Coronary Computed Tomographic Angiography for Rapid Discharge of Low-Risk Patients With Potential Acute Coronary Syndromes

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Study objective: Coronary computed tomographic (CT) angiography has excellent performance characteristics relative to coronary angiography and exercise or pharmacologic stress testing. We hypothesize that coronary CT angiography can identify a cohort of emergency department (ED) patients with a potential acute coronary syndrome who can be safely discharged with a less than 1% risk of 30-day cardiovascular death or nonfatal myocardial infarction.

Methods: We conducted a prospective cohort study at an urban university hospital ED that enrolled consecutive patients with potential acute coronary syndromes and a low TIMI risk score who presented to the ED with symptoms suggestive of a potential acute coronary syndrome and received a coronary CT angiography. Our intervention was either immediate coronary CT angiography in the ED or after a 9- to 12-hour observation period that included cardiac marker determinations, depending on time of day. The main clinical outcome was 30-day cardiovascular death or nonfatal myocardial infarction.

Results: Five hundred sixty-eight patients with potential acute coronary syndrome were evaluated: 285 of these received coronary CT angiography immediately in the ED and 283 received coronary CT angiography after a brief observation period. Four hundred seventy-six (84%) were discharged home after coronary CT angiography. During the 30-day follow-up period, no patients died of a cardiovascular event (0%; 95% confidence interval [CI] 0% to 0.8%) or sustained a nonfatal myocardial infarction (0%; 95% CI 0 to 0.8%).

Conclusion: ED patients with symptoms concerning for a potential acute coronary syndrome with a low TIMI risk score and a nonischemic initial ECG result can be safely discharged home after a negative coronary CT angiography test result. [Ann Emerg Med. 2009;53:295-304.]

0196-0644/$-see front matter

doi:10.1016/j.annemergmed.2008.09.025

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INTRODUCTION

Background

Approximately 6 million patients present to the emergency department (ED) annually with a complaint of chest pain or other symptoms suggestive of myocardial ischemia,[1] 55% to 85% of whom do not have a cardiac cause for their symptoms.[2-18] Eight to 10 billion dollars are spent annually on hospital stays to rule out an acute coronary syndrome.[4,5,10] Although the identification of high-risk patients has improved during the past 20 years,[4-6] the rapid cost-effective evaluation and accurate identification of low-risk patients remain problematic.[2,7-9,17] Clinical and computerized algorithms can successfully risk-stratify patients; however, they cannot identify a group of patients at such low risk that they can be safely and immediately released from the ED with a less than 1% risk of 30-day adverse events.[5,6,9-17]

Importance

Coronary computed tomographic (CT) angiography has excellent correlation with cardiac catheterization, and studies have shown that it has a sensitivity of 93% to 100% and specificity of 75% to 98% for identification of coronary artery

Editor's Capsule Summary

What is already known on this topic

Coronary computed tomographic (CT) angiography has been advocated as a sensitive test for future adverse events related to coronary syndromes. There are, however, limited data on its performance in low-risk emergency department (ED) patients.

What question this study addressed

Can CT angiography identify a cohort of low-risk patients who can safely be discharged from the ED or chest pain observation unit?

What this study adds to our knowledge

Five hundred sixty-eight patients with possible acute coronary syndrome and low TIMI score underwent CT angiography. Four hundred seventy-six (84%) were discharged after coronary CT angiography, with no adverse events during the 30-day follow-up period.

How this might change clinical practice

This study suggests that low-risk patients who have a normal coronary CT angiography results are at very low risk for adverse events and can safely be discharged home.

stenosis.[19-24] It is accepted that previous normal coronary catheterization predicts patients at low risk for cardiovascular complications,[25,26] and a recent normal coronary angiogram result is often used to identify patients safe for discharge from the ED. Therefore, a normal coronary CT angiography result may also accurately predict patients at low risk for adverse cardiovascular events and allow safe discharge of patients who were initially considered to have a potential acute coronary syndrome.[27] In addition, studies have documented that coronary CT angiography performs similarly to myocardial perfusion imaging[28] and identifies patients at low risk for cardiovascular events.[27-31] However, it has not been shown to be safe when used alone to rule out acute coronary syndrome in low-risk patients.

