Eur Radiol (2009) 19: 789–799
DOI 10.1007/s00330-008-1231-3

CHEST

Thomas Frauenfelder
Philippe Appenzeller
Christoph Karlo
Hans Scheffel
Lotus Desbiolles
Paul Stolzmann
Borut Marincek
Hatem Alkadhi
Thomas Schertler

Triple rule-out CT in the emergency department: protocols and spectrum of imaging findings

Received: 15 August 2008
Revised: 2 October 2008
Accepted: 9 October 2008
Published online: 18 November 2008

T. Frauenfelder (✉) · P. Appenzeller · C. Karlo · H. Scheffel · L. Desbiolles · P. Stolzmann · B. Marincek · H. Alkadhi · T. Schertler
Department of Medical Radiology, Institute of Diagnostic Radiology, University Hospital Zurich,
Raemistrasse 100,
8091 Zurich, Switzerland
e-mail: thomas.frauenfelder@usz.ch
Tel.: +41-44-2559383
Fax: +41-44-2554443

Abstract Triage decisions in patients suffering from acute chest pain remain a challenge. The patient's history, initial cardiac enzyme levels, or initial electrocardiograms (ECG) often do not allow selecting the patients in whom further tests are needed. Numerous vascular and non-vascular chest problems, such as pulmonary embolism (PE), aortic dissection, or acute coronary syndrome, as well as pulmonary, pleural, or osseous lesions, must be taken into account. Nowadays, contrast-enhanced multi-detector-row computed tomography (CT) has replaced previous invasive diagnostic procedures and currently represents the imaging modality of choice when the clinical suspicion of PE or acute aortic syndrome is raised. At the same time, CT is capable of detecting a multitude of non-vascular causes of acute chest pain, such as pneumonia, pericarditis, or fractures. Recent technical advances in CT technology have also shown great advantages for non-invasive imaging of the coronary arteries. In patients with acute chest pain, the optimization of triage decisions and cost-effectiveness using cardiac CT in the emergency department have been repetitively demonstrated. Triple rule-out CT denominates an ECG-gated protocol that allows for the depiction of the pulmonary arteries, thoracic aorta, and coronary arteries within a single examination. This can be accomplished through the use of a dedicated contrast media administration regimen resulting in a simultaneous attenuation of the three vessel territories. This review is intended to demonstrate CT parameters and contrast media administration protocols for performing a triple rule-out CT and discusses radiation dose issues pertinent to the protocol. Typical life-threatening and non-life-threatening diseases causing acute chest pain are illustrated.

Keywords Cardiac · CT · Chest · Chest pain

Introduction

Chest pain is one of the most common symptoms in emergency departments, comprising 5–20% of emergency department visits [1, 2]. Despite this relatively common symptom, however, early triage of these patients remains difficult. The patient's history, initial biomarkers, and the results from electrocardiography (ECG) often do not allow a safe distinction between patients who require hospital admission with further testing and those who can be safely discharged home [3–5]. This complexity results in a high number of unnecessary hospital admissions that in turn have enormous economic consequences for the health-care system [6].

Nowadays, chest CT using a non-ECG-gated protocol represents the reference imaging modality for the diagnosis or exclusion of pulmonary embolism (PE) and aortic dissection [7, 8]. On the other hand, potentially life-threatening underlying diseases such as acute coronary syndrome (ACS) — accounting for 15–25% of the patients with acute chest pain [1] — cannot be assessed by using a non-ECG-gated protocol.

Recently, the use of ECG-gated CT coronary angiography in the emergency department has been shown to improve the triage of patients with acute chest pain by decreasing the delay in diagnosis and treatment and thus morbidity and mortality [9, 10]. In addition, CT coronary angiography has shown a good diagnostic performance for the detection of ACS and an excellent negative predictive value for excluding the disease [7, 8, 11], emphasizing a potential role of CT for facilitating and optimizing triage decisions in the emergency patient [11, 12].

One of the most recent CT types, dual-source CT (DSCT), maintains the high spatial resolution of previous single-source 64-slice CT systems while enabling ECG-gated imaging with an increased temporal resolution [13]. A number of studies have shown robust and auspicious results of DSCT coronary angiography regarding image quality [14, 15] and accuracy [16, 17].

Recently, several studies have demonstrated that an ECG-gated CT of the entire chest is feasible and allows for an accurate evaluation of the pulmonary artery, the thoracic aorta, and the coronary arteries as well as of non-vascular structures within a single examination [18, 19]. Such a protocol, in jargon also called *triple rule-out CT*, requires the adjustment of the contrast media application protocol for the simultaneous attenuation of three vascular territories, i.e., aorta, pulmonary, and coronary artery [20]. Nevertheless, the precise indication, the optimal triple rule-out CT protocol, and the appropriate patient population are still not defined. A recently published prospective study concluded that in a low-to-moderate risk ACS population, triple rule-out coronary CT angiography identifies non-coronary diagnoses, limiting additional diagnostic testing to a small proportion of the population and facilitating a safe, rapid discharge of the majority of patients suspected of having ACS [21].

This article is intended to review CT parameters and contrast media administration protocols that allow performing a triple rule-out CT examination in the acute chest pain patient and discusses radiation dose issues pertinent to the protocol. A few life-threatening and non-life-threatening diseases causing acute chest pain are illustrated.

Patient population

As mentioned above, the appropriate indication and the patient population profiting most from tripe rule-out CT has not yet been defined. Patients presenting to the emergency department usually are monitored with an ECG, and cardiac biomarkers are tested in the blood sample. Figure 1 demonstrates possible triage decisions for a patient with acute chest pain with respect to CT imaging. In general, inclusion criteria of a triple rule-out CT chest protocol have to be adequately defined and adapted to patient-specific characteristics, such as age, sex, clinical presentation, and pretest probability. We recommend in our institution performing a triple rule-out CT in patients with acute chest pain in whom initial cardiac biomarkers are negative and ECG is non-diagnostic and in whom a combined clinical suspicion of (1) acute PE and acute aortic syndrome (AAS), (2) acute PE and ACS, or (3) acute PE and AAS and/or ACS has been raised.

