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Emergency Cardiac Imaging: State of the Art

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One of the most difficult challenges for emergency physicians is to determine whether chest pain is cardiac related and if the patient is at increased risk for a cardiac event (eg, nonfatal myocardial infarction or death). A certain group of high-risk patients can be identified readily based on history, ECG changes, and cardiac enzyme elevations. Based on recommendations by the American College of Cardiology (ACC) and American Heart Association (AHA), these patients usually undergo urgent coronary angiography [1]. A larger group of patients presenting with a less urgent clinical scenario and varying degrees of pretest likelihood for coronary artery disease require additional testing to evaluate their cardiac risk. Several noninvasive imaging modalities are helpful in this group of patients. Nuclear stress perfusion testing and stress echocardiography are useful in risk stratifying these patients, and new-generation CT scanners and MRI may soon develop their own roles.

Cardiac angiography remains the reference standard for imaging of the coronary vessels and provides an avenue for intervention, but cardiac catherization is an invasive procedure. An estimated 1.46 million cardiac catherizations were performed in 2002, although only 657,000 percutaneous transluminal coronary angioplasty procedures were performed [2]. Because most cardiac catherizations are diagnostic, there has been a long search for a noninvasive technique to diagnose coronary artery disease and visualize the coronary vessels, but until recently few techniques have been satisfactory.

Imaging of the heart in the emergency department begins with the plain chest radiograph. Although the plain chest radiograph states little about the coronary vessels, it provides important background information. Other options now available to visualize the coronary arteries without cardiac catherization include electron beam CT (EBCT), multidetector or multislice CT (MDCT) with CT angiography (CTA), and cardiac MR (CMR) with angiography. Provocative and nuclear testing can also provide much useful information in the evaluation of the patient who has suspected angina.

Plain chest radiograph

The plain chest radiograph has served for many years as a first-line imaging technique in the assessment of the cardiac patient in the emergency room. The chest radiograph is quite sensitive for diagnosis of some noncardiac causes of chest pain including pneumonia, pneumothorax, and rib fractures.

Direct evidence of myocardial ischemia is often absent on chest radiographs, but indirect evidence may be present in the form of atherosclerotic calcification of vessels. This calcification is usually most evident in the aorta but is more specific when found in the coronary arteries. The sensitivity for detection of coronary artery calcification on radiography is less than 50%. The usual location of visible coronary artery calcification is in the coronary triangle in the mid-upper part of the left heart corresponding to the proximal portions of the left coronary arteries [3]. Calcification may

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also be present on the lateral radiograph arising from the aortic root (Fig. 1). Data from a fluoroscopic study suggest that radiographically evident coronary calcification is associated with a higher likelihood of significant coronary artery stenosis [4].

A plain chest radiograph may also be useful for assessment of complications of early episodes of myocardial ischemia. An enlarged cardiac silhouette may be evidence of a previous myocardial event. Calcification along the left heart border is often an indication of a prior myocardial infarction (Fig. 2) [5]. The presumed mechanism is impaired wall motion followed by local thrombus formation, which may ultimately calcify. A focal bulge of the left heart border may represent a postinfarct myocardial aneurysm or pseudoaneurysm [6].

Other indirect signs of ischemic chest pain may be identified, including congestive heart failure. There is some correlation between the radiographic findings and the severity of congestive heart failure. In mild heart failure, cephalization may be present consisting of reduced flow to lower lobe vessels and diversion of flow to upper lobes. Cephalization requires a gravitational gradient and therefore is difficult to recognize on a supine or semierect radiograph. More severe heart failure is associated with interstitial and alveolar (airspace) pulmonary edema, respectively [7]. In a recent study of patients presenting to the emergency department with acute dyspnea, a plain chest radiograph showing enlarged heart size identified patients for whom a final diagnosis of heart failure was confirmed by two cardiologists with a sensitivity of 88% and a specificity of 72% [8].

The plain chest radiograph is unlikely to be replaced because it provides a large amount of useful information, and cardiac patients will almost uniformly require a chest radiograph to exclude other potential diagnoses associated with cardiac symptoms.

Electron beam CT

Current EBCT scanners deploy temporal resolutions of 50 to 100 milliseconds and ECG gating to evaluate the cardiac anatomy. For comparison, conventional angiography has a temporal resolution of less than 10 milliseconds. Multiple studies have evaluated the ability of EBCT to evaluate coronary stenosis and provide prognostic information for patients who have coronary calcifications. CT scanning, in particular EBCT, has been used to risk stratify patients who have suspected coronary artery disease by demonstrating coronary calcium. The presence of coronary calcium indicates coronary artery disease and is conventionally measured with the method described by Agatston and colleagues [9], in which the extent and density of coronary calcification are used to derive a global score. Coronary calcium is strongly associated with coronary artery disease and has been shown to have an odds ratio of 13.7 for any coronary artery disease and an odds ratio of 10.3 for obstructive coronary artery disease [10,11]. This association must be balanced with the results of a recent meta-analysis that found only a moderately increased risk for cardiac events (unstable angina, myocardial infarction, need for

