Cardiac Computed Tomography in the Rapid Evaluation of Acute Cardiac Emergencies

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Approximately 6 million patients are evaluated annually in US emergency departments for acute chest pain. The delineation of the presence or absence of acute coronary syndromes in these patients must be accurate and efficient in order to prevent missed diagnoses. Coronary computed tomography angiography has great promise as a tool to expedite the triage of patients with acute chest pain to early discharge or further inpatient diagnosis and treatment.
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Emergency departments (EDs) in the United States evaluate approximately 6 million patients annually for acute chest pain.[1] Studies estimate that between 2% and 5% of patients later diagnosed with an acute coronary syndrome (ACS) were inappropriately sent home from EDs. Since the advent of chest pain centers and provocative testing protocols, the current rate of inappropriately discharged ED patients is closer to 0.5%.[2-4] Previous studies show that discharged patients suffer a higher morbidity than patients admitted to the hospital. Missed ACS patients have the highest insurance payout per case and account for 41% of claims paid.[5] Not surprisingly, physicians do not want to miss ACS, which results in an annual US cost of $10 to $13 billion to rule out.[1] Therefore, the delineation of the presence or absence of an acute coronary syndrome must be accurate and efficient.

Coronary computed tomography angiography (CCTA) shows significant promise as the tool to accurately expedite the triage of acute chest pain patients. CCTA is especially suited to the undifferentiated chest pain patients, because it not only able to directly visualize the coronary anatomy, but simultaneously image the rest of the thorax to exclude aortic dissection and significant pulmonary embolism and provide alternate causes of chest pain, such as pneumonia, pericardial fluid, and esophageal inflammation.

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The State of Computed Tomography (CT) Technology

The introduction of helical/spiral CT imaging technology, combined with advances in the temporal and spatial resolution of CT[6] have made it possible to visualize the coronary arteries with systems that allow the image reconstruction to be synchronized with the cardiac phase.[7,8] Recent advances include decreased gantry rotation times to 330 milliseconds, providing a completed image in 165 milliseconds, with improved detector and collimator hardware providing submillimeter image resolution (0.4-0.5 mm). High-resolution 64-slice and dual-64 slice scanners are the standard for CCTA, and offer decreased breath-hold time and cardiac motion artifacts. The end result is a reduction in the percentage of "uninterpretable" scans, which has allowed imaging without the strict bradycardia parameters necessary with previous scanners. Heavily calcified coronary arteries, coronary artery stents, and markedly obese patients remain challenging.

CCTA Accuracy

Quantitation of coronary artery lesion severity by CCTA correlates well with invasive coronary angiography (Pearson correlation, r = 0.72).[9-11] The mean percentage difference in stenosis diameter measured by CCTA as compared with quantitative coronary angiography (QCA) was 1.3% ± 14.0%. Although the mean difference was small and would not impact clinical management significantly, the standard deviation was high and this variability limits CCTA's quantitative accuracy and, as a result, its ability to make recommendations regarding invasive treatment.

Diagnostic Utility of CT in ED Patients Evaluated for Undifferentiated Chest Pain

Several recent studies have investigated the safety and diagnostic accuracy of 64-slice CCTA in the disposition of ED patients evaluated for acute chest pain.[12-18] Six studies enrolled a total of 376 ED acute chest pain patients (predominantly with low pretest coronary risk) who were prospectively evaluated over a 30-day to 15-month follow-up period after CCTA. All 6 studies were designed to capture low-risk patients and appropriately excluded patients with abnormal cardiac biomarkers, CK-MB (creatine kinase-myocardial band) or troponin (Tn) I, or ischemic electrocardiographic changes. One-third of the studies also excluded patients with preexisting coronary artery disease (CAD).[15,17] Despite the enrollment of low-risk patients, an adjudicated diagnosis of ACS occurred in 19.1% (72/376) of the study patients. CCTA accurately excluded the presence of ACS in 301 of the 304 remaining patients who did not show evidence of significant coronary artery stenosis. In these studies, CCTA had a negative predictive value of 99% for adverse 30-day outcomes, suggesting that CCTA identifies a subset of ED chest pain patients who can be safely discharged home.

Goldstein and colleagues[17] reported the results of a randomized trial in 197 low-risk acute chest pain patients with an initial nondiagnostic electrocardiogram (ECG) and negative Tn/CK-MB to either early CCTA or a standard diagnostic protocol, which included serial ECG, Tns or CK-MB, and stress imaging. Patients randomized to CCTA were eligible for discharge if they had no or minimal (< 25%) coronary stenosis and a negative 4-hour CK-MB or Tn test. Those patients with stenosis > 70% were referred emergently for invasive angiography. By protocol, the remainder with intermediate-grade stenosis or uninterpretable scans underwent additional stress testing. The outcome of interest was 180-day safety, diagnostic accuracy, and efficiency. Seventy-five percent of patients randomized to CCTA had a definitive triage decision; 67% were discharged without further work-up and 8% were referred for catheterization, which revealed significant disease in 7/8. By protocol, CCTA was

