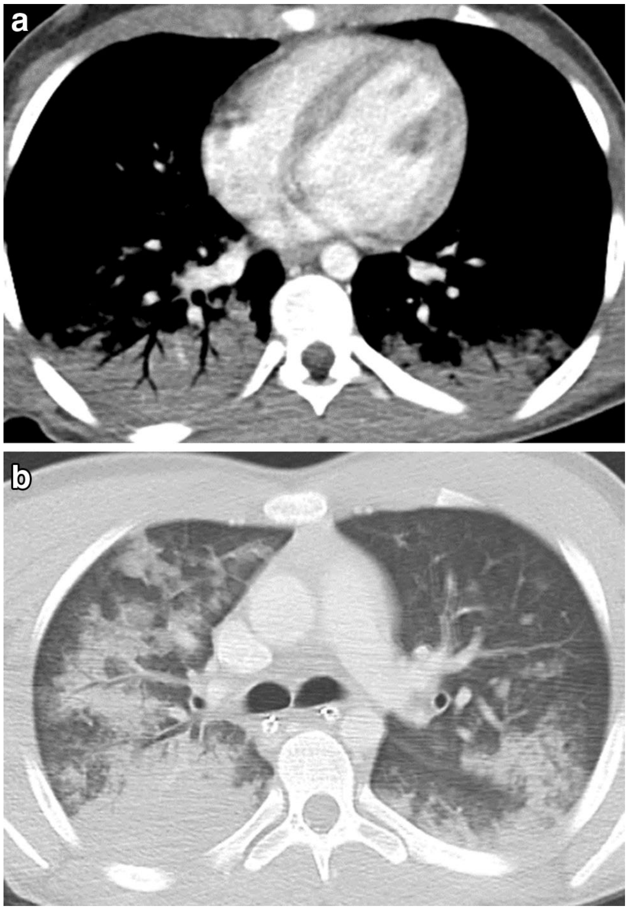


Fig. 11 **a**, **b** 14-year-old boy playing baseball. When he fell, another player landed with his knee pounding on his chest. The patient went into ventricular tachycardia, ventricular fibrillation, and was pulseless. The patient was resuscitated and intubated and presented with respiratory failure with hypotension. Catheter coronary angiography prior to the MDCT demonstrated injury to the left main coronary artery extending to the left anterior descending coronary artery. Axial MDCT images with intravenous contrast performed after angiography show left ventricular chamber enlargement and airspace opacities consistent with pulmonary edema (both secondary signs of cardiac injury. Of note, heterogeneous enhancement of the myocardium is secondary to retained contrast from the prior angiography

contained within the potential space between the visceral and parietal pericardium while the gas in pneumomediastinum extends about the mediastinal fat.

Extensive hemopericardium can result in findings of tamponade with early diastolic collapse of the RV free wall with notching (Fig. 9a). If images are acquired in late diastole, right atrial flattening may be seen. Non ECG-gated studies often have a combination of findings. Secondary findings of tamponade include enlarged collateral pathway formation, dilation of the inferior vena cava, a fluid–fluid level in the inferior vena cava, and reflux of contrast into the intrahepatic inferior vena cava (Fig. 9b, c).

Contour irregularities, dimpling, and discontinuity of the pericardium should raise suspicion of injury to the pericardium (Fig. 8). Frank tears of the pericardium are less commonly encountered, but can also be seen on MDCT (Fig. 8). In severe cases, blunt thoracic trauma can