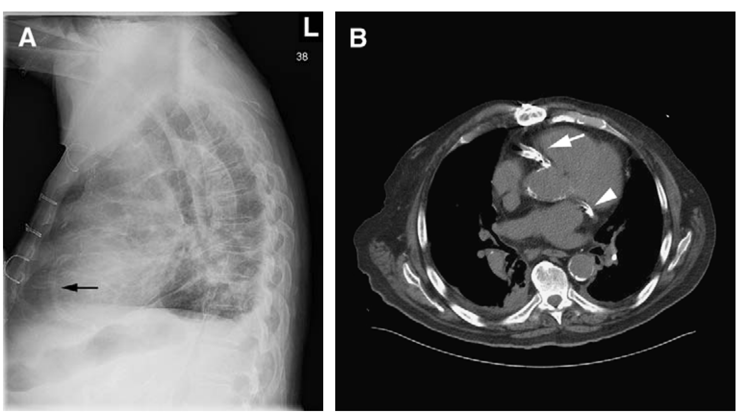

Fig. 1. Coronary calcification. (*A*) Lateral chest radiograph shows coronary artery calcification overlying the anterior cardiac silhouette (*arrow*). (*B*) Nonenhanced CT scan shows that the anterior calcification corresponds to the right coronary artery (*arrow*). The left circumflex artery is also calcified (*arrowhead*).

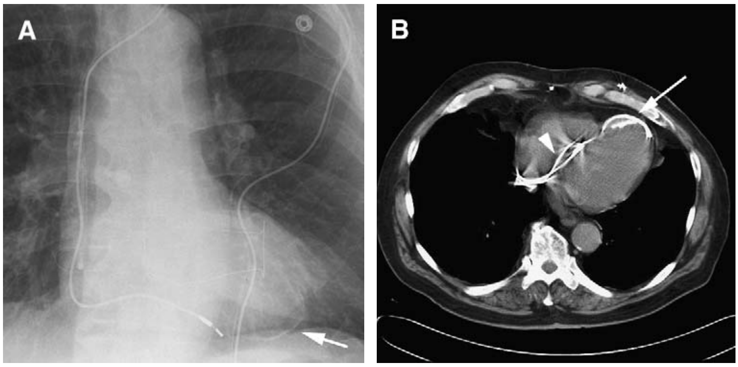

Fig. 2. Myocardial calcification. (*A*) Posteroanterior radiograph shows curvilinear calcification along the left heart border (*arrow*) in a patient with an implantable defibrillator. (*B*) Nonenhanced CT shows curvilinear myocardial calcification in the left ventricular apex (*arrow*). Defibrillator wires are also identified (*arrowhead*).

revascularization, cardiac death) associated with coronary calcifications in asymptomatic populations [12].

Several studies have also sought to evaluate coronary stenosis greater than 50% with EBCT. Reddy and colleagues [13] found an overall sensitivity of 88% and specificity of 79% in 23 patients although coronary artery calcifications resulted in decreased specificity. Budoff and colleagues [14] studied 52 patients and reported an overall sensitivity of 78% and a specificity of 91%. In this study 11% of the cardiac segments were noninterpretable, usually because of motion. The authors also noted difficulty in viewing the right coronary and circumflex arteries. Schmermund and colleagues [15] also reported increased false negatives secondary to segmental calcification with a sensitivity of 82% and a specificity of 88% in 28 patients. Another study by Achenbach and colleagues [16] discovered a sensitivity of 92% and a specificity of 94% in 125 patients although there 25% of segments were noninterpretable in this study. These studies illustrate the capabilities of EBCT but may not be applicable to patients in an emergency department where risk stratification and outcomes are more important measures of the success of a particular test, and where patients cannot be excluded secondary to their ‘‘noninterpretable segments.’’

A few studies have assessed the use of EBCT in the emergency department setting to evaluate patients who have angina-like chest pain [17–19]. Table 1 summarizes studies in which patients presenting to the emergency department with chest pain were evaluated by new techniques. Using the presence of coronary calcium as a marker, these studies demonstrate a sensitivity ranging from 88% to 100% for coronary stenosis or cardiac events and negative predictive values of 97% to 100%. In addition, a high negative predictive value was found. In the study by Laudon and colleagues [17], no patient presenting with chest pain who had a negative EBCT had a cardiac event in the 4 months after presentation to the emergency department [17]. In the study by McLaughlin and colleagues [19], the 1-month cardiac event rate was 2%, compared with 8% in patients who had coronary artery calcium (CAC) scores greater than one. More recently Georgiou and colleagues [18] found a strong association between the age- and gender-adjusted CAC score and a subsequent cardiac event in a cohort of 192 patients who had undergone EBCT during the course of their emergency department evaluation for chest pain. Overall, the 1-year annualized rate for cardiac events was 0.6% for patients who had a CAC score of zero compared with a cardiac event rate of 13.9% in patients who had CAC scores greater than 400 (average follow-up after presentation in the emergency department was 50 $\pm$ 10 months with a range of 1–84 months). The results of this study are somewhat difficult to generalize, because follow-up time was not standard; instead, results were statistically annualized. This study, however, seems to confirm that a CAC score of zero has a high negative predictive value for cardiac events.