Table 1
Early and 6-Month Clinical Outcomes

	MSCT n = 99	Standard of Care n = 98	*P* Value
Index visit outcomes			
Test complications	0(0%)	0(0%)	NA
Direct ED discharges	88(88.1%)	95(96.9%)	0.03
AMI	0(0%)	0(0%)	NA
Death	0(0%)	0(0%)	NA
In-hospital diagnostic cath	11(11.1%)	3(3.1%)	0.03
Positive caths	9(9.1%)	1(1%)	0.02
In-hospital PCI	3(3.0%)	1(1.0%)	0.62
In-hospital CABG	2(2.0%)	0(0%)	0.50
6-mo outcomes			
Test complications	0(0%)	0(0%)	NA
Unstable angina	0(0%)	0(0%)	NA
MI	0(0%)	0(0%)	NA
Death	0(0%)	0(0%)	NA
Late ED R/O ischemia	6(6.1%)	6(6.1%)	1.00
Late office R/O ischemia	2(2.0%)	2(2.0%)	1.00
Late diagnostic cath	1(1.0%)	4(4.1%)	0.21
Late stress/MSCT test	1(1.0%)	3(2.0%)	0.37
Cath cumulative	12(12%)	7(7.1%)	0.24
True-positive cumulative	8/12(67.7%)	1/7(14.3%)	0.06
True-negative cumulative	1/12(8.3%)	4/7(57.1%)	0.04
False-positive cumulative	3(25%)	2(28.5%)	1.00
False-negative cumulative	0(0%)	0(0%)	NA
Cath-accuracy cumulative	9(75%)	5(71.4%)	1.00
Clinically correct diagnosis	96/99(97.0%)	96/98(98.0%)	1.00
Late tests cumulative	2(2.0%)	7(7.1%)	0.10
Diagnostic efficacy	94/99(94.9%)	89/98(90.8%)	0.26
PCI cumulative	4(4.0%)	1(1.0%)	0.37
CABG cumulative	2(2.0%)	0(0%)	0.50

AMI, acute myocardial infarction; CABG, coronary artery bypass grafting; Cath, cardiac catheterization/invasive coronary angiography; ED, emergency department; MI, myocardial infarction; MSCT, multislice computed tomography; PCI, percutaneous coronary intervention; R/O, rule out.
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considered inadequate for definitive diagnosis in 24 of the 99 cases, due to either lesions of unclear hemodynamic significance (stenosis = 26%-70%) in 13 or to inadequate quality scans in 11. All 24 patients underwent subsequent noninvasive stress testing. None of the CCTA patients who were discharged immediately based upon their CCTA findings had a major cardiac event or subsequent diagnosis of CAD at the 6-month follow-up period (Table 1). The overall diagnostic accuracy of CCTA was 94%, as compared with 91% for the standard protocol, and the negative predictive value for adverse events was 100% with either strategy. Diagnostic efficiency, defined as time from randomization to definitive diagnosis, showed that the CCTA approach was more rapid (3.4 vs 15.0 h) and reduced costs by 15%.

In the Goldstein study,[17] 2 years after enrollment there were 4 deaths, all in the Standard of Care (SOC) group, and none were cardiac related. In the CCTA arm, 8 patients had additional stress testing, all with negative results, and none suffered an adverse cardiac event. Patients in the SOC arm suffered 2 acute myocardial infarctions (AMIs); both occurred at the 22-month mark post-randomization after an initial normal stress test result. Hospitalizations for suspected cardiac cause, rates of ED visits for potential cardiac complaints, and rate of repeat stress testing were similar between the 2 studies.[19]

Independently, a similar triage strategy has been evaluated by other centers. Hollander and colleagues[20] evaluated low-risk chest pain patients (Thrombosis in Myocardial Infarction [TIMI] score < 3) with no acute ischemia on ECG, and negative initial Tn markers with CT coronary angiography in the ED. In this protocol, a CCTA with < 50% stenosis and a calcium score of < 100 was considered negative.. Fifty-four patients were evaluated, 46 (85%) of whom were immediately released from ED, typically without a repeat Tn and none had cardiovascular complications within 30 days. The other 8 were admitted after CCTA: 1 with >70% stenosis, 5 with 50% to 69% stenosis, 2 with 0% to 49% stenosis. The authors concluded that, in the evaluation of low-risk ED patients, negative CCTA results can allow safe, rapid discharge.

Hollander and coworkers[21] also published a 1-year follow-up study of 481 low-risk (TIMI < 3) patients undergoing CCTA. During follow-up, there were 53 (11%) rehospitalized and 51 (11%) who received further diagnostic testing (stress testing or cardiac catheterization). There was 1 death of unclear etiology, no AMI, and no revascularization procedures. The authors concluded that the low-risk ED chest pain patient with a negative CCTA result has a very low risk of adverse events over 1 year.