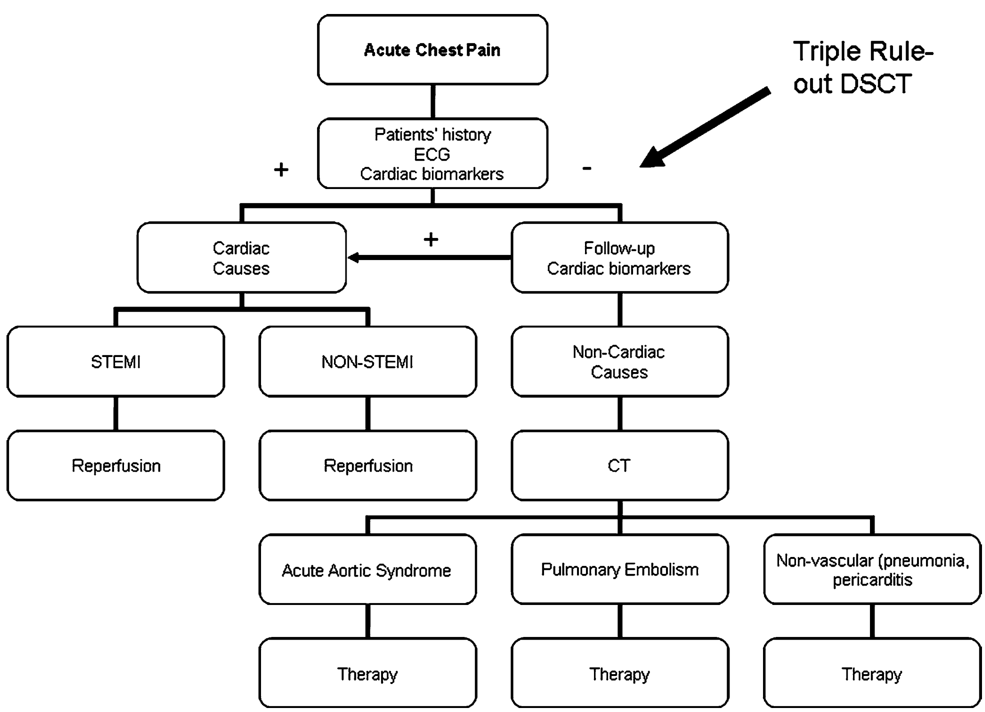


Fig. 1 The exact role of CT imaging in these patients has not yet been defined. For evaluating non-cardiac causes of acute chest pain, CT nowadays can be considered the imaging modality of choice. An earlier time point for the use of CT in patients with acute chest pain as indicated in the flow chart could potentially improve the patient triage and accelerate therapy decisions

Exclusion criteria are pregnancy, previous adverse reaction to iodinated contrast agents, nephropathy, elevated cardiac biomarkers (troponine-I or creatine kinase-MB) in the initial blood sample, ECG changes indicating an ACS, and interference with standard clinical care of patients. In addition, patients aged ≤40 years should be excluded from a triple rule-out CT because of the increased radiation exposure associated with the protocol [22].

CT parameters

In our institute, all CT examinations of patients suffering from acute chest pain are performed on a DSCT system (Somatom Definition, Siemens Medical Solutions, Forchheim, Germany). No beta-receptor antagonists are administered before CT, irrespective of the regularity or mean heart rate of the patients.

All patients are instructed to hold their breath during mild inspiration to avoid a Valsava maneuver. The acquisition parameters are as follows: detector collimation 2×32×0.6 mm using a z-flying focal spot for the simultaneous acquisition of 2×64 overlapping 0.6-mm slices, rotation time 330 ms, tube current time product 330 mAs per rotation, tube potential 120 kV, and pitch 0.2–0.5 depending on the heart rate.

For a triple rule-out CT, the optimal direction of movement of the patient during CT data acquisition is still a matter of debate. We generally acquire data in a cranio-caudal direction, as previously reported [18, 19].

Radiation dose considerations

ECG-gated triple rule-out CT is associated with a higher radiation dose when compared to a standard, non-ECG-gated CT pulmonary angiogram [22]. Several techniques can be used to reduce the radiation dose to a level that is as low as reasonably achievable (ALARA).

An important technique is ECG-based tube current modulation (or ECG-pulsing) that reduces the tube current outside the pulsing window to 25% of the nominal tube output [23]. DSCT allows the flexible adaptation of the ECG-pulsing window width that helps in tailoring the ECG-pulsing window to be as narrow as possible for maximal reduction of radiation exposure and to be as wide as necessary to obtain diagnostic image quality. As previously recommended [24], nominal tube current should be applied from 60 to 70% of the RR interval at mean heart rates below 60 bpm, from 50 to 80% at 61–70 bpm, and from 30 to 80% at heart rates above 70. The use of this ECG-pulsing protocol results in an effective dose of a cardiac DSCT examination of approximately 8–9 mSv [25].

Another technique is called MinDose (Siemens) that further reduces the tube current outside the pulsing window from 25% to 4% of the nominal tube output. This enables an additional, significant dose reduction to approximately 7 mSv for a cardiac DSCT scan [25]. Finally, patients with a body mass index below 25 kg/m^2 can be examined with a tube voltage of 100 kV, resulting in an effective radiation dose of 4–7 mSV for cardiac DSCT [26].

Taking into account the wider coverage when examining the entire chest, triple rule-out DSCT is associated with an average estimated effective dose of 16–17 mSv.

This level of radiation dose is below [27] or close to [28] that of previous single-source 64-slice CT coronary angiography protocols. The radiation dose levels of a standard, non-ECG-gated CT pulmonary angiogram are approximately 5 to 7 mSv [29] and range from 2 to 23 mSv for a purely diagnostic catheter coronary angiography [30]. These values must be taken into account when discussing the dose values of a triple rule-out CT. Nevertheless, the extra radiation burden has to be weighed against the potential clinical benefit when exposing a patient to triple rule-out CT.

Contrast administration protocol

Determining the optimal contrast material application regime to yield diagnostic image quality of each arterial territory (i.e., aorta, pulmonary, and coronary arteries) remains a challenge. The peak arterial contrast enhancement of the aorta and coronary arteries can be assumed to occur at a comparable time after injection. In contrast, the peak arterial enhancement of the pulmonary arteries takes place earlier (Fig. 2). This difference between the pulmonary and aortic/coronary artery enhancement is referred to as the transit time and lasts about 11 s [20]. This transit time has to be taken into account when aiming at a homogeneous attenuation of all three vascular territories. A recent study has compared bolus-tracking with the test-bolus technique with regard to the

