Review

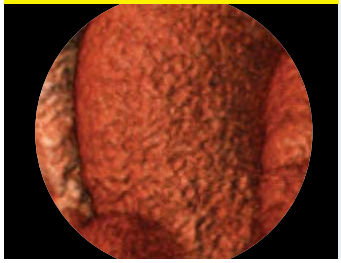
Key words:
Multidetector CT,
coronary CT angiography,
emergency room,
chest pain

Multidetector CT: can it provide a global evaluation of the patient presenting to the emergency department with chest pain?

Charles S. White

University of Maryland Medical School, Baltimore, USA

Address for correspondence:
Charles S. White MD, Professor
Department of Diagnostic Radiology,
University of Maryland School of Medicine,
22 S Greene St, Baltimore, MD 21201, USA
Tel: +1-410-328-3477 Fax: +1-410-328-0641
Email: mailto:cwhite@umm.edu



Dr Charles S. White is Professor of Radiology and Internal Medicine at the University of Maryland School of Medicine and the Director of Thoracic Imaging and Vice-Chairman for Clinical Affairs at the University of Maryland Medical Center. He received his training at Columbia-Presbyterian Medical Center. Dr White is certified by both the American Board of Radiology and the American Board of Internal Medicine. He is the author of over 100 publications in different areas of cardiothoracic radiology with a recent emphasis on cardiac CT imaging. He is the current Editor-in-Chief of the *Journal of Thoracic Imaging*.

Abstract

In patients who present to the emergency department with acute chest pain, distinguishing between insignificant and life-threatening causes remains a major challenge. Initial evaluation with history, electrocardiography and biochemical markers is often unrevealing, leading to further work-up. Nuclear perfusion and echocardiography may be diagnostic but provide only indirect assessment of coronary status. The development of multidetector CT (MDCT) and its increasingly frequent placement near the emergency suite has facilitated its use for serious non-cardiac diagnoses such as pulmonary embolism and aortic dissection. More recently, MDCT, with further refinements such as addition of detectors and better temporal resolution, has shown considerable promise in the depiction of coronary arteries. These advances have led to the possibility of using CT to evaluate cardiac aetiologies of chest pain, using either a comprehensive protocol to assess both cardiac and non-cardiac causes or a dedicated coronary protocol. This review discusses both options and describes our preliminary experience with the first. It describes the potential value of an acute chest pain CT protocol and the considerable challenges that remain prior to its implementation for routine clinical use.

Introduction

In the USA alone, approximately 5 million patients present annually to the emergency department (ED) for the evaluation of chest pain. The majority of these patients do not have a cardiac aetiology for their chest pain. Nevertheless, many patients are admitted unnecessarily for observation. Conversely, 2–5% of patients are discharged inappropriately and ultimately prove to have clinically significant ischaemia.

A group of high-risk patients classified as having acute coronary syndrome (ACS) can readily be identified on the basis of history, electrocardiographic findings or elevations in cardiac enzymes. These patients include those with transmural infarction, non-Q-wave or subendocardial infarction and unstable angina. According to recommendations by the American College of Cardiology and American Heart Association, such high-risk patients typically proceed to coronary angiography[1] either emergently or urgently.