Other strategies for managing patients who have chest pain include EBCT replacement of stress testing, the combination of EBCT and stress testing [20], or EBCT scanning in patients who have indeterminate stress results [21].

Table 1
Studies evaluating patients presenting to the emergency department patients with chest pain

Study	n	Sensitivity	Specificity	PPV	NPV	Standards	FU period and outcome	Event Rate
EBCT								
Lauden [17] 1999	100	100	63	30	100	+ test, sten > 40 vs CAC > 0	4 mo CE	0% in neg EBCT
Georgiou [18] 2001	192	97	55	48	97	CAC > 0 vs CE	1 mo–84 mo (mean 50 mo) CE	1 yr annualized
		93	59	55	95	CAC > 4 vs CE		0.6% CAC = 0 13.9% CAC > 400
McLaughlin [19] 1999	134	88*	37*	8*	98%	CAC > 1	1 mo CE	2% versus 8%
MDCT								
White [31] 2005	69	83	96	83	96	CTA > 50% stenosis versus final diagnosis		not studied
CMR								
Kwong [36] 2003	161	84	85	ns	ns	ACS, NSTEMI, UA 70%sten or true + stress test		not studied
Takahashi [37] 2004	18	78	89	78	89	AMI and ultrasound		not studied

Abbreviations: ACS, acute coronary syndrome; AMI, acute myocardial infarction; CAC, coronary artery calcification score; CE, cardiac events; CMR, cardiac magnetic resonance imaging; EBCT, electron beam CT; FU, follow up; MDCT, multidetector CT; NPV, negative predictive value; NSTEMI, nonST elevation myocardial infarction; PPV, positive predictive value; UA, unstable angina.

* Value not provided in text but calculated using standard 2 × 2 table from which NPV was calculated.

The consensus statement on CAC and EBCT from the ACC/AHA can be summarized briefly. Negative tests occur in most patients who have angiographically normal coronaries and may be consistent with a low risk of cardiovascular risk in the next 2 to 5 years. A positive EBCT confirms the presence of atherosclerotic plaque and is best correlated with total amount of plaque burden. The greater the amount of calcium, the greater the likelihood of occlusive disease, and a high calcium score may be consistent with moderate to high cardiovascular risk in the next 2 to 5 years [22].

Multidetector CT

The latest generation of MDCT scanners features ECG gating, submillimeter spatial resolution, and relatively good temporal resolution that permits increasingly accurate assessment of coronary artery anatomy. Currently, scanners are available with 64 detectors, a spatial resolution of 0.5 to 0.6 mm, and temporal resolution of 50 to 100 milliseconds. CT scanners are increasingly being placed in the emergency suite, alleviating concerns about monitoring some patients who have chest pain. The improved technical parameters of MDCT allow determination of the extent of coronary calcification and acquisition of acceptable coronary CTA, ventricular function, and, perhaps myocardial perfusion.

The scanning protocol may be optimized to assess the heart alone or be acquired as a compromise between a coronary and lung CT protocol to assess for pulmonary emboli and aortic dissection also. Generally, 10 evenly spaced phases throughout the cardiac cycle are obtained. This approach permits selection of the phase with the least amount of coronary artery motion, typically in early or late diastole. Reconstructions centered along the curving centerline of the individual coronary arteries are produced and evaluated for hard and soft plaque and critical stenoses. Software exists for a quantitative assessment of the extent of the stenosis. Left ventricular ejection fraction can also be derived from determination of end-systolic and end-diastolic volumes. This postscan processing currently is labor-intensive, and much effort is being directed to streamlining this analysis.

MDCT technique requires intravenous contrast material and is usually done with an automatic triggering mechanism that times the contrast bolus so that opacification is optimized. Patients who have renal insufficiency or significant contrast allergies are thus not eligible. Beta-blockade, typically with metoprolol, can be used in patients who have a heart rate greater than 70 beats per minute. This strategy has been shown to improve image quality because of image degradation at higher rates [23].

As with EBCT, there have been multiple investigations with multidetector CTA to evaluate stenosis. A study by Nieman and colleagues [24] reported a sensitivity of 95% and a specificity of 86% in 59 patients and also reported higher accuracy for left main and left anterior descending arteries than for circumflex and right coronary arteries. This finding is thought to result from the increased motion of those vessels. Ropers and colleagues [25] conducted a study with 77 patients; with 12% excluded segments, sensitivity was 92% and specificity was 93%.