Hoffman and associates[22] performed an observational cohort study in chest pain patients with normal initial Tn and nonischemic ECG who underwent a 64-slice CCTA to detect a > 50% stenosis. Results of the CCTA were blinded to the treating physicians. Of 368 patients, 31 had ACS (8%). By CCTA, 50% of these were free of coronary artery disease (CAD), 31% had nonobstructive disease, and 19% had inconclusive or positive CCTA for significant stenosis. Sensitivity and negative predictive value were both 100% for ACS and 77% and 98% for CAD, respectively. Specificity for presence of plaque or stenosis in ACS patients was 54% and 87%, respectively. Only 1 ACS occurred in the absence of calcified plaque. Both the extent of coronary plaque and presence of stenosis predicted ACS independently and were associated with the TIMI risk score. They concluded 50% of patients with acute chest pain and low to intermediate likelihood of ACS did not have ACS or CAD by CCTA.

The above studies used a variety of sampling times for cardiac biomarkers, from a single initial measurement at the time of ED arrival to serial sampling. Of note, each study excluded patients with positive initial enzymes because these patients would more than likely receive a cardiac angiogram. In the studies by Gallagher and colleagues[15] and Goldstein and colleagues,[17] which used serial testing at 4 hours, none of the patients had a subsequent elevation in their biomarkers. From these studies the use of a single negative initial biomarker in combination with stenosis, < 50% by CCTA appears to define a very low-risk group that can be safely discharged from the ED for follow-up.

The Utility of Calcium Scoring in Addition to CCTA

Coronary calcification is a marker of atherosclerosis and its extent is proportional to the severity of atherosclerotic disease. The presence of calcium on CT has a high sensitivity for CAD; however, it has a relatively poor specificity for predicting obstructive disease. Calcium scoring represents the cardiac plaque burden and has shown value above and beyond the Framingham risk score, and those with increased calcium score have a 10-fold increase in their likelihood to suffer a cardiac event in the next 5 years.[23] Further, in patients with a calcium score < 100, < 2% had an abnormality by myocardial perfusion single photon emission computed tomography (SPECT).[24]

Since the emergence of CCTA, the added value of the calcium scoring in the coronary arteries is controversial. Several studies have evaluated the extent of CAD on 64-slice CCTA in patients undergoing evaluation of chest pain syndromes. In 668 consecutive CCTA patients obstructive (> 50% lesion) CAD was present in 27 of 231 patients (7%) with a 0 calcium score, and in 17% with a low calcium score (1-100). Of the 27 patients with obstructive CAD, invasive coronary angiography confirmed these findings in 21 of 23 (positive predictive value 91%).[25]

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O'Neil and colleagues[26] presented data at the 2007 American College of Cardiology Annual Scientific Session on a retrospective analysis of 2 prospective published trials on the use of CCTA in the diagnosis of ED patients with acute chest pain. They reported the prevalence of catheterization-proven noncalcified plaque and lesions > 50% luminal stenosis in patients with absent or minimal coronary calcification. Among the 300 ED patients enrolled, 198 underwent both coronary artery calcium scoring and CCTA. In this low-risk population, 141 patients had calcium scores under 20, with 2.8% (4/141) having coronary stenoses > 50% on invasive angiography (3 with maximum QCA stenosis > 90%, 1 with 65% stenosis). In total, 22 (15.6%) patients with a calcium score < 20 had significant (ie, > 25% stenosis) noncalcified atherosclerotic plaque. Nine of these patients underwent cardiac catheterization; 4 had severe CAD and 5 had moderate CAD. Similar findings were reported by Motoyama and colleagues[27] in a CCTA comparison of stable angina and culprit lesions in ACS. The researchers concluded that large calcification was significantly more frequent in stable lesions and positive remodeling and spotty calcification were significantly more frequent in the ACS lesions. Therefore, the efficacy of calcium scoring for the short-term risk stratification of acutely symptomatic chest pain patients is poor and provides little additional information to CCTA. We and many other centers have dropped calcium scoring as a routine portion of the CCTA protocol and in doing so have further reduced the radiation exposure.

Identification of Unstable Plaques by CCTA

Our collaborators recently published data showing that high-resolution CCTA can identify vulnerable plaques and provide additional relevant information even beyond angiography.[28] Complex plaque morphology is the angiographic hallmark of unstable coronary lesions. CCTA-documented lesion morphology is strikingly similar to that seen on subsequent invasive angiographic features indicative of plaque disruption, including lesion haziness, irregularity, ulceration, and intraplaque contrast penetration. On CCTA, complex lesions typically appeared bulky, hypodense, eccentric, and positively remodeled; these features are similar to complex ruptured plaque seen by intravascular ultrasound. The noninvasive characterization of plaque instability has obvious and far-reaching clinical implications. Further studies are required to delineate the diagnostic accuracy and prognostic value of CCTA for characterization of complex plaque (Figures 1-3).