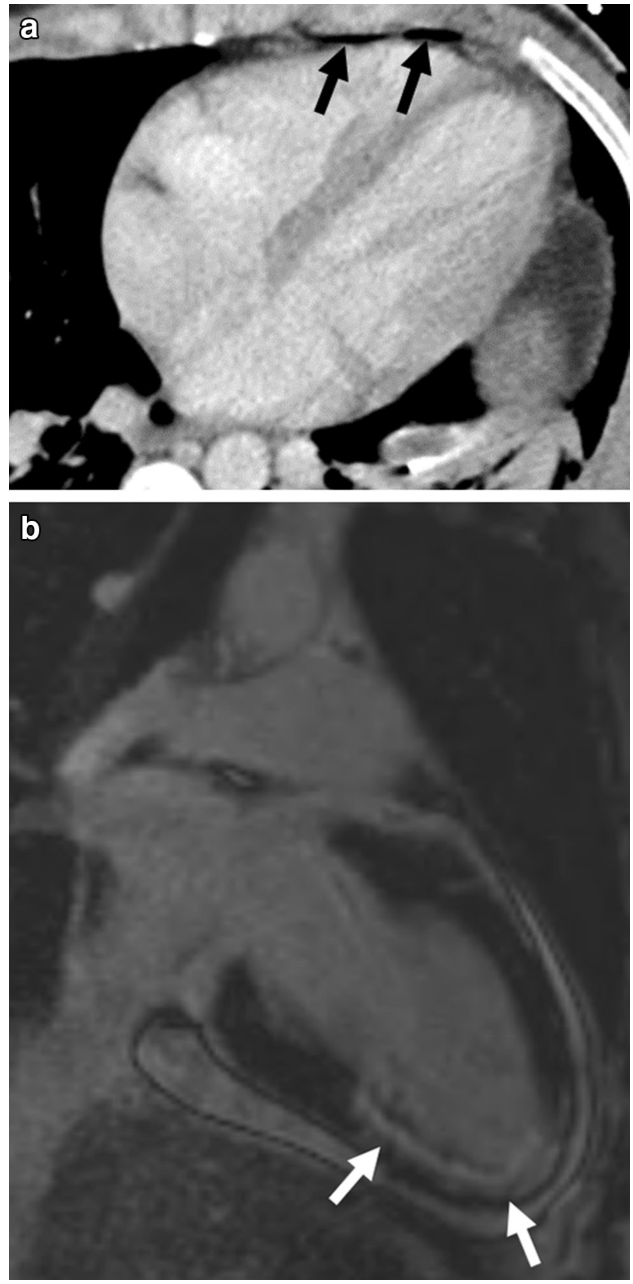


Fig. 12 **a**, **b** 28-year-old man involved in an MVC. Axial MDCT image with contrast (**a**) demonstrates pnuemopercardium (black arrow), but no direct signs of cardiac injury. At presentation, the patient had elevated troponins and a right coronary artery injury was confirmed on catheter angiography (images not included). A follow-up cardiac MRI was performed with 2-chamber long axis delayed post-contrast phase sensitive inversion recovery image showing subendocardial and transmural delayed contrast enhancement of the inferior septal wall near mid ventricle and apex (white arrow) consistent with a resultant myocardial infarct in the right coronary artery territory