In a more recent study evaluating coronary arteries greater than 2 mm in patients undergoing elective evaluation for chest pain, coronary CTA has shown considerable potential, with sensitivity and specificity of 83% and 97%, respectively [26]. Thirty-seven percent of patients in this study had CAC scores of 400 or higher; if these patients were excluded, CTA sensitivity increased to 89% and specificity increased to 98%.

A PUB MED search (search terms: chest pain, multislice or multidetector, and emergency) found no studies using multislice CT for CTA of the coronary anatomy to evaluate patients presenting to the emergency department with chest pain, although there have been a couple of case reports showing acute myocardial infarction in patients presenting with chest pain [27,28]. Also, a couple of studies have used MDCT in acute coronary syndrome (ACS). Although it may be assumed that these patients presented to the emergency department initially, this information is not confirmed in the text of the articles. One study evaluated ejection fraction and stenosis with a 4-slice scanner [29], and another study used a predictive model to determine if a use of a 16-slice MDCT could decrease the number of diagnostic cardiac angiographies [30].

Currently, the appropriate use and timing of the MDCT in the emergency setting is unclear, and the authors have devised a protocol to test one scenario [31]. The authors have proposed that the examination be obtained in patients who have chest pain and an intermediate probability of angina, as initially assessed by the emergency physician by examination and ECG. Patients who have a high probability would be taken for emergent coronary angiography; those with low probability are unlikely to benefit from MDCT. In the authors' protocol, patients were brought to the emergency suite scanner between 30 minutes and 1 hour after initial assessment. The 16-slice CT scan using a dual heart–lung protocol was intended to provide a comprehensive evaluation of both coronary and noncoronary causes of chest pain.

In this study, 69 patients met all criteria for enrollment, 45 (65%) of whom otherwise would not have undergone CT scanning [29]. Fifty-two patients (75%) had no significant CT findings and a final diagnosis of clinically insignificant chest pain. Thirteen patients (18%) had significant CT findings concordant with the final diagnosis (10 cardiac, 3 noncardiac). Fig. 3 shows an example of a curved planar reconstruction used to visualize the coronary vessels. CT failed to suggest a diagnosis in two patients (3%), both of whom proved to have clinically significant coronary artery stenoses. In two patients (3%), CT overdiagnosed a coronary stenosis. Sensitivity and specificity for the establishment of a cardiac cause of chest pain were 83% and 96%, respectively. Overall sensitivity and specificity for all cardiac and noncardiac causes of chest pain were 87% and 96%, respectively. The cardiac assessment was done several hours or more after acquisition of the CT scan because of software limitations. The study suggests that MDCT is logistically

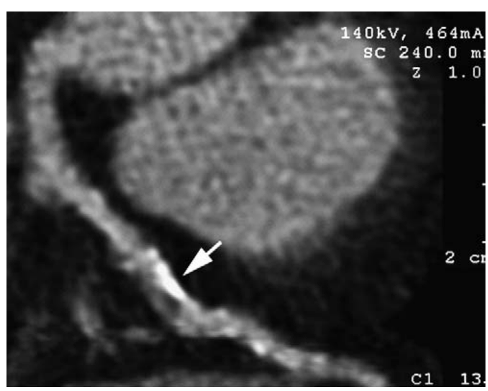

Fig. 3. CT scanning in the emergency room. A curved planar reconstructed image of a diagonal branch shows calcification and narrowing (*arrow*).

feasible and may prove useful if hardware and software improvements continue. Current technology involves the use of 40- and 64-slice scanners; studies evaluating their use in patients presenting to the emergency department with chest pain have yet to be published.

Cardiac MR and angiography

MRI is effective in evaluating myocardial ischemia and thus has potential applications in the emergency room setting. After intravenous infusion of gadolinium chelate, myocardial perfusion can be assessed with rapid temporal imaging. Wall-motion abnormalities can be delineated with bright blood cine imaging. Delayed images after gadolinium enhancement are valuable to depict myocardial viability. Delayed hyper-enhancement 10 to 20 minutes after injection is a strong indicator of myocardial infarction (Fig. 4) [32].

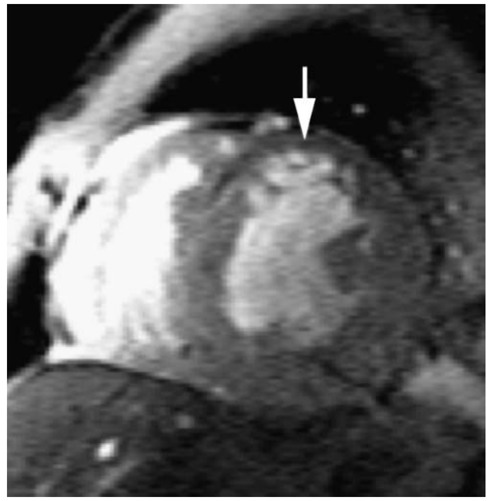

Fig. 4. CMR of myocardial infarction. Short-axis image from CMR viability study shows an area of hyper enhancement in the anterior wall, indicating myocardial infarction (*arrow*).