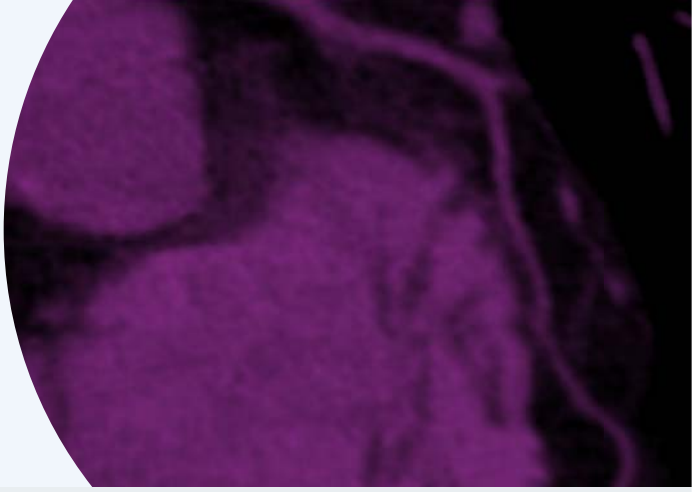
However, most patients who present to the ED are not immediately classified as having ACS. These patients usually undergo further testing to evaluate their risk for ACS or a non-life-threatening cardiac aetiology of their chest pain and are usually classified as 'probable angina' or 'possible angina'. In addition, serious non-cardiac causes of acute chest pain such as aortic dissection and pulmonary embolism need to be considered. Several non-invasive imaging modalities that have conventionally been used in this group of patients are briefly described here. More recently, multidetector CT (MDCT) scanning has been proposed as a means of providing a single, comprehensive evaluation of the intermediate-risk patient.

Chest radiography

Chest radiographs (CXR) are often taken in patients with chest pain in the emergency room. They can be used to identify non-cardiac causes of chest pain such as pneumothorax, pneumonia or musculoskeletal conditions. Although CXR does not provide a definitive diagnosis of ACS, certain findings can direct further diagnostic work-up. Calcification of the coronary arteries, a sign of atherosclerotic disease and potential stenosis, may be visible overlying the upper left cardiac silhouette in the 'coronary triangle'.[2,3] Left ventricular myocardial calcification is an indication of a prior myocardial infarction (MI). Congestive heart failure due to ischaemia is evident radiographically as an enlarged cardiac silhouette associated with cephalisation or pulmonary oedema.[4–6]

Radionuclide and echocardiographic testing

In patients who present with chest pain and non-diagnostic ECG changes, myocardial perfusion SPECT (single photon emission computed tomography) has been shown to provide incremental risk stratification value over clinical data for predicting unfavourable



cardiac events.[7] Typically, ^{99m}Tc sestamibi is injected during chest pain followed by imaging 45–60 minutes later. The imaging thus reflects myocardial blood flow at the time of injection. In multiple observational studies, the negative predictive value for ruling out myocardial infarction (MI) has equalled or exceeded 99% in the ED setting. This suggests that a normal myocardial perfusion study in this setting portends a very small risk of MI or ischaemic event.[8] In contrast, patients exhibiting abnormal regional perfusion defect have a higher risk of cardiac events during hospitalisation and follow-up. A major disadvantage of radionuclide stress testing is the necessity of moving the patient from the ED to the nuclear medicine department.

In the evaluation and risk stratification of patients presenting to the emergency room with chest pain, stress echocardiography is a versatile and powerful imaging modality. The prognostic information provided is powerful and comparable to nuclear stress testing. It also has the advantage of providing valuable incremental information by assessing baseline ventricular function, valvular function, aortic root morphology and pericardial anatomy. A negative stress echocardiography study predicts very low cardiac event rates and thus can be the basis for discharge of the patient from the ED. However, echocardiography may be problematic in patients with resolved symptoms or non-transmural infarctions.

Magnetic resonance imaging

Magnetic resonance imaging (MRI) permits assessment of perfusion, function and viability, all valuable in the assessment of chest pain in the emergency room. Kwong *et al* evaluated the utility of MRI in 161 patients with suspected ACS. They demonstrated a sensitivity of 84% and specificity of 85%, and superior sensitivity in comparison with strict ECG criteria for ischaemia and elevated peak troponin-I. Nevertheless, users of MRI must contend with comparatively long scanning protocols and the necessity of moving the patient from the ED suite to the scanner.[9]

CT scanning

Electron-beam CT (EBT) is valuable in risk stratification of patients who present with acute chest pain by demonstrating the presence of coronary calcium, an indication of coronary artery disease. The Agatston score, derived from the extent and density of coronary calcification, is commonly used.[10] In the emergency department, EBT has been used to assess patients with an indeterminate chest pain evaluation using coronary calcium as a marker. These studies showed a high sensitivity and negative predictive value.[11–13]