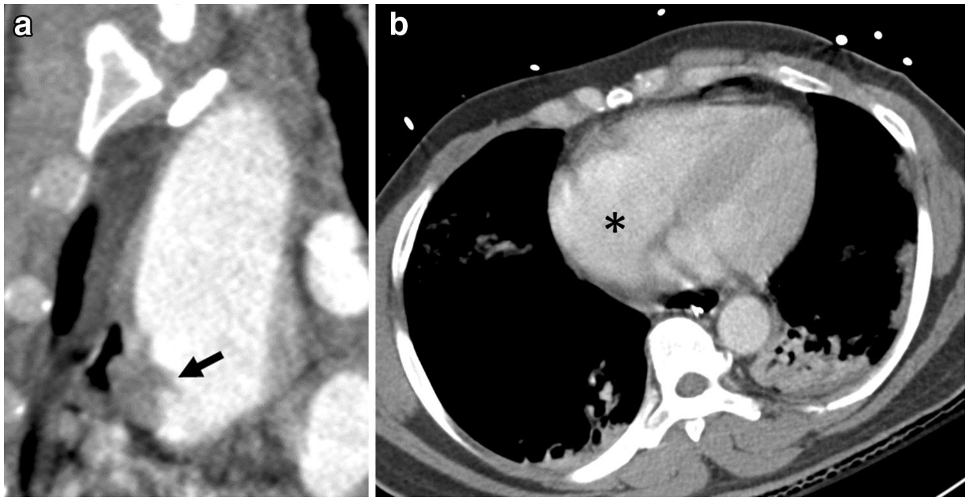
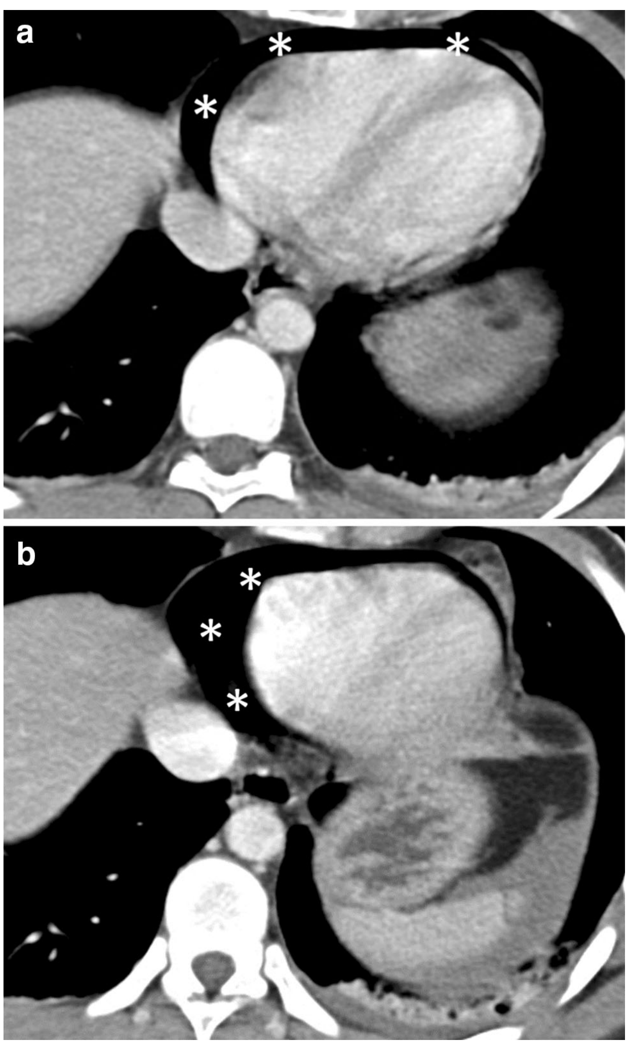


Fig. 13 **a**, **b** 28-year-old man involved in an MVC. Axial post-contrast MDCT image (**a**) demonstrates an aortic injury as noted by the hematoma effacing the fat plate with the ascending aorta (black arrows). The patient went to the operating room for repair of the aorta and valve replacement. The patient subsequently developed symptoms of right sided heart failure with severe tricuspid regurgitation seen on echocardiography. Review of the initial images (**b**) at time of presentation show enlargement of the right atrium (black asterisk), a finding which retrospectively is suggestive of tricuspid valve dysfunction



◀**Fig. 14** **a**, **b** 38-year-old man status post stab wound to the chest. Axial MDCT images with intravenous contrast demonstrate extensive pneumopericardium (white asterisks), an indirect finding of cardiac injury. At surgery, a right ventricular free wall injury was confirmed

result in traumatic diaphragmatic hernias which can herniate into the pericardial sac or pleural space leading to compression of the ventricles (Fig. 10a, b). Cardiac luxation is a rare but serious complication of pericardial rupture leading to cardiac herniation and volvulus, placing the patient at risk for superior vena cava and right heart obstruction. MDCT may demonstrate displacement of the heart within the thoracic cavity herniating through a pericardial defect with possible leftward bowing of the septum and/or ventricular entrapment.