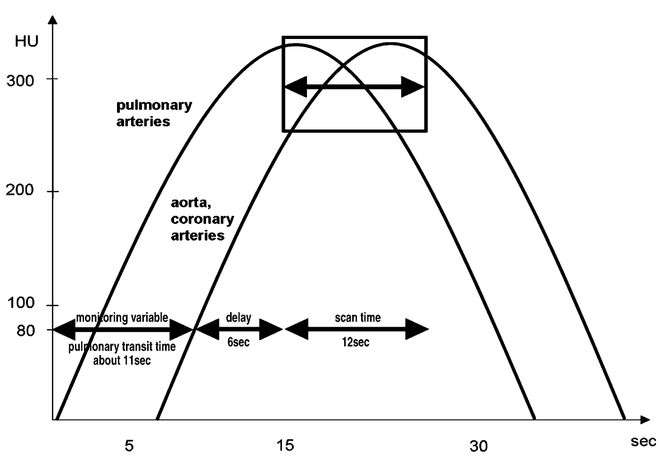
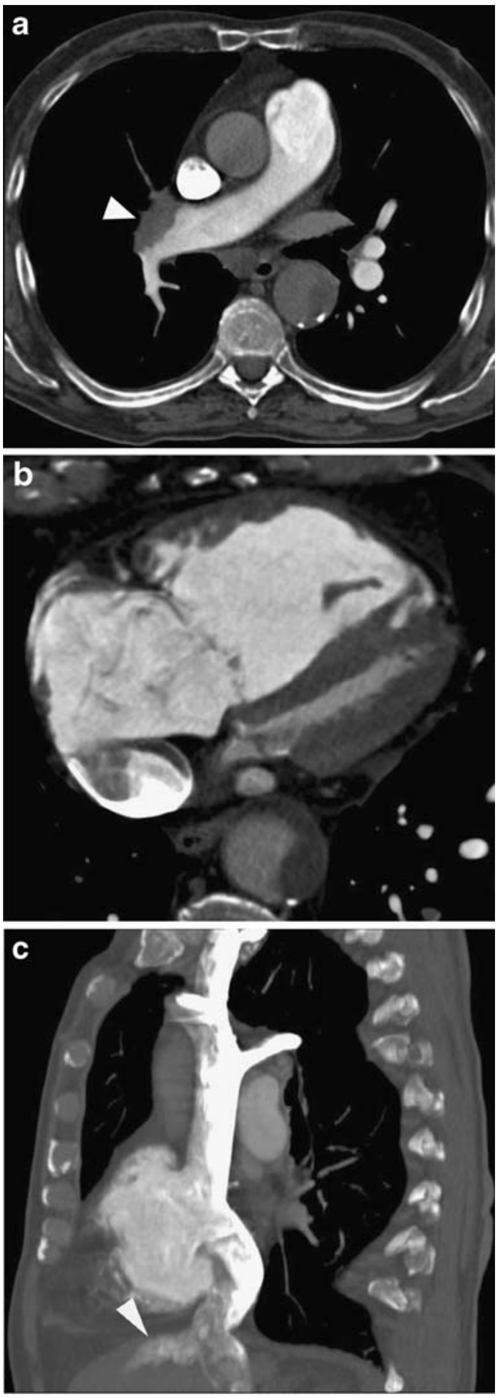


Fig. 2 Triple rule-out CT is aimed at a simultaneous, homogenous, and high contrast attenuation (>250 HU) of the pulmonary arteries, the aorta, and the coronary arteries that requires the use of a dedicated contrast-medium application protocol. This must take into account the transit time between the pulmonary and aortic/coronary opacification that normally lasts about 11 s

simultaneous opacification of these vascular territories and found no significant difference between the techniques [20]. The authors concluded that the bolus-tracking technique may be preferable in order to avoid the additional amount of contrast medium required for the test bolus.

In our institution, the initiation of CT data acquisition is timed by using the bolus tracking technique. A single non-enhanced low-dose image at the level of the aortic root is obtained first. In this slice, a region of interest (ROI) is set in the lumen of the ascending aorta for monitoring enhancement. A total of 120 ml iodinated contrast material (Ultravist 370; 370 mg/ml, Bayer Schering Pharma, Berlin, Germany) is administered at a flow rate of 4 ml/s via an 18-gauge needle placed into a superficial vein in the right antecubital fossa, followed by 30 ml saline solution at the same flow rate (4 ml/s). After reaching the preset contrast enhancement level of 80 Hounsfield units (HU) in the ROI, a breath-hold signal is given, and the formal CT acquisition is initiated automatically after a delay of 6 s.

Use of such a contrast medium application protocol usually results in homogeneous attenuation of the pulmonary trunk, ascending aorta, and coronary arteries [19]. This is important, as a minimum coronary attenuation of 250 HU is required to obtain diagnostic images of the coronary arteries [31].



◀**Fig. 3** A 75-year-old male patient with known pulmonary artery hypertension presented to the emergency department with acute chest pain and worsening of the pulmonary function. Triple rule-out CT (**a**) showed a pulmonary embolus in the right main pulmonary artery (arrowhead). Four-chamber view of the heart (**b**) demonstrated a dilated right atrium and right ventricle resulting from chronic pulmonary artery hypertension with thickening of the right ventricular myocardium. Oblique MPR (**c**) revealed contrast media backflow into the inferior cava vein and the hepatic veins (arrowhead) as an indirect sign of right-heart failure. As a result of the increased pressure in the pulmonary circulation and right heart failure, a decreased attenuation of contrast media was found in the ascending and descending aorta. Note the thrombotic wall lesion in the descending aorta

CT data reconstruction

Retrospective ECG-gating for phase synchronization is generally used. The feasibility of prospective ECG-triggering (or step-and-shoot mode) [32] for a triple rule-out CT protocol has not been tested so far. Reconstructions of the heart and coronary arteries are routinely performed during mid-diastole. Images with a slice thickness of 0.75 mm (increment of 0.5 mm) and a medium soft-tissue convolution kernel (B26f and 45f) using a field-of-view (FOV) of 180–200 mm are reconstructed. If considered necessary, additional images are reconstructed in 5% steps within the time window of full tube current. Images of the mediastinum with a FOV of about 300 mm including the aorta and pulmonary arteries are reconstructed with a slice thickness of 1 mm (increment of 0.8 mm) by using a medium soft-tissue convolution kernel (B30f). Images of the lung are reconstructed with a slice thickness of 1 mm (increment of 0.8 mm) by using a sharp convolution kernel (B60f) and using the same FOV (300 mm).

Image analysis

All images are then analyzed on a workstation equipped with cardiac post-processing software. The evaluation of

CT images is performed by the combination of transverse source images, multi-planar reformations (MPR), curved MPR, maximum intensity projections (MIP), and volume rendering (VR).

MPR/curved MPR is the postprocessing technique of choice to generate cross-sectional images of the coronary arteries as well as of other thoracic vascular and non-vascular structures. Due to isotropic voxels, MPR of equal quality can be generated in any plane inside the 3D data volume. Curved MPR is used to depict an anatomic structure showing a tortuous course.

MIP displays the voxel with the maximal attenuation along a line through the volume dataset. The resulting images are 2D projections, giving a 3D impression by rotating the object [33]. Main applications are the depiction of vessels.

Compared to other 3D postprocessing techniques, *VR* renders the entire volume of image data. Each attenuation value is attributed a relative shading of opacity and color. VR is nowadays considered as the method of choice in 3D postprocessing [34], particularly in the visualization of complex vessel anatomy, but has minor diagnostic value.

In general, the combined use of the various post-processing techniques improves the overall understanding of the cardiovascular anatomical situation and therefore has the potential to reduce the time needed for a CT-based diagnosis [35].

Life-threatening causes of acute chest pain

Pulmonary embolism

Acute PE is a common and often fatal disease with a variable and unspecific clinical presentation. Mortality can be reduced by a prompt diagnosis and therapy. Frequently undiscovered until autopsy [36], fatal PE typically leads to death within 1 to 2 h of the event [37]. CT is nowadays the imaging modality of choice for acute PE and has replaced ventilation-perfusion lung scintigraphy and catheter pulmonary angiography, not only due to the higher accuracy, but also due to the fact that many other pathologies may cause similar symptoms [38, 39]. CT angiography enables the direct visualization of emboli within the pulmonary arteries as low attenuation filling defects within the vessel. The value of indirect CT signs of PE, such as pleural-based densities, linear densities, or plate-like atelectases, central or peripheral dilatation of pulmonary arteries, and pleural effusions of variable sizes, is less clear [40].