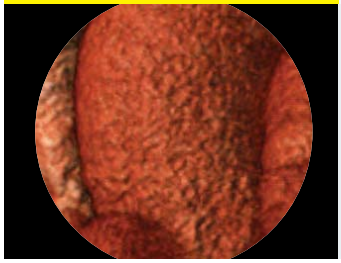
Increasingly, attention has focused on the use of MDCT to delineate coronary artery disease. The current generation of MDCT scanners uses ECG-gating, sub-millimeter spatial resolution and relatively good temporal resolution to provide increasingly accurate assessment of coronary artery anatomy. Currently, MDCT scanners have up to 64 detectors and offer a spatial resolution of 0.5–0.6 mm and temporal resolution of 50–100 msec. In the US, CT scanners are increasingly being placed in or near the emergency suite, alleviating concerns about monitoring the patient with chest pain.

Advances in MDCT technology allow routine direct visualisation of the coronary arteries as well as acquisition of functional information and, potentially, detection of perfusion deficits. In patients who undergo elective evaluation for chest pain, coronary CT angiography (CTA) has shown sensitivity and specificity substantially greater than 80% in coronary arteries larger than 2 mm.[14]

In the ED setting, two types of MDCT protocol may be used. If a coronary aetiology is the overriding consideration, a dedicated coronary CTA can be performed. Coronary CTA is performed with injection of intravenous contrast that is timed with a test bolus or triggering mechanism that begins the scan at a pre-determined threshold level. Beta-blockers, given either orally or intravenously, are used in patients with a heart rate above 70 bpm.

Multidetector CT: can it provide a global evaluation of the patient presenting to the emergency department with chest pain? *continued*

Charles S. White



However, ED physicians are often less confident of a coronary cause, and other life-threatening aetiologies of chest pain may be serious concerns. In such instances, a scanning protocol that represents a compromise between a coronary CTA and pulmonary embolism/aortic dissection protocol is advisable (Table 1). This approach has been designated the 'one-stop-shop' or 'triple-threat' protocol because it includes most serious causes of chest pain, particularly pulmonary embolism and aortic dissection. The low pitch and large extent of z-axis coverage required make this a lengthy scan and thus a late generation MDCT is recommended. With a 64-detector row scanner, the study can be completed in as few as 15 seconds, and difficulties with patient compliance are minimised. Options exist as to the timing of MDCT. It may prove valuable after initial patient work-up in the ED to speed assessment and allow early discharge. Later, coronary CTA may be appropriate in the higher-risk group that is to be admitted in order to facilitate further testing and triage.

Table 1. Sample ED chest pain MDCT protocols.

Parameter	16-slice	64-slice
kv	120	120
mAs/slice	500	600
FOV	400	400
Thickness (mm)	1.0	0.9
Increment (mm)	0.5	0.4
Rotation time (sec)	0.4	0.4
Direction	Cranial–cephalad	Cranial–cephalad
Time (sec)	30–35	12–15

With both dedicated and comprehensive CTA protocols, 10 evenly spaced phases are acquired through the cardiac cycle. The phase with the least coronary motion, often in early or late diastole, is used to evaluate for coronary plaque and stenosis. Curved planar images in the plane of the coronary arteries are reconstructed and current software permits quantification of the extent of stenosis. Functional information is derived from the end-systolic and end-diastolic images. In the comprehensive protocol, an initial large field-of-view image set is reconstructed, typically at 75% of the R–R interval, to evaluate for non-coronary disease.