Triple Rule-Out CT Protocol

The 3 most lethal potential causes of acute chest pain are acute myocardial infarction, aortic dissection, and pulmonary embolism (PE). Since the recent clinical accuracy of CCTA for exclusion of ACS in ED patients, combined with the proven clinical accuracy of CT angiography for diagnosis of acute aortic dissection[18,20-22,29-32] and pulmonary embolism,[33-37] a triple rule-out scan protocol is a very attractive option. A conventional cardiac CCTA field includes the anatomy between the carina and the diaphragm; the technical difficulty with a triple rule-out scan protocol is to maintain a consistently high contrast intensity within all 3 of the vascular beds under study. The simultaneous evaluation of the

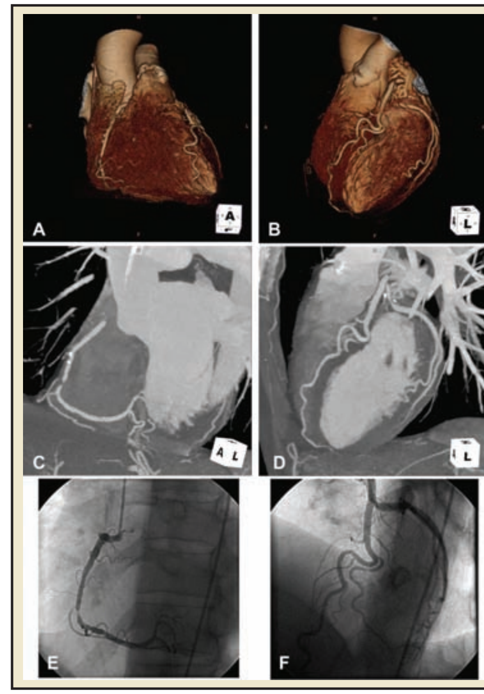
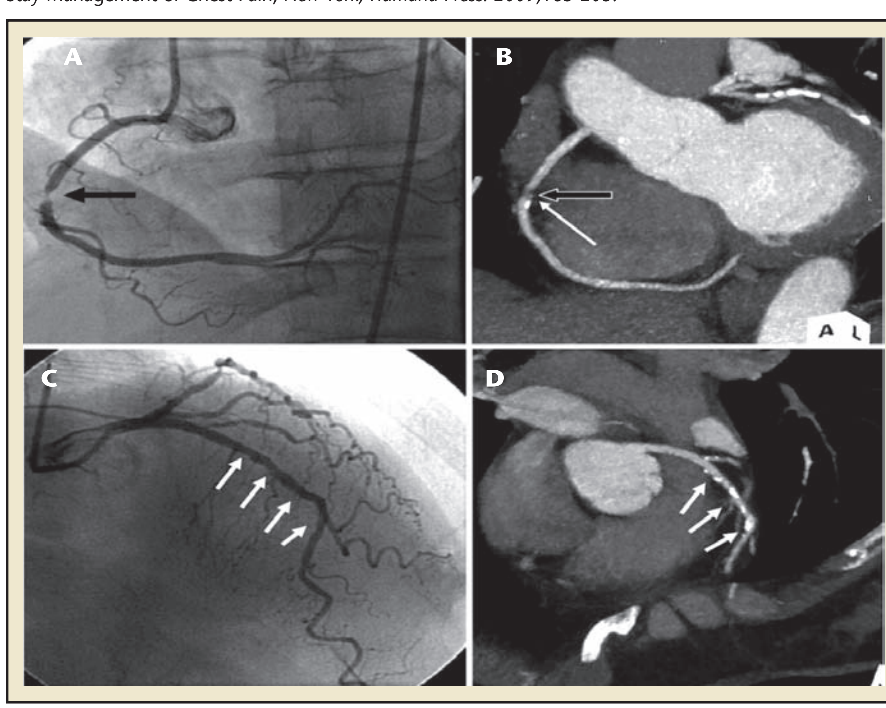


Figure 1. *Visualization of calcified and noncalcified coronary atherosclerotic plaques by 64-slice coronary computed tomography angiography.* **(A, B)** *Volume rendering technique demonstrates stenosis of the right coronary artery below the acute marginal branch* **(A)**, *as well as nodular coronary calcifications largely extrinsic to the right coronary lumen and* **(B)** *normal left coronary artery.* **(C, D)** *Maximum-intensity projection images of the same arteries demonstrate severe noncalcified stenosis of the right coronary artery and superficial calcified plaque.* **(E, F)** *Invasive coronary angiography of the same arteries. Reprinted with permission from O'Neil B, Gallagher MJ, Raff GL, "Use of multislice CT and MRI for the evaluation of patients with chest pain," In: Peacock WF, Cannon CP, eds,* Short Stay Management of Chest Pain, *New York; Humana Press: 2009;185-203.*[26]