The right/left ventricle short axes ratio has shown a significant positive or negative correlation with the severity or with fatal outcome (Fig. 3). Studies have estimated that a ratio superior to 1.5 indicates a severe episode of PE [41, 42]. Other factors are still a matter of debate, such as, for example, the clot load of pulmonary arteries, pulmonary artery diameter, the leftward bowing of the ventricular septum, or the reflux of contrast medium into the inferior vena cava [41–44]. A considerable advantage of an ECG-gated chest CT protocol represents the ability to diagnose right ventricular dysfunction [45], which is an important prognostic marker in patients with PE. Thus, CT allows not only diagnosing PE, but also assessing its severity and prognosis, allowing risk stratification, which is important for rapidly initiating optimal management, monitoring, and therapeutic strategies [42].

Acute aortic dissection

Aortic dissection is a relatively uncommon but catastrophic illness. In the majority of cases, acute aortic dissection presents with tearing chest pain and hemodynamic

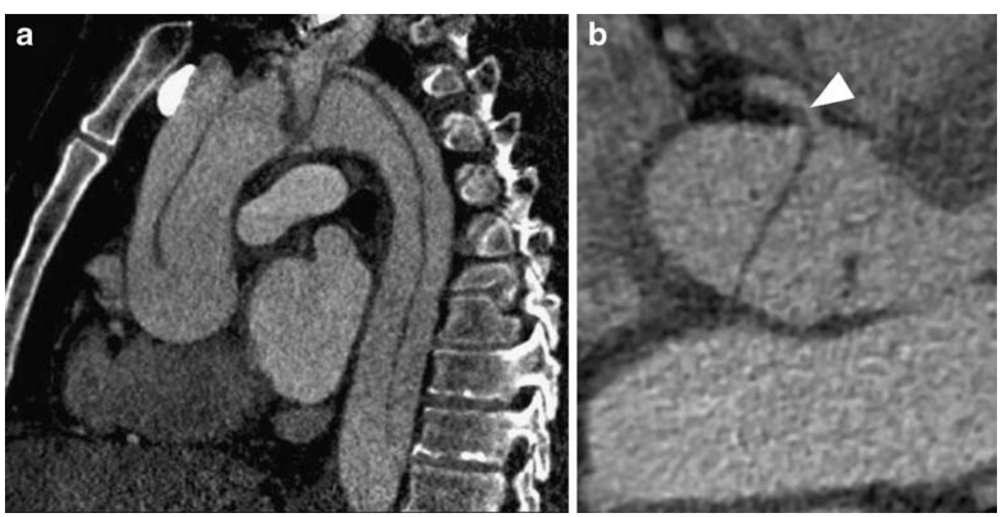


Fig. 4 A 52-year-old male patient with acute onset of severe, tearing, and radiating chest pain was referred to the emergency department. Triple rule-out CT using a sagittal MPR (**a**) showed a type A aortic dissection with an intimal flap forming the true and false lumen extending to the descending aorta. Curved MPR of the coronary arteries demonstrated extension of the dissection flap into the right coronary artery ostium (**b**; arrowhead)

compromise. Early diagnosis and treatment are crucial for survival. However, the diversity and complexity of the clinical presentation often predispose to a wrong or missed diagnosis [46]. Aortic dissections are classified according to the Stanford classification as type A (involving the ascending aorta) (Fig. 4 a) and type B (involving the aorta distal to the origin to the left subclavian artery) (Fig. 5).

There are occasional problems in diagnosing type A aortic dissection in non-ECG-gated CT examinations, as the extent of the dissection membrane at the level of the aortic valve cannot be evaluated [47]. The use of a triple rule-out DSCT protocol, including retrospective ECG gating, allows a motion artifact-free depiction of the membrane at the level of the aortic valve. This may demonstrate an extension of the dissection membrane into a coronary ostium or its occlusion [48]. Such information is mandatory for preoperative planning. Covering the entire cardiovascular structures of the chest with a single ECG-gated DSCT acquisition also makes possibile visualizing the run of the dissection membrane into the branches originating from the aortic root.

Acute coronary syndrome

ACS describes the clinical manifestation of acute myocardial ischemia induced by coronary artery disease (CAD) [9]. The typical clinical presentation of myocardial ischemia is acute chest discomfort. Although this disease is common, the clinical triage decisions are often ineffective, especially for patients who have chest pain but normal initial cardiac enzyme levels and normal or inconclusive

Fig. 5 A 64-year-old female patient was referred to the emergency department because of acute chest pain. An initially performed echocardiography was suspicious for a type A aortic dissection. However, triple rule-out CT using a sagittal MPR showed the intimal flap forming the true and false lumen arising just distal of the origin of the left subclavian artery (arrowhead), which corresponds to a type B aortic dissection

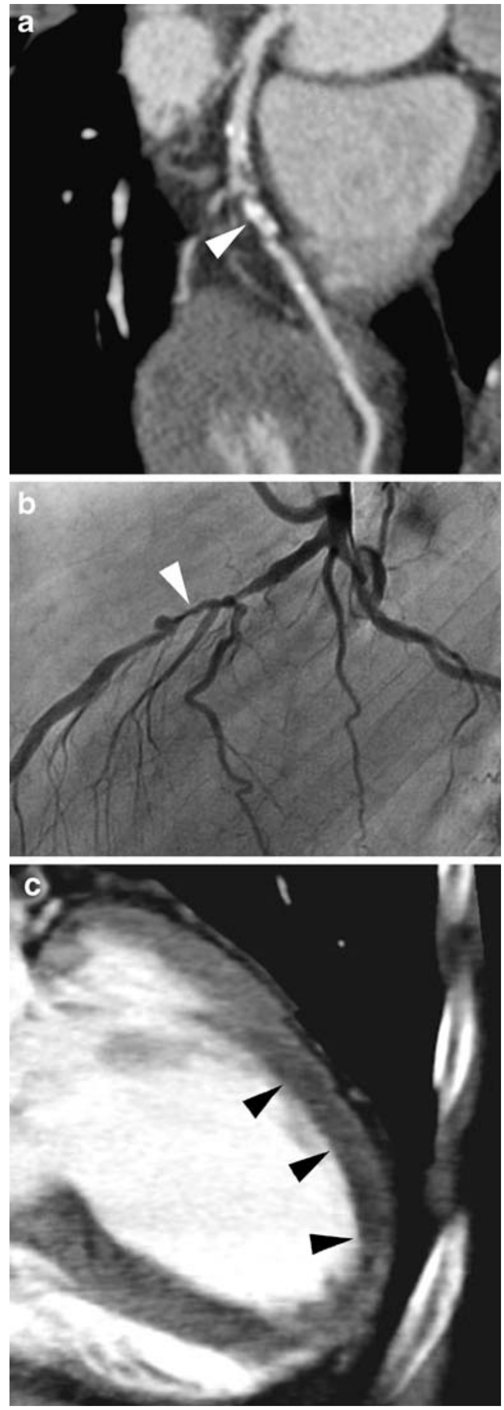


Fig. 6 A 53-year-old male patient with acute chest pain and shortness of breath arrives at the emergency department. Initial biomarkers were negative, and ECG was inconclusive. Curved MPR (**a**) showed a high-grade stenosis of the LAD (arrowhead) that was subsequently confirmed by catheter coronary angiography (**b**, arrowhead). Sagittal MPR of the left ventricle (**c**) demonstrated a myocardial perfusion defect of the anterior wall (arrowheads)