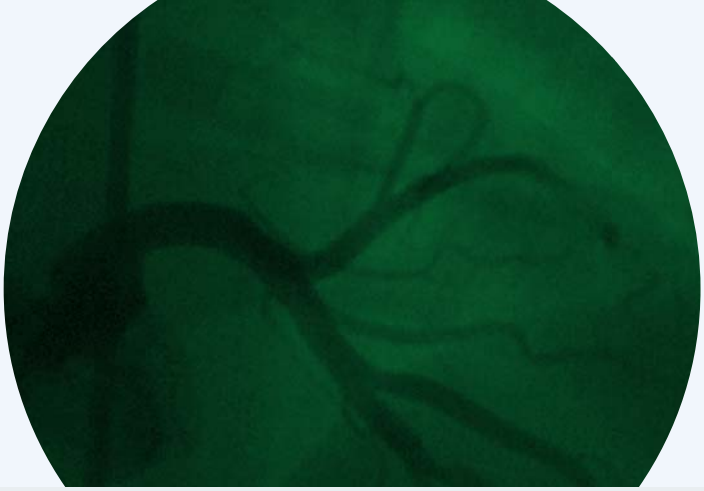
Pilot study of MDCT

Since the appropriate use and timing of MDCT in the emergency setting is unclear, we conducted a pilot study that included patients who presented with chest pain and low-to-intermediate probability of ACS.[15] We used the comprehensive protocol to evaluate for coronary and non-coronary causes of chest pain. After initial assessment and blood sampling, patients were brought to the 16-detector MDCT scanner in the emergency suite. Two readers reviewed all studies. A consensus consisting of a cardiologist, ED physician and radiologist provided ground truth for the final diagnosis.

Overall, 69 patients underwent MDCT, 45 (65%) of whom would not otherwise have undergone CT scanning.[15] Fifty-two patients (75%) had negative CT findings and a final diagnosis of clinically insignificant chest pain. Thirteen (18%) had significant CT findings concordant with the final diagnosis (10 cardiac, three non-cardiac). There were two false-positive and two false-negative results. Sensitivity and specificity for a coronary aetiology of chest pain were 83% and 96%, respectively. Overall sensitivity and specificity for all causes were 87% and 96%, respectively. In this study, the cardiac assessment was done several hours or more after acquisition of the CT scan due to software limitations and so did not contribute to the clinical care of the patient.

Several tentative conclusions appear reasonable based on our pilot study:

1. MDCT for ED chest pain is logistically feasible depending on hardware and software improvements to allow real time diagnosis.
2. MDCT has the potential to decrease admissions if the results are used to triage patients with low-to-intermediate risk of angina.
3. The comprehensive protocol appears to diagnose a small number of cases of non-coronary disease that might be missed if only a dedicated coronary CTA protocol is used.

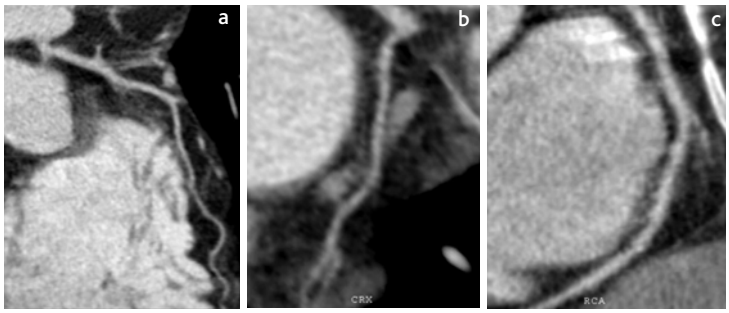


4. The adoption of this protocol will almost certainly lead to increased use of MDCT in the ED. This must be weighed against the potential decrease in other imaging studies currently used for evaluating ED chest pain.