Coronary Artery Injury

Coronary artery injury is a rare complication of blunt cardiac trauma. The most recent autopsy series demonstrated a 3% incidence of coronary artery injury in the setting of blunt trauma [5]. The most commonly injured coronary vessel is the left anterior descending coronary artery. Given its location posterior to the sternum, injuries to the right coronary artery also may occur. Injuries to the left circumflex coronary artery are rarely encountered. Patients may present with symptoms including arrhythmia and hypotension. ECG may show ST-segment elevation suspicious for myocardial infarction and chest radiograph may demonstrate pulmonary edema. If clinical and EKG findings are suggestive of acute coronary syndrome after sustaining blunt thoracic trauma, coronary artery

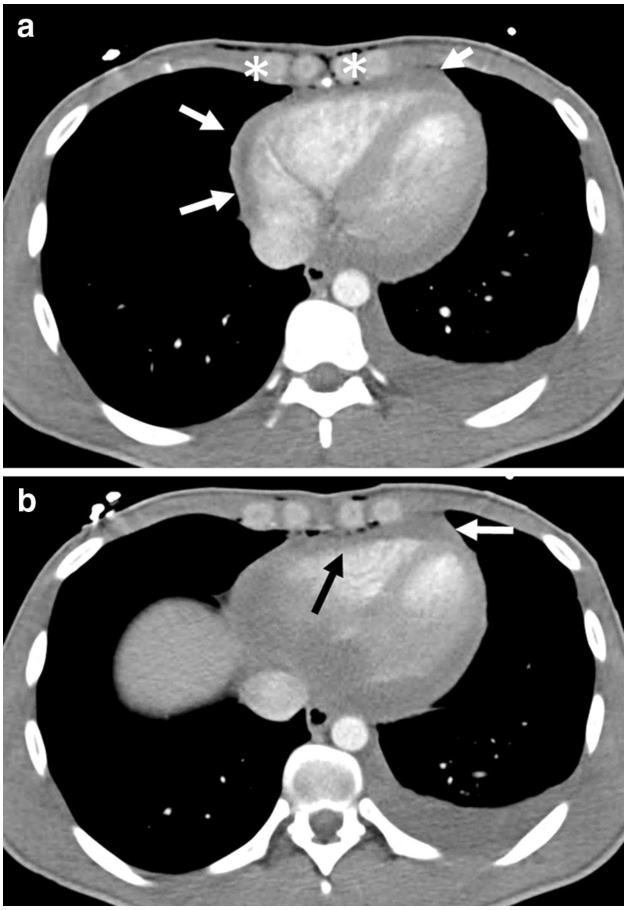


Fig. 15 **a**, **b** 23-year-old man status post stab wound to the chest. Axial MDCT images with intravenous contrast demonstrate extensive small soft tissue gas overlying the chest wall (white asterisks) with small volume hemopericardium (white arrow). There is resultant mass effect with dimpling of the right ventricular free wall (black arrow). While no direct sign of myocardial injury was present on the MDCT examination, the suspicion of a right ventricular free wall injury was raised given the hemopericardium. Injury to the right ventricular free wall was confirmed and repaired at time of surgery