Goals of This Investigation

The purpose of our study was to determine whether a negative coronary CT angiography result could accurately identify patients who presented to the ED with symptoms consistent with a potential acute coronary syndrome, low TIMI risk score, and a nonischemic ECG result who are safe for release from the ED, which we defined as less than 1% risk of 30-day cardiovascular death or nonfatal myocardial infarction.

MATERIALS AND METHODS

Study Design

We conducted a prospective observational study of consecutive ED patients who received coronary CT angiography for evaluation of a potential acute coronary syndrome to assess whether a negative coronary CT angiography result could safely predict freedom from 30-day cardiovascular death or nonfatal myocardial infarction. The study was approved by the University of Pennsylvania Institutional Review Board.

Setting

The study was conducted in the Hospital of the University of Pennsylvania from January 1, 2005, to October 1, 2007. The hospital is an urban tertiary referral center with an annual ED census of approximately 55,000 during the enrollment period. The ED has an 8-bed clinical decision/observation unit managed by emergency physicians that can be utilized for evaluation of risk for chest pain patients. The observation unit chest pain protocol includes serial markers and ECGs, followed by myocardial perfusion imaging or coronary CT angiography the next morning. The observation unit is not used for admission of chest pain patients on Friday or Saturday, because myocardial perfusion imaging is not available on Saturday or Sundays.

Selection of Participants

Patients were eligible for inclusion if they presented to the ED with a chief complaint of chest discomfort that prompted an ECG for evaluation of a potential acute coronary syndrome, had an initial TIMI score of 0 to 2 inclusive, the emergency physician would otherwise admit the patient to rule out an acute coronary syndrome, and the emergency physician ordered a coronary CT angiography on the patient.

Two cohorts of patients were studied. The first cohort was eligible for the immediate coronary CT angiography protocol while in the ED. The "immediate" cohort was defined by the patient's having a coronary CT angiography ordered during the initial evaluation phase before serial markers or admission to the hospital or clinical decision/observation unit. The immediate group was required to have a creatinine level test before coronary CT angiography but was not required to have any cardiac markers. In practice, most patients had cardiac markers sent simultaneously with the creatinine results, and the first set of markers was typically available before the coronary CT angiography was performed. The second cohort met the same criteria, but because coronary CT angiography was unavailable (because of time of day), they were admitted to the clinical decision/observation unit and a coronary CT angiography was ordered by the observation unit team.

Patients were excluded if they had chest pain explained by local trauma, had radiographic abnormalities, or were at such low risk that they would otherwise be discharged home without admission or a provocative test to exclude an acute coronary syndrome. High-risk patients were defined as patients who presented with an initial ECG result diagnostic of ischemia or

acute myocardial infarction, transient ST-segment elevation or depression greater than 1 mm that persisted for at least 1 minute, increased cardiac markers, recurrent ischemic chest pain, or hemodynamic instability. These patients were admitted to the hospital, did not receive a coronary CT angiography, and were excluded from analysis. If patients received coronary CT angiography, they were included in the analysis, regardless of subsequent clinical course.

Patients were also excluded if they had a contraindication to coronary CT angiography (such as iodinated contrast allergy) or if coronary CT angiography was not available. Coronary CT angiography was available weekday daytime hours and approximately every third weekend when a certified radiologist was present. Therefore, patients who presented outside of these hours could be enrolled only in the observation unit cohort. An electronic log of all patients who received coronary CT angiography was maintained to ensure capture of all eligible patients.

Data Collection and Processing

Structured data collection was performed prospectively by the treating physician, using a closed-question data instrument that was in accordance with standardized reporting guidelines[32] and key definitions[33] and included self-reported demographic characteristics, cardiac risk factors, chest pain characteristics, associated symptoms, medications, and initial vital signs, ECG, treatment, and disposition.