Several important challenges remain:

1. The precise indication(s) for MDCT in the chest pain algorithm is unclear. It may prove most useful to exclude a coronary (and establish a non-coronary) cause of chest pain in patients at intermediate risk for ACS. Patients with indeterminate or positive MDCT would need to have further testing and perhaps admission.
2. Technical limitations and staffing issues persist. Our comprehensive protocol was performed using a 16-detector scanner, and motion artifact was a common problem. Our subsequent experience with 64-detector MDCT is much more favourable. The image quality of the coronary arteries is noticeably better and the scan time for the entire chest is decreased to approximately 15 seconds. Further technological advances will probably provide a more robust examination. The reconstruction and post-processing times have also decreased from several hours to about 1 hour, but full evaluation is still labour intensive.
3. Concern about radiation dose exists, associated with the increased volume of ECG-gated MDCT. Radiation exposure is a legitimate issue related to using CT in the ED and can be mitigated somewhat with dose modulation. Moreover, some imaging techniques currently used to evaluate ED chest pain, such as radionuclide perfusion and cardiac catheterisation, use radiation doses almost in the same range as MDCT. Thus, the impact of radiation exposure can be truly assessed only when the extent to which MDCT will obviate these techniques becomes known.
4. The economic impact is unknown. The increased use of MDCT in an ED protocol will add cost for the patient and the medical system. Nonetheless, if such a protocol results in a decreased use of other expensive testing such as cardiac catheterisation, and more importantly, a decreased requirement for hospital admission, savings may be realised. Further studies of the economic implications of using MDCT to evaluate chest pain in the ED are mandatory.

Several other studies of the use of MDCT to evaluate chest pain in the ED have been published.[16–18] Taken together, these studies indicate the large potential impact of MDCT in the ED setting. At the request of the ED clinical team, we have made the comprehensive MDCT ED protocol available on a clinical basis during times when staffing is sufficient, with early favourable results (Figures 1 and 2).



d

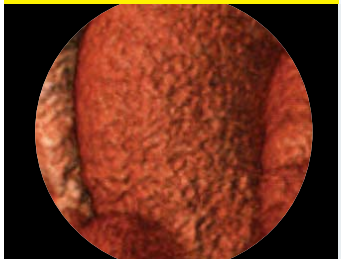
ED Volume (Phase 0%)(ml)	98.4	***
ES Volume (Phase 40%)(ml)	41.9	***
Stroke Volume (ml)	56.6	***
Ejection Fraction (%)	57.5	***
Cardiac Output (ml/min)	3676.5	***
LV Wall Muscle Mass	51.7 g	
LV Wall Muscle + Papillary Mass	62.7 g	
Heart Rate	65.0 bpm	

Figure 1. A 52-year-old woman presented to the ED with atypical chest pain and a normal comprehensive MDCT evaluation.

(a–c) Curved planar reconstructed images of the (a) left anterior descending artery, (b) left circumflex artery and (c) right coronary artery demonstrate no stenosis. (d) A normal ejection fraction was calculated (reproduced with permission from Eur J Radiol *2006;***57***(3):368–72).*

Multidetector CT: can it provide a global evaluation of the patient presenting to the emergency department with chest pain? *continued*

Charles S. White



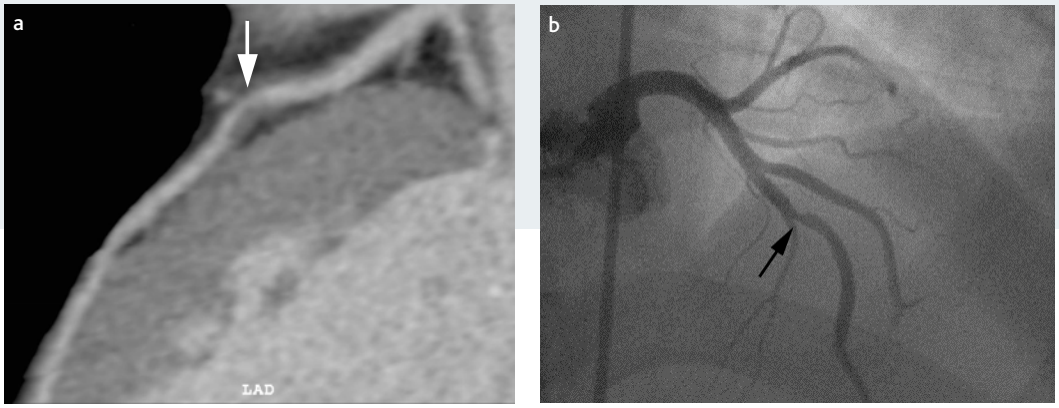


Figure 2. A 45-year-old man presented to the ED with atypical chest pain. Calcium score was 0 Agatston units.