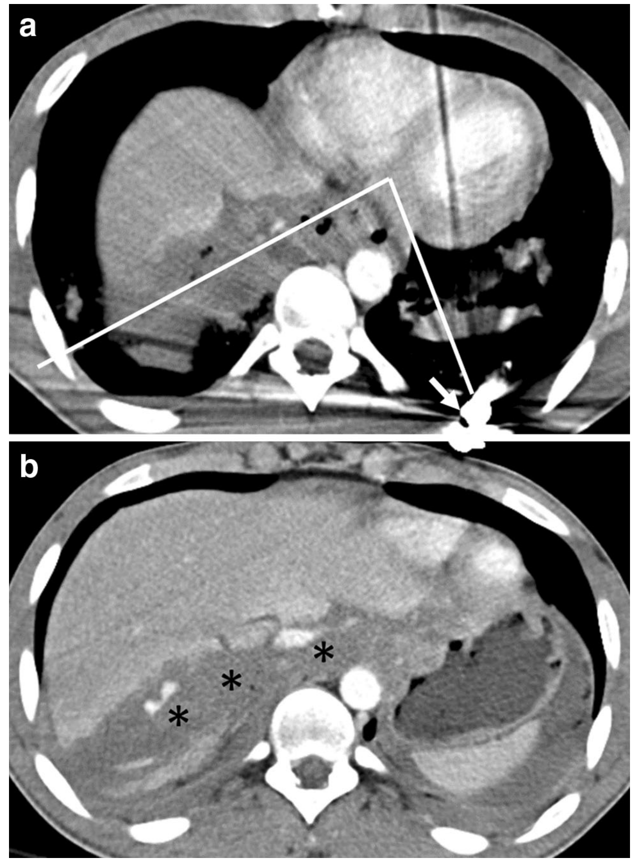


Fig. 16 **a**, **b** 34-year-old patient status post gunshot wound. Axial MDCT images with intravenous contrast show a bullet located within the posterior left hemithorax (white arrow). Evaluation of the bullet tract (yellow arrow) demonstrates that the bullet took a course (white line) from the right hemithorax through the liver ricocheting off of the posterior aspect of the left ventricle. Of note there is an extensive liver laceration (black asterisks). These findings raised the suspicion for injury to the posterior wall of the left ventricle, which was confirmed and repaired at surgery

angiography is the standard of care as interventions such as stenting or angioplasty can be performed at that time. In our practice, there is no primary role for coronary CT angiography in this setting. Findings suggestive of coronary artery injury on routine trauma MDCT injury include pulmonary edema, decreased attenuation of the myocardium in a vascular territory, and ventricular chamber enlargement secondary to ischemia [transient ischemic dilatation] (Fig. 11a, b). Although CT examinations in trauma are not routinely ECG gated, if gating or a high-pitch mode is used, direct findings of coronary artery injury including aneurysm or dissection may be identified. Coronary artery injury after blunt trauma may also present in a delayed fashion with findings of an infarct seen on follow-up MDCT or MRI (Fig. 12a, b).

Valvular Dysfunction

Valvular dysfunction is a rare consequence of blunt cardiac injury. At autopsy, the incidence of valvular injury has been reported in about 5% of patients sustaining blunt cardiac trauma [5]. The aortic valve is the most commonly injured valve in the setting of blunt chest injury [14]. The atrioventricular valves are the next most commonly injured followed by the pulmonic valve. While the exact mechanism is not definitively known, it is proposed that a sudden increase in intracardiac pressure against a closed valve creates a high pressure gradient across the valve and can ultimately result in injury [15]. Echocardiography remains the most useful imaging tool for evaluation of valvular dysfunction as it allows for dynamic imaging of the valve throughout the cardiac cycle. Valvular injury may present with immediate symptoms or in a delayed fashion several weeks after the injury, particularly in the setting of