The protocol for coronary CT angiography included patients with a TIMI risk score of 0 to 2 (approximately 60% to 70% of potential acute coronary syndrome patients),[15,16] with a serum creatinine level less than or equal to 1.5 mg/dL and without active asthma, pregnancy, or an iodinated contrast allergy. Verbal consent to receive coronary CT angiography was provided by the patients. Patients with a pulse rate greater than 70 beats/min were given intravenous or oral metoprolol to reduce the pulse rate and improve image quality. Coronary CT angiography was performed with predominantly 64-slice or 64-slice dual source scanners (Siemens Medical Solutions, Malvern, PA). The study began with a low-dose noncontrast ECG-triggered acquisition through the entire chest for the purpose of calcium scoring and evaluation of lung abnormalities. This was followed by a weight-based intravenous injection of 80 to 120 mL of nonionic iodinated contrast (Omnipaque 350; GE Amersham, Milwaukee, WI) with bolus tracking in the descending aorta. After the appropriate scan delay, an ECG-gated acquisition from the pulmonary artery bifurcation through the inferior heart border was performed. Studies were reviewed on a dedicated 3D workstations (Leonardo and MMWP, Siemens Medical Solutions; and AdvantageWindows4.2, GE Amersham) using axial, multiplanar reformatted, and thin-slab maximum-intensity projection images in an interactive display. Image data were reconstructed at multiple phases of the cardiac cycle and postprocessed and analyzed on independent workstations. The degree of any observed stenosis was measured with an electronic caliper by comparing the lumen diameter with the diameter of a proximal reference segment.[34] Studies were read by attending radiologists with subspecialty cardiovascular imaging training; all met American College of Cardiology/American Heart Association level 3 training guidelines for cardiac CT. Interpretations were provided for all studies. Study quality and technical limitations were reported in the reading, as well as any regions of coronary arteries that could not be interpreted. Management of these limitations was left to the treating physician. For clinical purposes, during the study period, the coronary CT angiography result was considered definitely positive if the patient had greater than or equal to 70% stenosis of the right coronary, left main, left anterior descending, or circumflex arteries or their first-order branches, and admission was recommended. The coronary CT angiography result was considered negative if the patient had less than 50% stenosis and a calcium score of less than 100, and no further evaluation was recommended for potential acute coronary syndrome. In patients with intermediate grades of stenosis (50% to 69%) or a calcium score greater than 100, further evaluation was as per physician discretion. Patients with a calcium score greater than 400 did not receive the contrast injection for the coronary CT angiography.

Patients with a negative coronary CT angiography result were discharged home from the ED, unless other medical problems warranted admission. Patients with an abnormal coronary CT angiography result were admitted to the hospital and followed daily for cardiovascular complications, including death, myocardial infarction,[35] heart failure, and dysrhythmias. For admitted patients, serial cardiac markers were obtained at entrance into the ED and at least 6 hours after presentation. During the study period, we used an enzyme-linked immunoassay for cardiac troponin I and creatine kinase-MB (Abbott AxSYM automated analyzer; Abbott Laboratories, Mountain View, CA). Levels were considered increased if any measurement exceeded the institutional threshold for normal (CK-MB >5 mg/dL and cardiac troponin I >0.4 mg/dL).

Patients with abnormal coronary CT angiography results, without evidence of myocardial necrosis or rest ischemia, underwent graded exercise testing using the modified Bruce protocol or pharmacologic imaging, if ordered by the treating physician. A positive stress test result was defined as ST-segment elevation or depression of greater than 1 mm or reversible ischemia with or without chest discomfort during the test. A positive cardiac catheterization was defined as stenosis of at least 1 vessel greater than or equal to 70%.