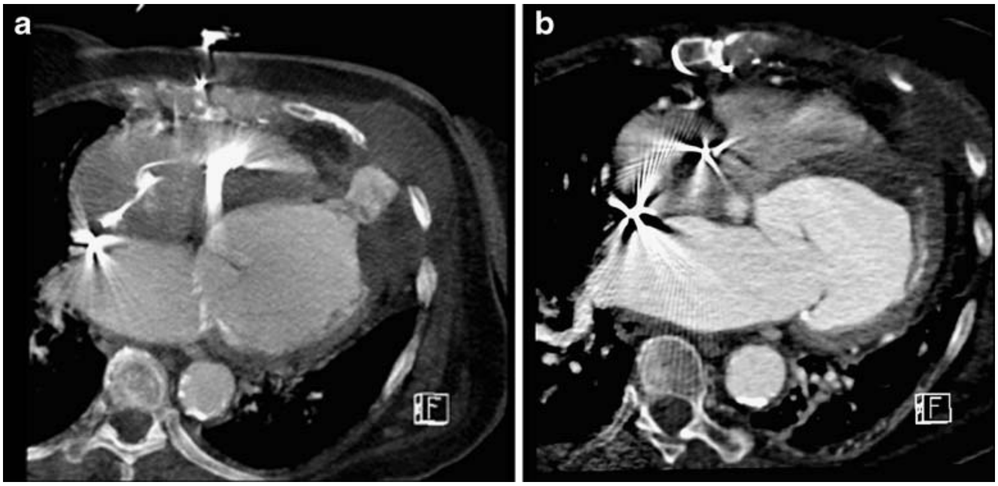


Fig. 7 A 67-year-old female patient presented to the emergency department with left-sided, sharp stabbing chest pain and dyspnea that was pronounced when changing from an upright to a supine position. Four months earlier, the patient had undergone a plastic repair of a left ventricular apical aneurysm after myocardial infarction. Triple rule-out CT with a four-chamber view of the heart (**a**) showed contrast media extravasation (arrowhead) from the apex into the adjacent chest wall, forming a hematoma (a; asterix). The patient underwent emergency surgery of the ruptured ventricle, and subsequent CT showed regular conditions after repair (**b**)

electrocardiograms [9]. It is known that over 50% of patients with acute chest pain do not have ACS [49]. In addition, in a considerable number — namely 2 to 4% — of patients with acute chest pain, the diagnosis of ACS is missed [50]. In recent years, CT has become an important non-invasive method for evaluating the coronary arteries. Especially the high sensitivity and negative predictive value of coronary CT angiography has rendered the modality an excellent filter test for patients with an intermediate pre-test probability of the disease [16].

It must be kept in mind, however, that the presence of coronary artery stenosis at cardiac CT cannot be equated with CAD as the cause of the patient's symptoms. CT only demonstartes the substrate for ACS, and not its presence.

In various studies, 64-slice CT accurately detected significant coronary artery stenosis compared to standard invasive coronary angiography (ICA), with sensitivities and specificities ranging between 91% and 100% [9, 12]. CT presents a fast and non-invasive method to detect the presence and extent of a CAD and provides information that cannot be obtained with a standard clinical evaluation (Fig. 6). Furthermore, CT may help to improve the triage in acute chest pain patients having an ACS and has the potential to lead to a clinical paradigm shift [51].

Nowadays, single-photon emission computed tomography myocardial perfusion imaging represents the most commonly applied clinical imaging modality for the detection of myocardial ischemia [52], although magnetic resonance imaging shows superior performance characteristics in controlled studies [53].

Recently, Cury et al. [54] showed that CT can also detect patients with recent myocardial infarction based on perfusion defects. In addition, CT has recently shown the capability to measure infarct size in acute myocardial

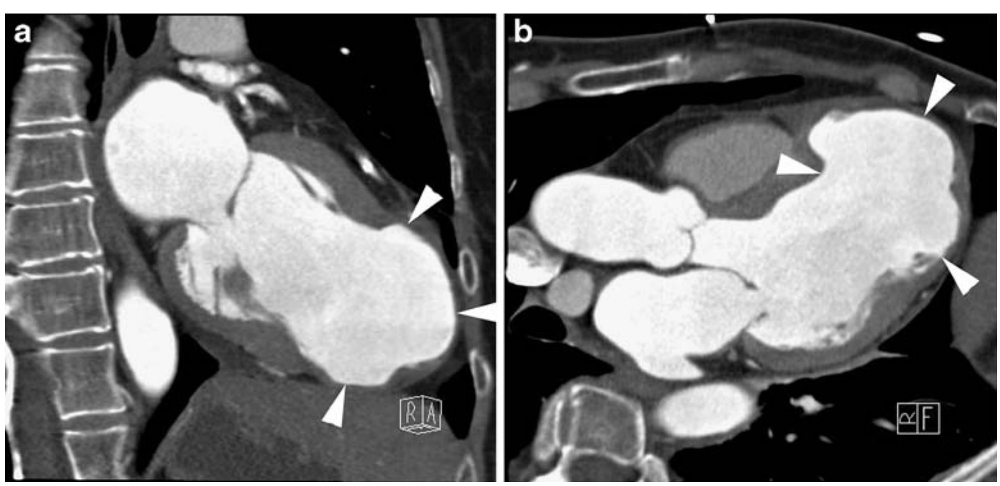


Fig. 8 A 54-year-old female patient presented to the emergency department with left-sided chest pain. Two years earlier, the patients had a myocardial infarction. Long axis (**a**) and sagittal oblique reconstruction (**b**) of the left ventricle showed a large pseudoaneurysm (arrowheads) on the apex

Fig. 9 A 42-year-old male presented to the emergency department with chest pain after exercise. Initial cardiac enzymes and ECG were negative. An anomaly of the RCA, originating from the left coronary sinus with an interarterial course between the pulmonary trunk and ascending aorta, was found (arrowheads). Note the calcified plaque on the proximal segment (arrow)

infarction by performing delayed contrast-enhanced imaging [55, 56].

An uncommon but dangerous complication after myocardial infarction is left ventricular wall rupture. This event is associated with a high mortality rate of 4% to 10% [57, 58] (Fig. 7). In contrast to ventricular wall rupture, a pseudoaneurysm is a contained rupture of the myocardium that can be seen after infarction, surgery, trauma, infection, or invasive medical procedures [59] (Fig. 8). Pseudoaneurysms are typically diagnosed with a delay of 6 months after infarction. The explanation for the development of a pseudoaneurysm is that the cardiac rupture is limited by pre-existing adhesions between the epicardium and the pericardium [60]. They are often located in the inferior or posterolateral wall [61]. CT maybe a useful method for the diagnosis of left ventricular pseudoaneurysms and allows a non-invasive preoperative planning.