In one of the earlier studies evaluating CMR for detection of coronary stenoses, Regenfus and colleagues [33] reported sensitivity of 94.4% and specificity of 57.1% on a patient basis with 50 patients in the study. Only 76.6% of segments could be evaluated, and the left circumflex could be evaluated in only 50% of cases. In a larger study of 109 patients, coronary magnetic resonance angiography was performed before elective radiographic coronary angiography, and the results of the two diagnostic procedures were compared. Six hundred thirty-six of 759 proximal and middle segments were interpretable on magnetic resonance angiography (84%). In these segments, the sensitivity, specificity, and accuracy for patients who had disease of the left main coronary artery or three-vessel disease were 100%, 85%, and 87%, respectively. The negative predictive values for any coronary artery disease and for left main artery or three-vessel disease were 81% and 100%, respectively [34]. In a recent brief report by van Geuns and colleagues [35], CMR was found to have only 46% sensitivity but 90% specificity for stenosis that was greater than 50% in a small study of 27 patients.

Again, fewer studies have examined the usefulness in emergency department patients. Kwong and colleagues [36] assessed the use of CMR in a prospective study of 161 patients who presented to the emergency room with suspected ACS. Inclusion criteria were an episode of chest pain lasting more than 30 minutes and an abnormal but nondiagnostic ECG. Resting CMR was performed within 12 hours of presentation. The image protocol consisted of perfusion, wall motion, and viability sequences. CMR demonstrated a sensitivity of 84% and specificity of 85%, respectively, for ACS.

Another small study of 18 patients in 2004 by Takahashi and colleagues [37] also evaluated CMR in patients who had ACS as defined by acute myocardial infarction and ultrasound. Because the majority of patients in this study actually were classified as having acute myocardial infarction, this study probably more accurately appraises the utility of CMR in acute myocardial infarction and than in true ACS.

CMR has the advantage of good spatial and excellent temporal resolution, and Gadolinium contrast agent is widely available. Nevertheless, CMR is limited by the need for specialized, often expensive equipment that may not be located near the emergency room. Other issues that potentially make CMR unfeasible for many emergency department patients are patient claustrophobia and the need to monitor an acutely ill patient appropriately in the bore of the MR imager.

Other techniques

Although there are other new techniques available to evaluate patients who have chest pain that better establish plaque composition, these new techniques are invasive and investigational and have little if any application in the emergency department or in the initial evaluation of the patient who has potential cardiac disease. These techniques include intravascular ultrasound, optical coherence tomography, thermography, and angioscopy and are beyond the scope of this discussion.

Stress echocardiography

Stress echocardiography is readily available, is relatively low in cost, and can assess cardiac anatomy and function during stress. It also has the advantage of providing incremental information of value by evaluating baseline ventricular function, valvular function, aortic root morphology, and pericardial anatomy. Such information can provide further insight into the possible causes of the chest pain. Regional wall-motion abnormalities are early signs of myocardial ischemia and provide an indirect evaluation of abnormal myocardial perfusion [1] and coronary blood flow. Wal-motion abnormalities at rest identify patients who have had ischemic injury. The number of abnormal wall-motion segments is quantified by the wall-motion score index (Fig. 5). The higher the wall-motion score index, the greater the number of abnormal segments and, thus, the higher risk for the patient [38].

The decision to perform either an exercise or pharmacologic stress echocardiogram depends on the functional status of the patient. Ideally, an exercise stress test should be performed because it provides valuable physiologic information including functional capacity. A normal exercise stress echocardiogram confers an excellent prognosis. The overall cardiac event rate (cardiac death, nonfatal myocardial infarction) ranges from 0.9% to 1.1% per year. An abnormal study increases the risk of a cardiac event by three to four times [39–42].

Other factors may affect prognosis as well. Exercise stress–induced wall-motion abnormalities in the left anterior descending distribution predict a fivefold higher cardiac event rate at 5 years than wall-motion abnormalities in other regions [43]. Even with a normal stress echocardiogram, patients who have diabetes mellitus have significantly higher cardiac event rates (6% per year) than nondiabetics (2.7% per year) [44], and hypertensive patients who have a normal