Figure 2. *Putative computed tomography (CT) differences between unstable and stable plaque in the same patient. Panels A-D show comparative images in a patient with unstable, ruptured right coronary artery (RCA) lesion, but stable plaque in the left anterior (LAD) descending and circumflex arteries. Invasive angiography* **(A)** *documents complex plaque severely narrowing the mid-RCA* (black arrow). *The coronary computed tomography angiography (CCTA) images* **(B)** *are concordant, revealing a bulky, eccentric, and hypodense RCA lesion* (black arrow) *with intraplaque contrast penetration indicative of ulceration and rupture* (white arrow). *Panel C shows stable plaque in the left coronary artery from same patient. Invasive angiogram* **(C)** *demonstrates noncomplex mild plaque in the mid-LAD* (white arrows). *The CCTA image* **(D)** *similarly reveals mild noncomplex plaque with punctuate calcific elements and moderate luminal narrowing* (white arrows) *but lacking the bulky, hypodense disrupted features characteristic of complex plaques. Reprinted with permission from O'Neil B, Gallagher MJ, Raff GL, "Use of multislice CT and MRI for the evaluation of patients with chest pain," In: Peacock WF, Cannon CP, eds,* Short Stay Management of Chest Pain, *New York; Humana Press: 2009;185-203.*[26]



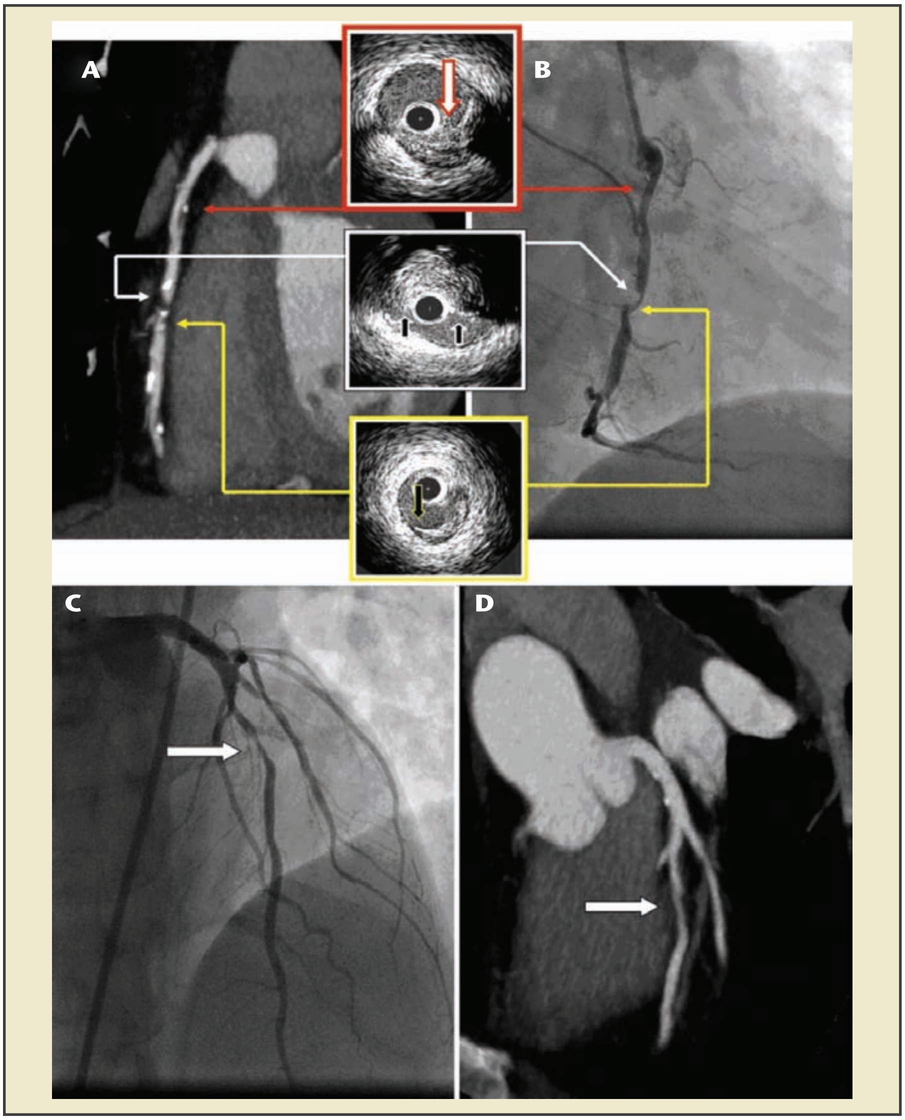


Figure 3. *Putative computed tomography (CT) differences between unstable and stable plaque in the same patient. The coronary computed tomography (CCTA) image* **(A)** *documents an ulcerated, bulky, eccentric, hypodense mid-right circumflex artery (RCA) lesion; intravascular ultrasound confirms complex morphology with bulky, eccentric, disrupted plaque in the proximal* (middle box, white arrows) *and distal* (lower box, yellow arrows) *aspects of this lesion. Invasive angiography* **(B)** *reveals a concordant bulky, eccentric, scalloped complex RCA lesion* (white and yellow arrows). *Proximally to the culprit lesion, CCTA documents a bulky, eccentric, hypodense lesion* (red arrows) *confirmed by intravascular ultrasound* (upper red box)*, which is less apparent by invasive imaging. An invasive angiogram* **(C)** *demonstrates noncomplex stenotic plaque in the mid-left anterior descending coronary artery* (white arrow). *The CCTA image* **(D)** *similarly reveals noncomplex plaque lacking the bulky, hypodense disrupted features characteristic of complex plaques. Reprinted with permission from O'Neil B, Gallagher MJ, Raff GL, "Use of multislice CT and MRI for the evaluation of patients with chest pain," In: Peacock WF, Cannon CP, eds,* Short Stay Management of Chest Pain, *New York; Humana Press: 2009;185-203.*[26]