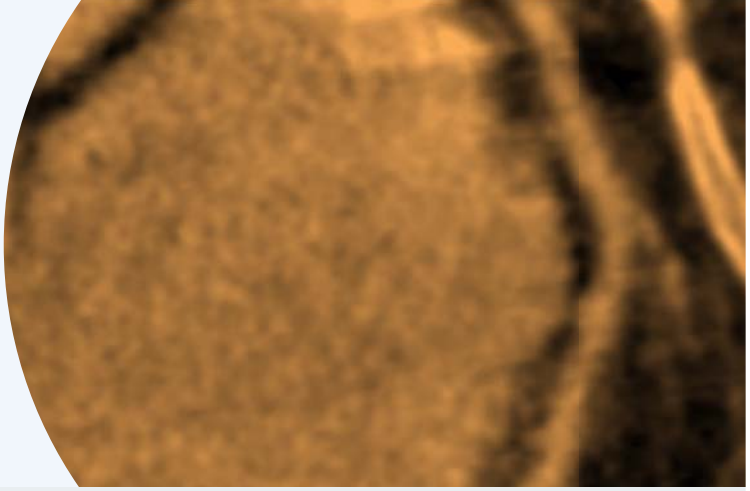
(a) Curved planar reconstructed image from a comprehensive MDCT evaluation shows an area of focal stenosis (arrow) in the mid left anterior descending artery due to non-calcified plaque. (b) Coronary angiography confirms a 50–60% stenosis (arrow) (reproduced with permission from Eur J Radiol *2006;**57**(3):368–72).*

Conclusions

The current approach to evaluate chest pain in the ED has well-recognised limitations. Early data suggest that MDCT has the potential to alter substantially the algorithms used in ED chest pain assessment. Clearly, further investigation is needed prior to routine implementation of either a comprehensive or dedicated MDCT protocol in the ED. Nevertheless, our pilot study created such interest among our ED physicians that they requested that a CT-based chest pain option be made available for selected patients on a clinical basis, a protocol now approaching completion of its first year.

Key Learning

- Chest pain accounts for 5 million emergency department visits in the USA
- Assessment of acute chest pain remains challenging. Up to 5% of patients are discharged inappropriately and many admissions prove unnecessary
- Perfusion testing and echocardiography are often used in non-specific cases but may be inconclusive and sometimes involve moving the patient from the emergency suite
- MDCT has been used to evaluate non-cardiac causes of life-threatening chest pain such as pulmonary embolism, and recent improvements allow good visualisation of coronary artery anatomy
- Dedicated coronary CT angiography or a comprehensive chest protocol assessing both coronary and non-coronary aetiologies are two potential approaches for evaluating chest pain with MDCT
- Our pilot study using a comprehensive MDCT chest pain protocol suggests that this approach is feasible in evaluating patients with low-to-intermediate risk for acute coronary syndrome
- Major technical and labour issues as well as considerations related to radiation and economics remain to be resolved prior to routine adoption of MDCT for the evaluation of chest pain in the emergency department



References

1. Braunwald E, Antman EM, Beasley JW, *et al*. ACC/AHA 2002 guideline update for the management of patients with unstable angina and non-ST-segment elevation myocardial infarction – summary article: a report of the American College of Cardiology/American Heart Association task force on practice guidelines. *J Am Coll Cardiol* 2002;**40**:1366–74.