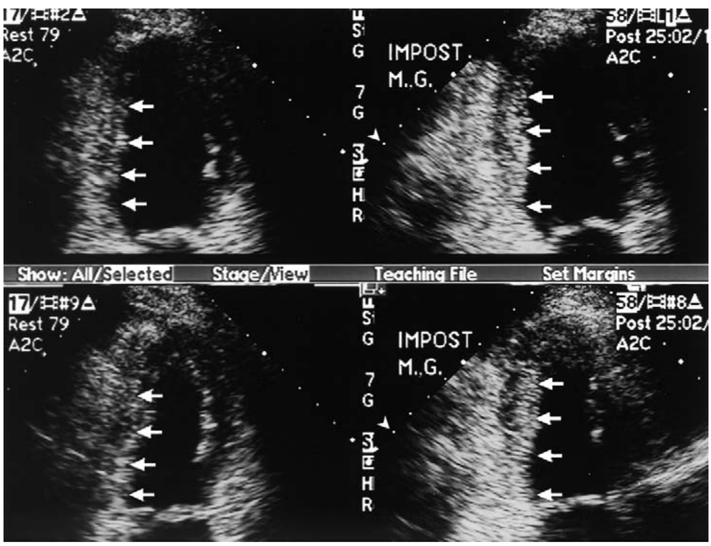

Fig. 5. Exercise echocardiogram recorded in a patient with a disease of the right coronary artery. The two left panels were recorded at rest and the two right panels immediately after treadmill exercise; the top panels show diastole, and the bottom panels show systole. In each panel the arrows note the location of the inferior wall endocardium at end-diastole. At rest there is appropriate thickening and inward motion of the inferior wall that can be seen to move inward through the body of the arrows. Immediately after exercise the proximal inferior wall (*lower two arrows*) becomes frankly dyskinetic, and the mid and diastole portion of the inferior wall is akinetic. There is no incursion of the endocardium into the previously placed arrows. (*From* Braunwald E. Heart disease: a textbook of cardiovascular medicine. 6th edition. Philadelphia: Elsevier Inc.; 2001. p. 214; with permission.)

dobutamine stress echocardiogram have an overall higher cardiac event rate (1.8% per year) than the general population (approximately 1% per year) but a significantly lower rate than those who have an abnormal study (3.8% per year) [45].

When the patient is unable to exercise, pharmacologic testing provides a valuable alternative and provides similar prognostic information. The most common drug used for a pharmacologic stress test is dobutamine. The infusion begins at 5 μg/kg/min and is increased by 5- to 10-μg/kg/min increments until target heart rate is achieved. Frequently, atropine may be required if the dobutamine infusion does not achieve the target heart rate. Continuous ECG monitoring is performed throughout the stress test and the recovery period. Echocardiogram images are obtained during the pre-infusion period (resting state), at low-dose stress, at peak stress (when target heart rate is achieved), and then in recovery.

Several studies have found death and nonfatal myocardial infarction rates of approximately 1.1% per year for a normal test [46,47]. The death and nonfatal myocardial infarction rates for abnormal studies are about 7% per year [46–51]. In studies evaluating exercise and dobutamine stress echocardiography, a normal study translates into a low cardiac event rate (0.8%–0.9% per year) [52,53]. Abnormal studies could be further stratified into intermediate (3.1% per year cardiac event rate) and high (5.2% per year cardiac event rate) risk groups based on the wall-motion score index [52].

Because regional wall-motion abnormalities usually precede the onset of definitive echocardiographic signs of ischemia, echocardiographic detection of regional left ventricular dysfunction has been assessed as a tool to improve the diagnosis of acute cardiac ischemia in the emergency room. Among patients undergoing echocardiographic study during active chest pain in the emergency room, Peels and colleagues [54] found echocardiography to be highly sensitive for the detection of myocardial infarction and acute ischemia (92% and 88%, respectively). The specificity of this approach was limited, at 53% for infarction and 78% for ischemia. In the absence of ongoing symptoms, the sensitivity of echocardiography was limited [55]. Echocardiographic analysis in these studies was limited to patients exhibiting normal conduction systems and no prior myocardial infarction, because both conduction disturbances and prior areas of infarction can cause regional wall-motion abnormalities in the absence of acute ischemia.

Sabia and colleagues [56] examined the value of regional wall-motion abnormality for the diagnosis of acute myocardial infarction in the emergency room. The sensitivity for echocardiographically detected regional wall-motion abnormalities to identify acute ischemic heart disease presenting as myocardial infarction was 93%. The specificity, however, was modest (57%). These investigators estimated that the use of echocardiography in the emergency room could result in a 32% reduction in hospital admissions, but this estimate was not demonstrated in a prospective manner. In a small subset of patients ultimately diagnosed as having non-Q wave infarction, echocardiography failed to demonstrate regional wall-motion abnormality. False-negative findings by echocardiography have also been observed by other investigators [57,58].