pulmonary and coronary arteries and thoracic aorta requires a meticulously tailored imaging and injection protocol (Figure 4). In one such approach, we prospectively imaged 50 ED chest pain patients who underwent single-acquisition 64-slice CCTA to evaluate the enhancement of the coronary, pulmonary, and thoracic vasculature.[38] We used a triphasic injection protocol that delivered a standard 100 mL of iodinated contrast at 5 mL/s typical for CCTA examinations, followed by an additional 30 mL at 3 mL/s to maintain pulmonary artery opacification, followed by a standard saline flush injection. This injection protocol is easily achievable with commercially available radiographic injectors. Additionally, a caudal-cranial scan acquisition was used (as opposed to the cranial-caudal standard CCTA technique) in order to scan the distal pulmonary arteries at the lung base earlier, as this area classically has problems with low contrast intensity. In this trial, mean coronary artery, pulmonary artery, and aortic enhancement values were consistently higher than 250 Hounsfield units, and right atrial enhancement did not interfere with interpretation of the coronary arteries. There is significant controversy in the radiologic literature regarding the ability of the triple rule-out protocol to adequately rule out small pulmonary emboli in the distal vessels, and the clinical significance of these small pulmonary emboli is also controversial. Although this and similar protocols are promising, large-scale clinical trials assessing the clinical accuracy of such triple rule-out protocols are not yet available.

Dedicated Coronary or Triple Rule-Out Scans: Radiation Dose Considerations

In spite of the potential clinical advances, important radiation safety concerns should limit indiscriminate application of a triple rule-out scan protocol, especially in women. The scan's effective radiation dose is calculated as the dose-length product (measured and displayed by the scanner on each patient) multiplied by the European Commission thoracic conversion factor (0.017) to yield the effective dose in millisieverts. Therefore, the radiation dose is directly proportional to the scan length in centimeters. Compared with the usual radiation dose of a standard CCTA (ranging from 8-22 mSv, depending on body habitus,

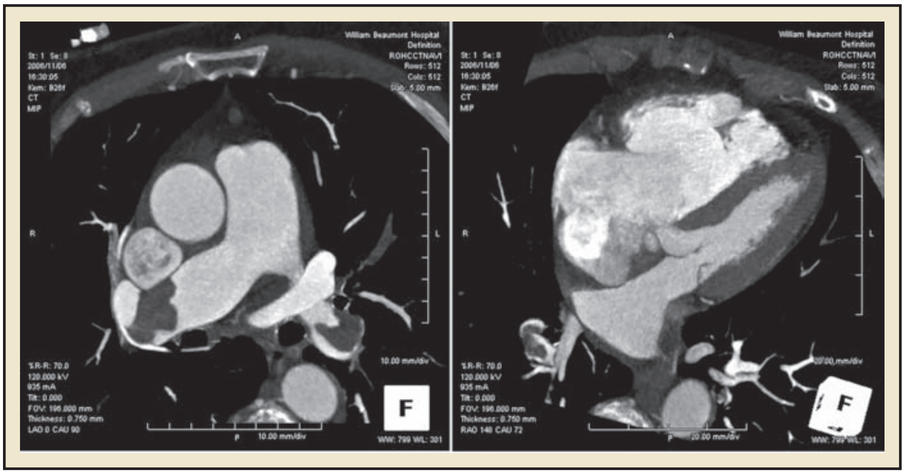


Figure 4. *Triple rule-out scan acquisition in a 79-year-old woman with acute chest pain, nonspecific electrocardiogram changes, and negative cardiac biomarkers.* **(A)** *Axial 5-mm maximum intensity projection images show uniform enhancement of the ascending aorta and main pulmonary artery bifurcation. Bilateral large pulmonary emboli are seen, as well as* **(B)** *marked right heart enlargement. The patient was also noted to have > 50% mixed calcified and noncalcified plaque in the proximal left anterior descending coronary artery.*

sex, and scan protocol), the effective radiation dose of a triple rule-out scan is often increased by 50% due to the increased field of view. By comparison, rest-stress radionuclide scans typically involve exposures in the range of 8 to 16 mSv, whereas diagnostic invasive angiography doses range from 5 to 13 mSv. In patients who undergo CCTA as a primary triage test in the ED, there is a subset who also require a noninvasive stress test (often a radionuclide test), potentially followed by invasive angiographic procedures. Excessive radiation exposure may be addressed by changing the 0.6-mm high-resolution used for coronary CCTA to 2 mm for scanning the upper lung fields (because pulmonary angiography does not require submillimeter resolution), which in theory can significantly reduce radiation dosage. Innovative imaging protocols involving tight heart rate control and "prospective gating" can also drastically reduce radiation exposure (to < 5 mSV).