Coronary artery anomalies representing another potentially life-threatening disease should also be considered in patients with acute chest pain. They are found incidentally in 0.3%–1% of healthy individuals [62]. For several decades, diagnosis of coronary artery anomalies was made with angiography. Currently, CT is now acknowledged as the gold standard technique for the diagnosis and characterization of coronary artery anomalies [63]. Potentially life-threatening anomalies include the origin of a coronary artery arising from the pulmonary artery, an interarterial course between the aorta and pulmonary trunk (Fig. 9), coronary artery fistulas, and occasionally myocardial bridging [63].

Myocardial bridging is defined as a segment of a major epicardial coronary artery running intramurally through the myocardium beneath a muscle bridge [64]. Although myocardial bridging is considered as a common, benign condition, complications, including transient ischemia and sudden death, have been repetitively described in the literature [65].

Non-life-threatening causes of acute chest pain

It is crucial to distinguish patients with life-threatening causes of acute chest pain that need immediate medical or surgical intervention from those that can be admitted home and managed on an out-patient basis. The spectrum of non-life-threatening causes of acute chest pain is broad and includes gastro-esophageal, musculoskeletal, pleuropulmonal, mediastinal, and mental disease. As triple rule-out CT covers the entire chest, it enables a comprehensive assessment of various vascular and non-vascular pathologies of the chest.

Musculoskeletal causes for chest pain are found in about 25% of patients with acute chest pain [66, 67]. The pain is mostly triggered by degenerative changes of the spine or a discus prolapse, originates in the chest or neck, and radiates into both arms [68]. In elderly patients, fractures of the ribs or vertebrae caused by osteoporosis or metastatic disease can be found.

Pulmonary or pleural lesions also have to be considered in the differential diagnosis of acute chest pain. Pleuritis with pleurodynia can be caused by pneumonia, a pleura-infiltrating tumor, or pneumothorax [69].

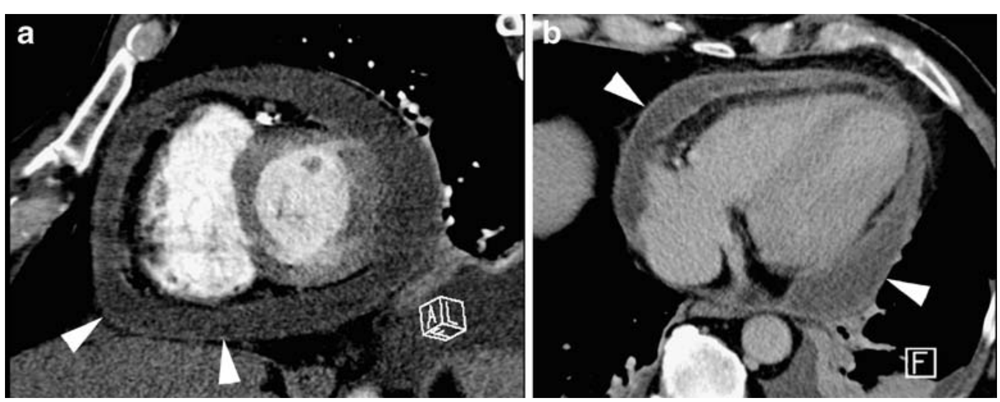


Fig. 10 A 56-year-old male patient with acute chest pain and tachycardia presented to the emergency department. Triple rule-out CT with a short axis reconstruction showed pericardial effusion with a slight enhancement of the parietal layers of the pericardium indicating pericarditis (**a**, arrowhead). An axial MPR of an abdominal CT obtained 3 days later clearly showed the pericardial enhancement (**b**, arrowhead)

Another important differential diagnosis is acute pericarditis, often manifesting with left-sided acute chest pain radiating into the arm and back (Fig. 10). Often, no specific ECG changes are found, echocardiography may fail or may reveal inconclusive results [69]. Then, CT may be an important alternative modality to complement the diagnosis. Nevertheless, MR still is the method of choice to assess pericardial inflammation [70]. However, triple rule-out CT also has the advantage of delivering information about the coronary arteries in a single examination.

In a significant number of patients with acute chest pain, different forms of esophageal disorders, such as gastroesophageal reflux and esophageal dysmotility, can be found [71]. The Boerhaave syndrome, a rare pathology, is caused by a spontaneous rupture of the distal esophagus secondary to explosive vomiting. It has a high mortality rate and has to be considered early after excluding ACS [72].

Finally, extrathoracic pathologies affecting the upper abdominal organs may also cause acute chest pain. For example, pyelonephritis, acute pancreatitis, or cholecystitis have to be considered in these patients after ruling out vascular or non-vascular chest pathologies. Twenty percent of patients with acute pancreatitis complain of left-sided chest pain, and chest CT shows left-sided pleural effusion and atelectasis of adjacent lung structures [73]. Among patients with cholecystolithiasis, 14% complain of right-sided chest pain [74]. Furthermore, gastric and duodenal ulcers are important differential diagnoses and may be hard to differentiate from aortic dissection or ACS [74].

Conclusions

Due to the fast data acquisition in combination with the high spatial and temporal resolution of new CT technology, patients can be examined with a single, retrospectively ECG-gated chest examination giving rise to diagnostic images of the pulmonary arteries, aorta, and coronary arteries, as well as of various non-vascular structures of the chest. As mentioned above, triple rule-out CT offers not only the ability to diagnose or to exclude three different diagnoses, but also offers a multitude of different vascular and non-vascular chest diseases that may similarly present with acute chest pain. Thus, the jargon term *triple* rule-out fails to describe the true potential of this examination.

Performing such a CT protocol requires the use of a dedicated scan and contrast agent application protocol and goes along with a higher radiation dose when compared to a standard, non-ECG-gated CT of the pulmonary arteries. The increase in potential harm associated with triple rule-out CT needs to be weighted against the potential benefits of the imaging test that may reduce the number of other, occasionally invasive, diagnostic procedures that also involve radition and contrast media exposure.

Acknowledgement This study has been supported by the National Center of Competence in Research, Computer-Aided, and Image-Guided Medical Interventions of the Swiss National Science Foundation.