Recently, Kontos and colleagues [59] demonstrated a high negative predictive value of normal echocardiographic studies in patients who had chest pain, which correlated with a benign prognosis at 10 months. In a subsequent study [60], these authors also compared myocardial perfusion imaging with single-photon emission CT (SPECT) and echocardiography in 185 patients who presented to the emergency room with chest pain and who were considered to have low to moderate risk of coronary ischemia based on history and echocardiography. In 90% of the patients, acute rest sestamibi perfusion and echocardiographic studies were performed within 1 hour of each other. The two techniques had similar sensitivities and specificities for the detection of acute myocardial infarction or acute myocardial ischemia. Further confirmatory studies are needed to determine the impact of symptom resolution on this comparison, because the earlier studies of echocardiography demonstrated that optimal sensitivity is dependent on the presence of symptoms during the emergency room evaluation [54–58]. The most recent studies evaluating the role of dobutamine tele-echocardiography [61] and contrast echocardiography [62] for patients presenting to the emergency room with chest pain have also reported favorable results. These techniques or technologies are not in widespread clinical use, however.

These studies suggest that regional wall-motion assessment by echocardiography to determine early signs of ischemia in patients presenting to the emergency room with chest pain is feasible. For optimal sensitivity this approach requires ongoing symptoms during the study. The suboptimal specificity suggests this technique has limited use in decreasing the number of false-positive admissions for patients presenting to the emergency department with chest pain. Moreover, no study has evaluated the actual impact of the use of echocardiography on triage from the emergency room.

Stress echocardiography has been shown to be comparable with nuclear stress perfusion scanning for detecting coronary disease and for predicting short- and long-term cardiac events [63–65]. Exercise stress testing and pharmacologic stress testing seem to provide comparable short- and long-term prognostic information. Dobutamine stress echocardiography is equal to dipyridamole Technetium sestamibi scanning in sensitivity and has greater specificity for detecting single-vessel and multivessel disease [64]. An abnormal exercise stress echocardiography or Thallium perfusion study predicted a 4.1-fold and 4.9-fold increase, respectively, in the risk of all cardiac events over an almost 4-year follow-up [65]. For even a longer follow-up period (mean, 7.3 years), a normal dobutamine stress echocardiogram predicted a cardiac event rate of 3.6% per year, whereas a normal dobutamine stress Technetium sestamibi scan predicted a cardiac event rate of 2.8% per year. Abnormal stress echocardiograms predicted a cardiac event rate of 6.5%, whereas abnormal Technetium sestamibi scans predicted a rate of 6.9% per year [63]. Therefore, exercise stress echocardiography and pharmacologic stress echocardiography provide similar detection and prognostic information when compared with nuclear stress studies.

Application of single-photon emission CT myocardial perfusion imaging in the emergency department

In patients who present in the emergency departments with chest pain and are suspected to be experiencing ACS, radionuclide myocardial perfusion imaging techniques can provide both diagnostic and prognostic information. Evidence from controlled, randomized trials suggests that incorporating SPECT myocardial perfusion imaging in emergency department patients who have suspected ACS but no definitive ECG changes can improve triage decisions. The ACC/AHA/American Society of Nuclear Cardiology Radionuclide Imaging Guidelines classify myocardial perfusion imaging in this setting as a class I, level A indication [66] for patients in whom the diagnosis is uncertain.

Among ACS patients who present with ST segment elevation myocardial infarction or non-ST segment elevation myocardial infarction/unstable angina, the typical role for imaging in the stabilized patient is to provide risk-stratification information to drive a management strategy aimed at improving natural history. Thus, the role of myocardial perfusion SPECT early during ST segment elevation myocardial infarction or non-ST segment elevation myocardial infarction/unstable angina is to identify the location and extent of myocardial injury. After therapeutic intervention a follow-up study is compared with the earlier study to identify the extent of myocardial salvage and final infarct size (Fig. 6).

The role of myocardial perfusion imaging in patients presenting with chest pain and nondiagnostic ECG changes

In patients presenting with chest pain and nondiagnostic ECG changes, myocardial perfusion SPECT data have been shown to have an incremental risk stratification value over clinical data for predicting unfavorable cardiac events [67]. The injection of Technetium-99m–based perfusion tracer in a patient during chest pain and imaging 45 to 60 minutes later allows the assessment of myocardial blood flow at the time of injection. In all observational studies, the negative predictive value for ruling out myocardial infarction has equaled or exceeded 99% in this setting. This finding suggests that a normal myocardial perfusion study in this setting portends very small risk of myocardial infarction or ischemic event [68]. In contrast, patients exhibiting abnormal regional perfusion defect have a higher risk of cardiac events during the index hospitalization as well as during follow-up. One study by Kontos and colleagues [69] found the sensitivity of SPECT sestamibi performed in the emergency department to be 92% for detecting acute myocardial infarction, whereas initial troponin I values drawn at the same time had a sensitivity of only 39%. The maximum troponin I over the first 24 hours had sensitivity similar to rest sestamibi imaging, but at a distinctly later time point. Thus, acute myocardial perfusion imaging has the potential to identify ACS earlier than biomarkers, thereby providing assistance in patient triage decisions (admit or discharge) in the emergency department.