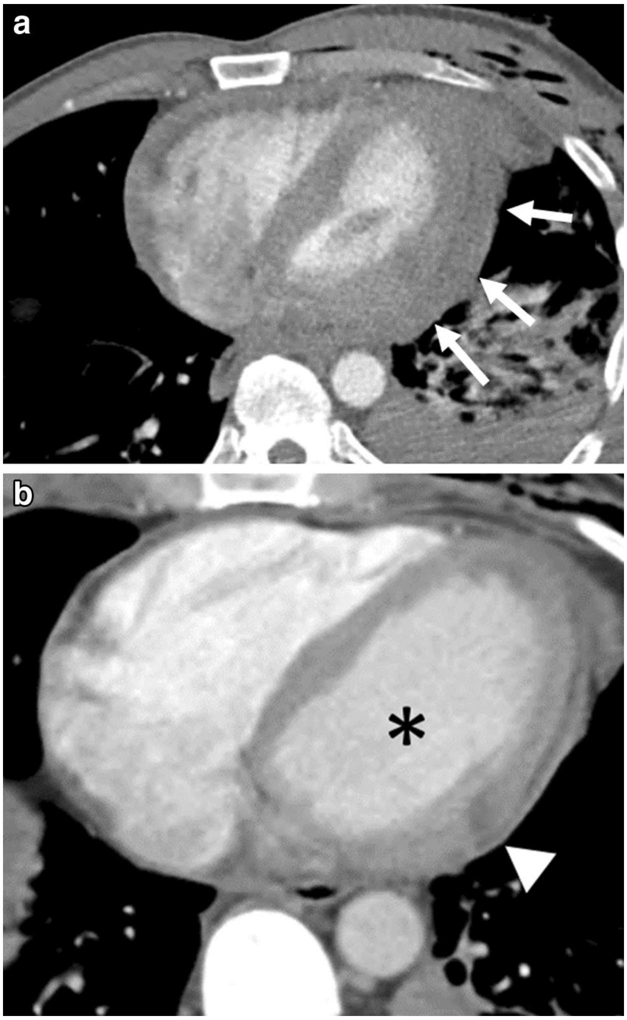


Fig. 17 **a**, **b** 34-year-old patient status post gunshot wound. Axial MDCT image with intravenous contrast at the time of presentation **a** shows hemopericadium (white arrow), an indirect finding of cardiac injury. Follow-up axial MDCT image with intravenous contrast several days later **b** shows enlargement of the left ventricle (black asterisk) and a focal area of myocardial hypoenhancement in the lateral wall of the left ventricle (white arrowhead). A cardiac laceration in this location was confirmed at surgery

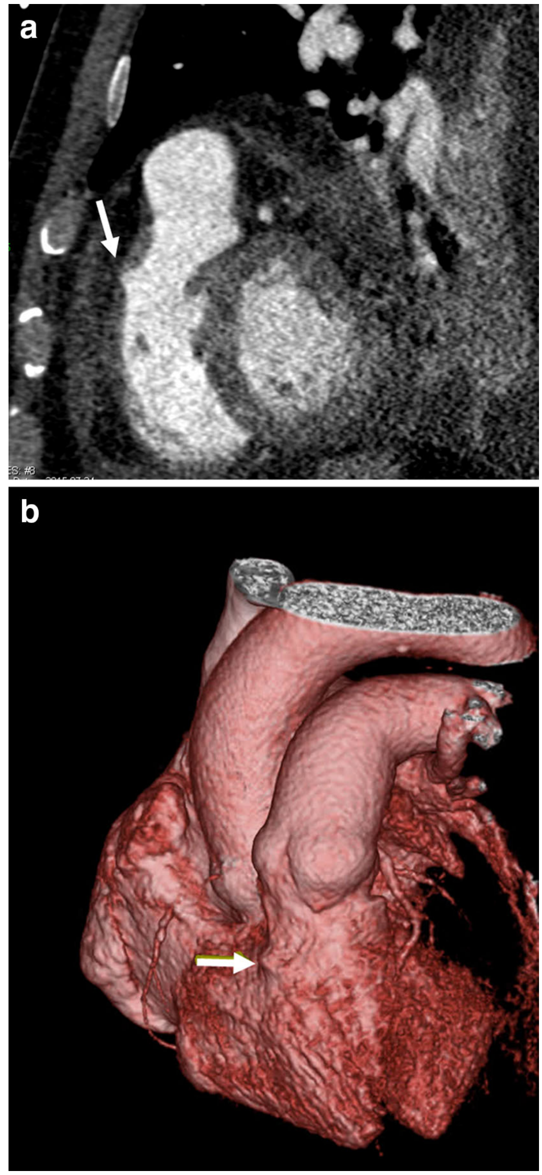


Fig. 18 **a**, **b** 28-year-old man stabbed in the chest. Sagittal MDCT images (**a**) and volumetric 3D reconstructions (**b**) with intravenous contrast demonstrate a contour irregularity and focal outpouching of the right ventricular free wall myocardium (white arrow) raising the suspicion for cardiac injury. The findings were confirmed at surgery at the time of repair

pulmonic or tricuspid injury [16]. Evaluation of valvular dysfunction is limited on non-gated MDCT examinations obtained in the setting of acute trauma, but the indirect finding of chamber enlargement may be seen at the time of initial evaluation or on follow-up (Fig. 13a, b). Traumatic injury to the mitral valve can present with findings of pulmonary edema which may be localized to the right upper lobe [17].