2. Souza AS, Bream PR, Elliott LP. Chest film detection of coronary artery calcification. The value of the CAC triangle. *Radiology* 1978;**129**:7–10.

3. Margolis JR, Chen JT, Kong Y, *et al*. The diagnostic and prognostic significance of coronary artery calcification. A report of 800 cases. *Radiology* 1980;**137**:609–16.

4. MacGregor JH, Chen JT, Chiles C, *et al*. The radiographic distinction between pericardial and myocardial calcifications. *AJR Am J Roentgenol* 1987;**148**:675–7.

5. Higgins CB, Lipton MJ, Johnson AD, *et al*. False aneurysms of the left ventricle. Identification of distinctive clinical, radiographic, and angiographic features. *Radiology* 1978;**127**:21–7.

6. Higgins CB, Lipton MJ. Radiography of acute myocardial infarction. *Radiol Clin North Am* 1980;**18**:359–68.

7. Heller GV, Stowers SA, Hendel RC, *et al*. Clinical value of acute rest technetium-99m tetrofosmin tomographic myocardial perfusion imaging in patients with acute chest pain and non diagnostic electrocardiogram. *J Am Coll Cardiol* 1998;**31**:1011.

8. Wackers FJ, Brown KA, Heller GV, *et al*. American Society of Nuclear Cardiology position statement on radionuclide imaging in patients with suspected acute ischemic syndrome in the emergency department or chest pain center. *J Nucl Cardiol* 2002;**9**:246.

9. Kwong RY, Schussheim AE, Rekhraj S, *et al*. Detecting acute coronary syndrome in the emergency department with cardiac magnetic resonance imaging. *Circulation* 2003;**107**:531–7.

10. Agatston AS, Janowitz WR, Hildner FJ, *et al*. Quantification of coronary artery calcium using ultrafast computed tomography. *J Am Coll Cardiol* 1990;**15**:827–32.

11. Laudon DA, Vukov LF, Breen JF, *et al*. Use of electron-beam computed tomography in the evaluation of chest pain patients in the emergency department. *Ann Emerg Med* 1999;**33**:15–21.

12. Georgiou D, Budoff MJ, Kaufer E, *et al*. Screening patients with chest pain in the emergency department using electron beam tomography: a follow-up study. *J Am Coll Cardiol* 2001;**38**:105–10.

13. McLaughlin VV, Balogh T, Rich S. Utility of electron beam computed tomography to stratify patients presenting to the emergency room with chest pain. *Am J Cardiol* 1999;**84**:327–8:A8.

14. Raff GL, Gallagher MJ, O'Neill WW *et al*. Diagnostic accuracy of noninvasive coronary angiography using 64-slice spiral computed tomography. *J Am Coll Cardiol* 2005;**46**:552–7.

15. White CS, Kuo D, Kelemen M, *et al*. Chest pain evaluation in the Emergency Room: Can multi-slice CT provide a comprehensive evaluation? *AJR Am J Roentgenol* 2005;**185**:533–40.

16. Hoffmann U, Pena A, Abbara S, *et al*. MDCT in early triage of patients with acute chest pain. Presented at RSNA (Radiological Society of North America) 2005 Meeting. Abstract SSG08-06. Available at http://rsna2005.rsna.org/rsna2005/V2005/index.cvn.

17. Klassen C, Nguyen M, Montes H, *et al*. Rule out of coronary artery disease: coronary ct angiography and calcium scores in chest pain patients presenting to the emergency department. Presented at RSNA (Radiological Society of North America) 2005 Meeting. Abstract SST06-09. Available at http://rsna2005.rsna.org/rsna2005/V2005/index.cvn.

18. Gaspar T, Halon D, Flugelman M, *et al*. Cardiac CT (64-slice) in triage and management of patients presenting with chest pain to the emergency department. Presented at RSNA (Radiological Society of North America) 2005 Meeting. Abstract SSG08-07. Available at http://rsna2005.rsna.org/rsna2005/V2005/index.cvn.