References

1. Erhardt L, Herlitz J, Bossaert L et al (2002) Task force on the management of chest pain. Eur Heart J 23:1153–1176
2. Karlson BW, Herlitz J, Pettersson P, Ekvall HE, Hjalmarson A (1991) Patients admitted to the emergency room with symptoms indicative of acute myocardial infarction. J Intern Med 230:251–258
3. Lee TH, Rouan GW, Weisberg MC et al (1987) Clinical characteristics and natural history of patients with acute myocardial infarction sent home from the emergency room. Am J Cardiol 60:219–224
4. Swap CJ, Nagurney JT (2005) Value and limitations of chest pain history in the evaluation of patients with suspected acute coronary syndromes. JAMA 294:2623–2629
5. Zimmerman J, Fromm R, Meyer D et al (1999) Diagnostic marker cooperative study for the diagnosis of myocardial infarction. Circulation 99:1671–1677
6. Kaul P, Newby LK, Fu Y et al (2004) International differences in evolution of early discharge after acute myocardial infarction. Lancet 363:511–517
7. Hayter RG, Rhea JT, Small A, Tafazoli FS, Novelline RA (2006) Suspected aortic dissection and other aortic disorders: multi-detector row CT in 373 cases in the emergency setting. Radiology 238:841–852
8. Quiroz R, Kucher N, Zou KH et al (2005) Clinical validity of a negative computed tomography scan in patients with suspected pulmonary embolism: a systematic review. JAMA 293:2012–2017
9. Hoffmann U, Nagurney JT, Moselewski F et al (2006) Coronary multidetector computed tomography in the assessment of patients with acute chest pain. Circulation 114:2251–2260
10. Sato Y, Matsumoto N, Ichikawa M et al (2005) Efficacy of multislice computed tomography for the detection of acute coronary syndrome in the emergency department. Circ J 69:1047–1051
11. Gallagher MJ, Ross MA, Raff GL, Goldstein JA, O'Neill WW, O'Neil B (2007) The diagnostic accuracy of 64-slice computed tomography coronary angiography compared with stress nuclear imaging in emergency department low-risk chest pain patients. Ann Emerg Med 49:125–136
12. Goldstein JA, Gallagher MJ, O'Neill WW, Ross MA, O'Neil B, Raff GL (2007) A randomized controlled trial of multi-slice coronary computed tomography for evaluation of acute chest pain. J Am Coll Cardiol 49:863–871
13. Flohr TG, McCollough CH, Bruder H et al (2006) First performance evaluation of a dual-source CT (DSCT) system. Eur Radiol 16:256–268
14. Achenbach S, Ropers D, Kuettner A et al (2006) Contrast-enhanced coronary artery visualization by dual-source computed tomography-initial experience. Eur J Radiol 57:331–335

15. Johnson TR, Nikolaou K, Wintersperger BJ et al (2006) Dual-source CT cardiac imaging: initial experience. Eur Radiol 16:1409–1415
16. Alkadhi H, Scheffel H, Desbiolles L et al (2008) Dual-source computed tomography coronary angiography: influence of obesity, calcium load, and heart rate on diagnostic accuracy. Eur Heart J 29:766–776
17. Scheffel H, Alkadhi H, Plass A et al (2006) Accuracy of dual-source CT coronary angiography: First experience in a high pre-test probability population without heart rate control. Eur Radiol 16:2739–2747
18. Johnson TR, Nikolaou K, Becker A et al (2008) Dual-source CT for chest pain assessment. Eur Radiol 18:773–780
19. Schertler T, Scheffel H, Frauenfelder T et al (2007) Dual-source computed tomography in patients with acute chest pain: feasibility and image quality. Eur Radiol 17:3179–3188
20. Johnson TR, Nikolaou K, Wintersperger BJ et al (2007) Optimization of contrast material administration for electrocardiogram-gated computed tomographic angiography of the chest. J Comput Assist Tomogr 31:265–271
21. Takakuwa KM, Halpern EJ (2008) Evaluation of a "triple rule-out" coronary CT angiography protocol: use of 64-Section CT in low-to-moderate risk emergency department patients suspected of having acute coronary syndrome. Radiology 248:438–446
22. Ketelsen D, Luetkhoff MH, Thomas C et al (2008) Estimation of the radiation exposure of a chest pain protocol with ECG-gating in dual-source computed tomography. Eur Radiol:ePub
23. Jakobs TF, Becker CR, Ohnesorge B et al (2002) Multislice helical CT of the heart with retrospective ECG gating: reduction of radiation exposure by ECG-controlled tube current modulation. Eur Radiol 12:1081–1086
24. Leschka S, Scheffel H, Desbiolles L et al (2007) Image quality and reconstruction intervals of dual-source CT coronary angiography: recommendations for ECG-pulsing windowing. Invest Radiol 42:543–549
25. Stolzmann P, Scheffel H, Schertler T et al (2008) Radiation dose estimates in dual-source computed tomography coronary angiography. Eur Radiol 18:592–599
26. Leschka S, Stolzmann P, Schmid FT et al (2008) Low kilovoltage cardiac dual-source CT: attenuation, noise, and radiation dose. Eur Radiol 18:1809–1817
27. Mollet NR, Cademartiri F, van Mieghem CA et al (2005) High-resolution spiral computed tomography coronary angiography in patients referred for diagnostic conventional coronary angiography. Circulation 112:2318–2323
28. Hausleiter J, Meyer T, Hadamitzky M et al (2006) Radiation dose estimates from cardiac multislice computed tomography in daily practice: impact of different scanning protocols on effective dose estimates. Circulation 113:1305–1310
29. Gerber TC, Kuzo RS, Morin RL (2005) Techniques and parameters for estimating radiation exposure and dose in cardiac computed tomography. Int J Cardiovasc Imaging 21:165–176
30. Einstein AJ, Moser KW, Thompson RC, Cerqueira MD, Henzlova MJ (2007) Radiation dose to patients from cardiac diagnostic imaging. Circulation 116:1290–1305
31. Becker CR, Hong C, Knez A et al (2003) Optimal contrast application for cardiac 4-detector-row computed tomography. Invest Radiol 38:690–694
32. Scheffel H, Alkadhi H, Leschka S et al (2008) Low-dose CT coronary angiography in the step-and-shoot mode: diagnostic performance. Heart 94:1132–1137
33. Calhoun PS, Kuszyk BS, Heath DG, Carley JC, Fishman EK (1999) Three-dimensional volume rendering of spiral CT data: theory and method. Radiographics 19:745–764
34. Dalrymple NC, Prasad SR, Freckleton MW, Chintapalli KN (2005) Informatics in radiology (infoRAD): introduction to the language of three-dimensional imaging with multidetector CT. Radiographics 25:1409–1428
35. Bean MJ, Pannu H, Fishman EK (2005) Three-dimensional computed tomographic imaging of complex congenital cardiovascular abnormalities. J Comput Assist Tomogr 29:721–724
36. Bergqvist D, Lindblad B (1985) A 30-year survey of pulmonary embolism verified at autopsy: an analysis of 1274 surgical patients. Br J Surg 72:105–108
37. Soloff LA, Rodman T (1967) Acute pulmonary embolism. II. Clinical. Am Heart J 74:829–847
38. Cross JJ, Kemp PM, Walsh CG, Flower CD, Dixon AK (1998) A randomized trial of spiral CT and ventilation perfusion scintigraphy for the diagnosis of pulmonary embolism. Clin Radiol 53:177–182
39. Fedullo PF, Tapson VF (2003) Clinical practice. The evaluation of suspected pulmonary embolism. N Engl J Med 349:1247–1256
40. Coche EE, Muller NL, Kim KI, Wiggs BR, Mayo JR (1998) Acute pulmonary embolism: ancillary findings at spiral CT. Radiology 207:753–758
41. Collomb D, Paramelle PJ, Calaque O et al (2003) Severity assessment of acute pulmonary embolism: evaluation using helical CT. Eur Radiol 13:1508–1514
42. Ghaye B, Ghuysen A, Willems V et al (2006) Severe pulmonary embolism: pulmonary artery clot load scores and cardiovascular parameters as predictors of mortality. Radiology 239:884–891
43. Araoz PA, Gotway MB, Trowbridge RL et al (2003) Helical CT pulmonary angiography predictors of in-hospital morbidity and mortality in patients with acute pulmonary embolism. J Thorac Imaging 18:207–216
44. Walsh PN GR, Simon M et al (1973) An angiographic severity index for pulmonary embolism. Circulation:101–108
45. Dogan H, Kroft LJ, Huisman MV, van der Geest RJ, de Roos A (2007) Right ventricular function in patients with acute pulmonary embolism: analysis with electrocardiography-synchronized multi-detector row CT. Radiology 242:78–84
46. Hagan PG, Nienaber CA, Isselbacher EM et al (2000) The International Registry of Acute Aortic Dissection (IRAD): new insights into an old disease. JAMA 283:897–903
47. Roos JE, Willmann JK, Weishaupt D, Lachat M, Marincek B, Hilfiker PR (2002) Thoracic aorta: motion artifact reduction with retrospective and prospective electrocardiography-assisted multi-detector row CT. Radiology 222:271–277
48. Johnson TR, Nikolaou K, Wintersperger BJ et al (2007) ECG-gated 64-MDCT angiography in the differential diagnosis of acute chest pain. AJR Am J Roentgenol 188:76–82
49. Hollander JE, Sease KL, Sparano DM, Sites FD, Shofer FS, Baxt WG (2004) Effects of neural network feedback to physicians on admit/discharge decision for emergency department patients with chest pain. Ann Emerg Med 44:199–205
50. Hoffmann U, Pena AJ, Cury RC et al (2006) Cardiac CT in emergency department patients with acute chest pain. Radiographics 26:963–978 discussion 979–980
51. Hoffmann U, Pena AJ, Moselewski F et al (2006) MDCT in early triage of patients with acute chest pain. AJR Am J Roentgenol 187:1240–1247