Penetrating Cardiac Injury

Penetrating cardiac injury is frequently lethal and has a reported incidence of 0.16% of admissions to trauma centers [18]. Current mortality rates of penetrating cardiac injury vary depending upon the mechanism of injury, with gunshot wounds being more fatal than stab wounds. Reported survival rates range from 3 to 84% [6••, 19–23]. The right ventricle is the most frequently injured cardiac chamber in penetrating trauma [6••, 24, 25]. Injury to the left ventricle has a poor prognosis with a majority of the patients expiring in the field. Trauma to more than one cardiac chamber is often seen in penetrating injury, particularly in the setting of gun violence.

Diagnosis of penetrating cardiac injury should begin with a physical examination and evidence of injury to the

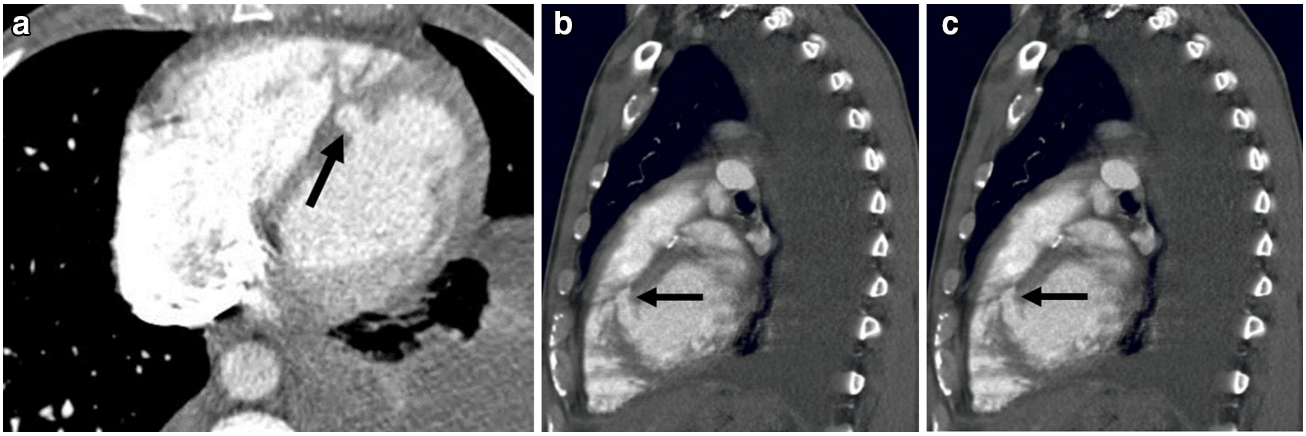


Fig. 19 **a**, **b** 28-year-old man stabbed in the chest. Axial (**a**) and sagittal (**b**) MDCT images with intravenous contrast demonstrate a post traumatic ventricular septal defect (black arrow) as a result of the stab wound. The septal defect was repaired at surgery