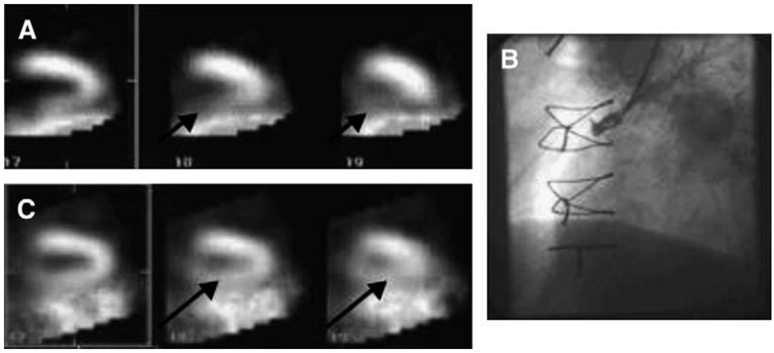

Fig. 6. Inferior myocardial perfusion defect in a patient with chest pain but no ischemic ECG abnormalities. (*A*) Vertical long-axis resting SPECT myocardial perfusion images of a 67-year-old-man who presented to the emergency room with chest pain and no ischemic ECG changes. His troponin T was negative and troponin I was less than 0.1. He was injected with Technetium-99m sestamibi at rest in the emergency room and underwent SPECT imaging soon thereafter. The images show severely reduced inferior perfusion defect (*arrows*), which in the setting of ongoing symptoms was suggestive of acute coronary syndrome. (*B*) Cardiac catheterization showed totally occluded right coronary artery and graft. (*C*) A prior myocardial perfusion SPECT study performed showed normal perfusion in all myocardial regions, including the inferior region (*arrows*).

Although these observational studies emphasize the importance of myocardial perfusion imaging for ruling out ACS, in none of those studies were the imaging data allowed to affect patient triage decisions in the emergency department. In a prospective study by Stowers and colleagues [70], 46 patients who had ongoing chest pain and a nondiagnostic ECG were randomly assigned to an image-guided strategy (in which patient management was based on the SPECT results) or a conventional strategy (in which imaging results were kept blinded, and patient management was independent of the SPECT data). The results showed that an image-guided strategy incurred approximately 50% lower costs and resulted in shorter lengths of hospital stay. In a larger prospective trial (the ERASE Chest Pain Trial) [71], 2475 patients who had symptoms suggestive of ACS and a normal or nondiagnostic ECG were randomly assigned to a usual emergency department evaluation strategy or a strategy including acute rest SPECT myocardial perfusion information. The results showed that the imaging data were among the most powerful factors associated with the appropriate decision to discharge the patient from the emergency department. For patients ultimately determined not to have ACS as the presenting syndrome, SPECT myocardial imaging was associated with a 32% reduction in the odds of being admitted unnecessarily to the hospital for treatment or observation [71]. On 30-day follow-up of all patients, there were no differences in outcomes between the usual emergency department evaluation strategy and SPECT image-guidance. These findings suggest that the incorporation of SPECT perfusion imaging into the emergency department triage decision-making process reduces unnecessary hospital admissions without inappropriately reducing admission for patients who have ACS. In the future, metabolic imaging with a fatty acid tracer called methyl-[123I]-iodophenyl-pentadecanoic acid (BMIPP) may extend the time window for identifying myocardial ischemia in the emergency room up to 30 hours after the cessation of chest pain [72].

The chest pain center protocol: stress myocardial perfusion single-proton emission CT

Another strategy that has been proposed for patients who have suspected ACS but a nondiagnostic ECG is serial evaluation of cardiac specific enzymes over 6 to 24 hours, followed by stress testing if the enzymes are negative. Among patients who are considered clinically to be at very low risk, however, stress myocardial perfusion SPECT study can be performed rather early. SPECT myocardial perfusion imaging in this setting can potentially allow earlier patient triage decisions than serial enzyme evaluation. The current data suggest that if stress myocardial perfusion studies are normal, the risk of ACS or unfavorable cardiac events is low, and therefore early discharge from the emergency department may be considered. On the other hand, if the stress imaging results are abnormal (ischemia or infarction), rapid admission and entry into an appropriate evidence-based treatment pathway for ACS are in order.

Summary

Multiple strategies and testing modalities are available to evaluate patients presenting to the emergency department with cardiac complaints. Many provide anatomic and prognostic information about coronary stenosis and long-term outcomes. Although nuclear and stress echo imaging have the ability to predict outcomes in patients in the emergency department population, the newer modalities of cardiac imaging (EBCT, MDCT, and CMR) continue to show promising results and may soon be incorporated into emergency department chest pain centers. Protocols can be developed within an institution to meet the needs of the patient population while minimizing risk and improving outcomes for all patients.

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