52. Brindis RG, Douglas PS, Hendel RC et al (2005) ACCF/ASNC appropriateness criteria for single-photon emission computed tomography myocardial perfusion imaging (SPECT MPI): a report of the American College of Cardiology Foundation Quality Strategic Directions Committee Appropriateness Criteria Working Group and the American Society of Nuclear Cardiology endorsed by the American Heart Association. J Am Coll Cardiol 46:1587–1605
53. Kitagawa K, Sakuma H, Nagata M et al (2008) Diagnostic accuracy of stress myocardial perfusion MRI and late gadolinium-enhanced MRI for detecting flow-limiting coronary artery disease: a multicenter study. Eur Radiol: ePub
54. Cury RC, Nieman K, Shapiro MD et al (2008) Comprehensive assessment of myocardial perfusion defects, regional wall motion, and left ventricular function by using 64-section multidetector CT. Radiology 248:466–475
55. Habis M, Capderou A, Ghostine S et al (2007) Acute myocardial infarction early viability assessment by 64-slice computed tomography immediately after coronary angiography: comparison with low-dose dobutamine echocardiography. J Am Coll Cardiol 49:1178–1185
56. Sato A, Hiroe M, Nozato T et al (2008) Early validation study of 64-slice multidetector computed tomography for the assessment of myocardial viability and the prediction of left ventricular remodelling after acute myocardial infarction. Eur Heart J 29:490–498
57. Pollak H, Nobis H, Mlczoch J (1994) Frequency of left ventricular free wall rupture complicating acute myocardial infarction since the advent of thrombolysis. Am J Cardiol 74:184–186
58. Slater J, Brown RJ, Antonelli TA et al (2000) Cardiogenic shock due to cardiac free-wall rupture or tamponade after acute myocardial infarction: a report from the SHOCK Trial Registry. Should we emergently revascularize occluded coronaries for cardiogenic shock? J Am Coll Cardiol 36:1117–1122
59. Frances C, Romero A, Grady D (1998) Left ventricular pseudoaneurysm. J Am Coll Cardiol 32:557–561
60. Bekkers SC, Borghans RA, Cheriex EC (2006) Ventricular pseudoaneurysm after subacute myocardial infarction. Int J Cardiovasc Imaging 22:791–795
61. Yeo TC, Malouf JF, Oh JK, Seward JB (1998) Clinical profile and outcome in 52 patients with cardiac pseudoaneurysm. Ann Intern Med 128:299–305
62. Angelini P, Velasco JA, Flamm S (2002) Coronary anomalies: incidence, pathophysiology, and clinical relevance. Circulation 105:2449–2454
63. Kim SY, Seo JB, Do KH et al (2006) Coronary artery anomalies: classification and ECG-gated multi-detector row CT findings with angiographic correlation. Radiographics 26:317–333 discussion 333–314
64. Leschka S, Koepfli P, Husmann L et al (2008) Myocardial bridging: depiction rate and morphology at CT coronary angiography-comparison with conventional coronary angiography. Radiology 246:754–762
65. Alegria JR, Herrmann J, Holmes DR Jr, Lerman A, Rihal CS (2005) Myocardial bridging. Eur Heart J 26:1159–1168
66. Knockaert DC, Buntinx F, Stoens N, Bruyninckx R, Delooz H (2002) Chest pain in the emergency department: the broad spectrum of causes. Eur J Emerg Med 9:25–30
67. Spalding L, Reay E, Kelly C (2003) Cause and outcome of atypical chest pain in patients admitted to hospital. J R Soc Med 96:122–125
68. Frobert O, Fossgreen J, Sondergaard-Petersen J, Hede J, Bagger JP (1999) Musculo-skeletal pathology in patients with angina pectoris and normal coronary angiograms. J Intern Med 245:237–246
69. Butler KH, Swencki SA (2006) Chest pain: a clinical assessment. Radiol Clin North Am 44:165–179 vii
70. Misselt AJ, Harris SR, Glockner J, Feng D, Syed IS, Araoz PA (2008) MR Imaging of the Pericardium. Magn Reson Imaging Clin N Am 16:185–199
71. Howarth D, Oldfield G, Booker J, Tan P (2003) Esophageal dysfunction in patients with atypical chest pain investigated with esophageal scintigraphy and myocardial perfusion imaging: an outcome study. J Nucl Cardiol 10:490–497
72. Anastasiadou K, Pilavaki M, Vafiadis E, Petridis A, Drevelengas A (1998) [Boerhaave syndrome: a rare cause of acute thoracic pain]. Pneumologie 52:132–134
73. Korantzopoulos P, Pappa E, Dimitroula V et al (2005) ST-segment elevation pattern and myocardial injury induced by acute pancreatitis. Cardiology 103:128–130
74. Munk EM, Drewes AM, Gorst-Rasmussen A, Gregersen H, Funch-Jensen P, Norgard B (2007) Risk of peptic ulcer, oesophagitis, pancreatitis or gallstone in patients with unexplained chest/epigastric pain and normal upper endoscopy: a 10-year Danish cohort study. Aliment Pharmacol Ther 25:1203–1210