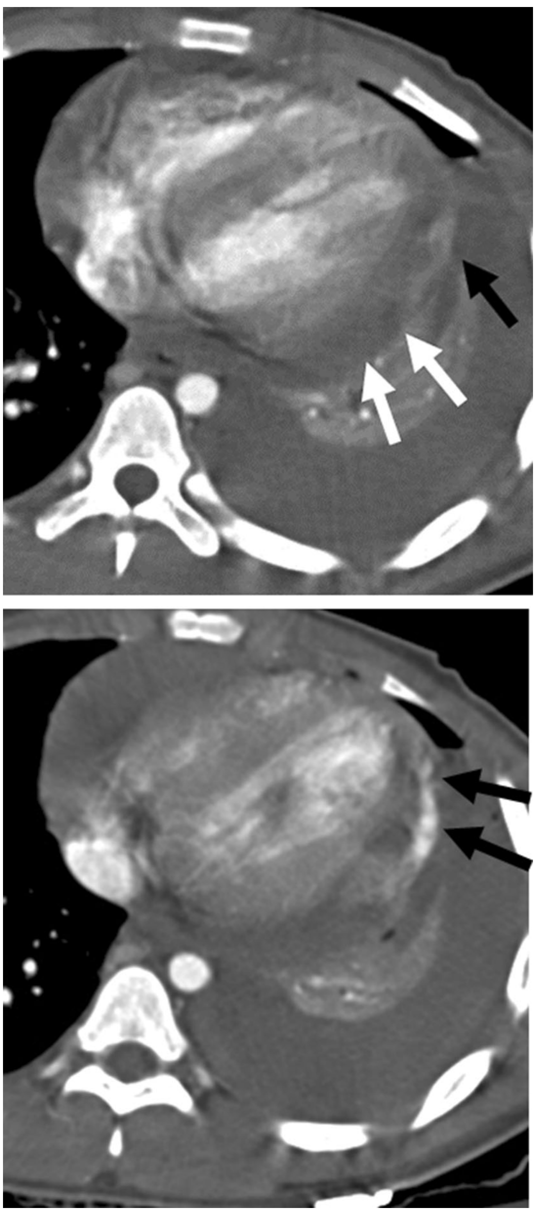


Fig. 20 **a**, **b** 44-year-old man stabbed in the chest. Axial MDCT images with intravenous contrast demonstrate hemopericardium (white arrow), an indirect finding of myocardial injury. Extravasation of contrast (black arrow) from the left ventricle, a direct finding of myocardial injury, was also present, consistent with penetrating cardiac injury to the left ventricle. The findings of penetrating injury to the left ventricle were confirmed and repaired at surgery

chest wall. In patients with thoracic gunshot wounds there should be a high concern for possible cardiac injury. Other clinical findings such as hypotension, jugular venous distension, and muffled heart sounds are suggestive of cardiac tamponade and can be used to raise the suspicion of cardiac injury.

In stable patients and those who receive imaging upon presentation to the hospital, MDCT can be a useful imaging tool for workup of penetrating cardiac injury with a high reported sensitivity, specificity, and accuracy [26]. Findings of penetrating injury may include indirect signs such as pneumopericardium, hemopericardium, intrapericardial herniation, and mediastinal hematoma (Fig. 14a). These indirect signs can prompt further investigation for possible myocardial injury (Fig. 15a, b).

In our experience, the most useful sign in penetrating injury is the trajectory of the projectile. Findings which can be seen in blunt trauma, including hemopericardium or pneumopericardium, may be absent. MDCT is a valuable tool when evaluating potential sites of injury as it allows for delineation of stab wound and ballistic trajectories which are not always apparent on physical examination (Fig. 16a). Furthermore, bullets that penetrate the thorax can take complex bullet pathways causing a great deal of collateral damage (Fig. 16b). Bullets that enter cardiac chambers and/or great vessels can embolize distally to other parts of the body and be seen elsewhere on MDCT examinations. Penetrating injury to the myocardium may present in a delayed fashion with indirect findings such as chamber enlargement and direct findings such as myocardial hypoenhancement seen on follow-up examinations (Fig. 17a, b). MDCT may also demonstrate direct signs of cardiac injury including the presence of a pseudoaneurysm/focal outpouching to the involved ventricles, posttraumatic ventricular septal defect, or frank ventricular rupture (Figs. 18a, b, 19a, b, 20a, b).

Conclusion

While the request to evaluate specifically for cardiac injury in the acute setting rarely occurs, MDCT is a valuable tool for evaluation of both blunt and penetrating thoracic trauma. MDCT offers advantages over other imaging modalities and is the workhorse for evaluation of acute cardiac injury. An understanding of the direct and indirect imaging findings of cardiac injury can help make a prompt diagnosis and direct life-saving care.

Compliance with Ethical Guidelines

Conflict of interest Demetrios A. Raptis, Sanjeev Bhalla, and Constantine A. Raptis each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- •• Of major importance

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