Previous studies of patients with undifferentiated acute chest pain reveal a low incidence of occult pulmonary embolism or aortic dissection (AoD) in patients without suggestive signs or symptoms.[39] Therefore a triple rule-out strategy should not be utilized unless there exists a high index of suspicion for PE and this test has the potential to eliminate an additional chest CT. Of note, the entire thoracic aorta up to the aortic arch and the lower two-thirds of the lungs are within the field of view during a conventional CCTA and would reveal abnormalities in the majority of dissections and large pulmonary emboli without additional radiation.

Value Added: Assessment for Noncardiac and Extravascular Pathology

Because the greater majority of ED chest pain patients do not have coronary or vascular conditions,[15] imaging the noncardiac thoracic structures contained in the CCTA field of view provides the opportunity to make alternative diagnoses. Additional diseases that can be detected include pericardial thickening and/or effusions, esophageal pathology, pneumonia, pulmonary nodules, pneumothoraces, mediastinal masses, pleural effusions and masses, as well as chest wall abnormalities. Previous studies have demonstrated that up to 1 in 6 patients without coronary abnormalities detected on CT were diagnosed with noncardiac findings that could explain their presenting symptoms.[40]

We evaluated patients undergoing CCTA to rule out cardiac chest pain for additional findings that either provided physicians with a plausible etiology for the chest pain or findings requiring further workup.[41] Chest findings considered not clinically significant included were lymphadenopathy < 1 cm, calcified lesions, atelectasis, fatty liver, or renal or hepatic cysts. Of the 151 patients enrolled, 13% had > 50% stenosis on CCTA; an additional 11.9% had noncardiac findings aiding in the physician's diagnosis, which included hiatal hernias, pulmonary infiltrates not seen on chest radiograph, and pericardial effusion. An additional 6.6% had significant findings requiring follow-up, primarily enlarged lymph nodes or noncalcified masses. The total percentage of significant findings on CCTA was 33%.

Imaging the noncardiac thoracic structures contained in the CCTA field of view provides the opportunity to make alternative diagnoses.

CCTA Limitations and Protocols

When choosing CCTA for the triage of ED patients several important limitations need to be considered. It has been shown that the heart rate and regularity of the rhythm are related to image quality and ergo accuracy of coronary stenosis estimation.[9] It is common practice to premedicate patients who have resting heart rates > 65 beats/min with β-blocking drugs, and to administer sublingual nitroglycerin to patients to enhance image quality. We surveyed our research logs and noted that about 15% of screened patients had some contraindication to β-antagonists. Newer technology such as dual-source CCTA nearly eliminates the need for β-blocker administration, improving resolution even at higher heart rates and improving resolution in irregular rhythms, including atrial fibrillation. As with any contrast study, it is essential to screen patients in the ED for a history of iodine allergy, and to avoid administration of contrast in patients with diminished glomerular filtration rates.

Most importantly, CCTA provides data regarding the anatomy of lesions only, not their physiologic impact on coronary blood flow. It was for this very reason our previous clinical trials protocolized additional noninvasive stress imaging for intermediate severity lesions detected on CCTA, which occurred in 15% of our subjects. Finally, the importance of a team approach to implementation of a CCTA ED triage protocol cannot be overstated. ED physicians and cardiologists must be well educated regarding the application and inherent limitations of CCTA, and a complete review of cardiac and adjacent structures available from the CT data should be performed by physicians with appropriate background and level of experience.

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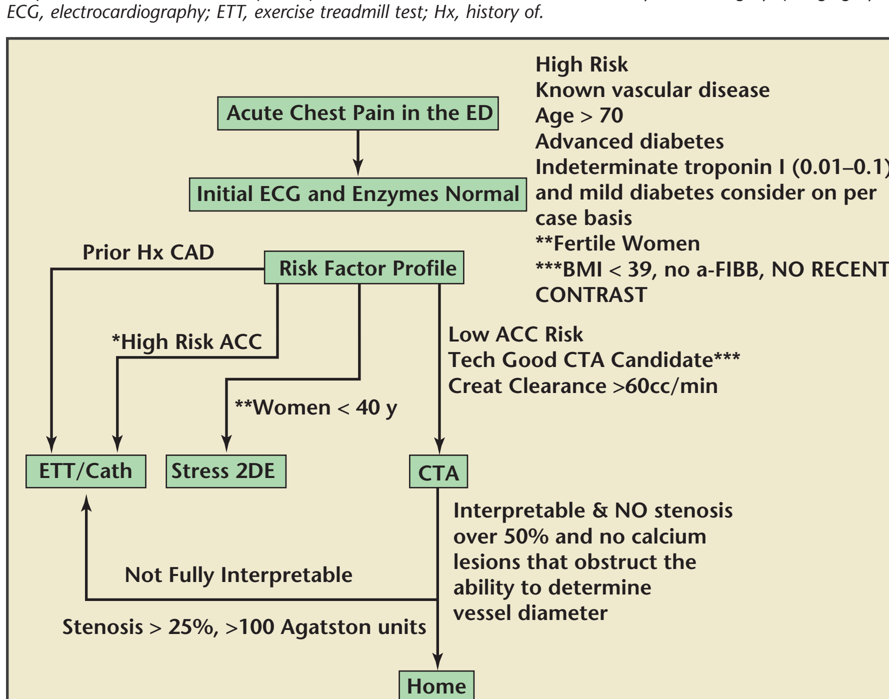
Currently, over 30 published studies encompassing over 2000 patients have compared CCTA to quantitative invasive coronary angiography.[9,10,42-45] Eighteen studies included per-patient analyses (totaling 1329 patients undergoing either 16- or 64-slice CT); the mean subject-weighted sensitivity and specificity for the detection of ≥ 50% luminal stenosis was 97% and 84%, respectively.[46] The sensitivity and specificity improved to 98% and 93%, respectively, when only the 64-slice CTs were analyzed. These data support the hypothesis that a normal CCTA obviates the need for invasive angiography in these appropriately selected circumstances. These studies further validate that patients at the opposite ends of the disease spectrum (ie, those with < 25% vs > 70% maximal luminal stenoses) can be accurately triaged by CCTA alone, whereas patients with lesions of intermediate severity (50%-70% stenosis) may require functional testing. There is an opportunity in the intermediate-severity patient for the inclusion of multibiomarker panels or ultrasensitive Tn that could potentially obviate the need for further provocative testing to rule out induced ischemia.

Conclusions

CCTA has evolved into a powerful imaging tool that has validated its clinical accuracy as a highly sensitive and reliable technique to confirm or exclude significant coronary stenosis in patients with suspected coronary artery disease. CCTA is an accurate and efficient test to triage appropriately selected acute chest pain patients to early discharge or further inpatient diagnosis and treatment. ED patients with a low to intermediate pretest likelihood of coronary disease and negative initial cardiac biomarkers and electrocardiograms are the group currently best suited for CCTA-based triage. Figure 5 provides a template on how this

Figure 5. *Protocol for suggested use of CTA in the evaluation of chest pain patients in the emergency department (ED). 2DE, 2-dimensional echocardiography; a-FIBB, atrial fibrillation; ACC, American College of Cardiology; BMI, body mass index; CAD, coronary artery disease; Cath, catheterization; CTA, computed tomography angiography; ECG, electrocardiography; ETT, exercise treadmill test; Hx, history of.*



technology can be incorporated into the evaluation of chest pain patients presenting to the ED. Technical advances now permit acquisition of well-opacified images of the coronary arteries, thoracic aorta, and pulmonary arteries from a single CT scan protocol. Although this triple rule-out technique can potentially exclude fatal causes of chest pain in all 3 vascular beds, the attendant higher radiation dose of this method precludes its routine use. ■

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Main Points

- An estimated 6 million patients per year are evaluated in US emergency departments (EDs) for acute chest pain. The delineation of the presence or absence of acute coronary syndromes (ACS) in these patients must be accurate and efficient. Coronary computed tomography angiography (CCTA) has great promise as a tool to expedite the triage of patients with acute chest pain to early discharge or further inpatient diagnosis and treatment. It is able to directly visualize the coronary anatomy, simultaneously image the rest of the thorax to exclude aortic dissection (AoD) and significant pulmonary embolism (PE), and suggest alternate causes of chest pain, such as pneumonia, pericardial fluid, and esophageal inflammation.
- Calcium scoring as a risk stratification tool is poor in ED patients with acute chest pain. It has been dropped from the authors' routine protocol to further reduce patients' exposure to radiation.
- Given the increasing use of CCTA to evaluate acute chest pain, characterization of plaque instability has considerable clinical implications. Further studies will be necessary to establish the sensitivity, specificity, and predictive accuracy of CCTA for characterization of complex plaque.
- Given the robust clinical performance of CCTA for exclusion of ACS in ED patients, as well as the widespread use and proven clinical accuracy of CTA for diagnosis of acute AoD and PE, a triple rule-out scan protocol to simultaneously exclude all 3 potentially fatal causes of acute chest pain with a single scan is an attractive option. However, important radiation safety concerns remain that should limit indiscriminate application of a triple rule-out scan protocol. Of note, if the index of suspicion is high, the entire thoracic aorta up to the aortic arch and the lower two-thirds of the lungs are within the field of view during a conventional CCTA and would reveal the majority of dissections and central pulmonary emboli without additional radiation.
- Well over 50% of acute chest pain cases represent noncardiac conditions. In patients who undergo a dedicated CCTA, images of noncardiac thoracic structures are contained in the field of view and are therefore available to the expert reader. This suggests that for patients with acute chest pain, a comprehensive review of the thoracic cardiac and noncardiac structures should be undertaken.
- CCTA has several important limitations that affect its usefulness in the triage of ED patients with acute chest pain. It has been shown that the heart rate and regularity of the rhythm are closely related to image quality and accuracy of coronary stenosis estimation. If available, dual-source CCTA obviates the need for β-blocker administration in most patients.

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