At presentation, all patients were asked to provide the telephone numbers of their homes, businesses, and a relative. Alternative contact information such as pager numbers and e-mail were also obtained, when applicable. Patients were contacted at least 30 days after discharge and specifically questioned about recurrent chest pain, nonfatal myocardial infarction, and repeated hospitalization. Thirty days was chosen as the primary outcome according to consensus

recommendation of major cardiology and emergency medicine societies.[32] If the patients or secondary contacts were unavailable, medical records were reviewed for repeated visits. For patients for whom these methods failed to provide survival information, we searched the Social Security Death Index (http://ssdi.rootsweb.ancestry.com/) on August 13, 2008. All reported adverse events (myocardial infarction, death) were confirmed by records review.

Primary Data Analysis

Patients were analyzed overall and in 2 prespecified subgroups: patients for whom coronary CT angiography was ordered while the patient was in the ED and patients for whom coronary CT angiography was ordered during a brief observation unit stay.

Our study was powered according to our main clinical outcome and the premise that we would not observe cardiovascular death or nonfatal myocardial infarction in patients with a negative coronary CT angiography result. With 500 patients, we could be 99% confident that the prevalence of cardiovascular death or nonfatal myocardial infarction in the population sampled from would be equal to or less than 1%.

For evaluation of diagnostic accuracy, a positive coronary CT angiography result was any stenosis greater than or equal to 50%. The rationale for this cutoff was that patients found to have a 50% to 69% stenosis had admission and further testing rates more analogous to patients with a 70% or greater stenosis than patients with a maximal stenosis less than 50%. Our criterion standard for the evaluation of diagnostic accuracy was a composite of diagnostic testing and clinical follow-up. If a patient received an objective assessment of coronary artery disease (stress test or cardiac catheterization), it was considered the criterion standard. When a patient received both tests, the cardiac catheterization was considered the criterion standard. Reversible ischemia on a stress test or evidence of a 70% or greater stenosis on cardiac catheterization was considered a positive result. In the absence of either test, 30-day death or nonfatal myocardial infarction was considered to be the criterion standard.

Data are presented as percentage frequency occurrence, with 95% confidence intervals (CIs). With a binomial distribution, Clopper Pearson CIs were calculated with StatXact 6.1 (Cytel Software Corporation, Cambridge, MA).

RESULTS

During the study period, 568 patients received coronary CT angiography in the ED. Patients in the immediate CT angiography and observation unit cohorts were similar with respect to demographic characteristics and medical history (Table 1). Patients had a mean age of 47.0±8.9 years, 44% were men, and 63% were black. Most patients (90%) had a TIMI score of 0 or 1. There were 155 patients who had previous stress tests performed and 14 patients had previous cardiac catheterization.

Presenting Characteristics

The chest pain duration was known in 553 of the patients (97%). For 406 of the patients, it was less than 6 hours' duration (73%); for 325, it was less than 3 hours (59%); and for 222, it was less than 1 hour (40%). The remainder had pain for longer than 6 hours. Presenting characteristics are shown in Table 1.

Clinical Course

Immediate CT angiography cohort. There were 285 patients in the immediate coronary CT angiography cohort, of whom 214 (75%) were discharged to home after testing. The 7 patients with a maximal stenosis greater than or equal to 70% and the 4 patients with calcium scores greater than 400 who did not receive contrast injection were all admitted, as were 21 of 23 patients (91%) with a maximal stenosis of 50% to 69%. There were 6 patients with a maximal stenosis less than 50% but calcium score greater than 100, of whom 2 were admitted (33%). Of the 245 patients with a maximal stenosis less than 50% and a calcium score less than 100, 210 (86%) were discharged home from the ED. Eighteen received further diagnostic testing for coronary disease because either the inpatient team (n=6) or the patient primary care physician (n=12) was not satisfied that the coronary CT angiography was sufficient, but none of these patients had a positive stress test or cardiac catheterization result. None of these patients sustained a cardiovascular death or nonfatal myocardial infarction within 30 days.

The ED length of stay from triage until disposition for patients in the immediate CT angiography cohort was a median of 7.1 hours (interquartile range [IQR] 5.5 to 9.4). At least 1 cardiac marker was obtained in 270 of the immediate CT angiography cohort (95%); however, only 53 patients (19%) had serial markers performed during 6 or more hours. Of them, 43 (81%) were admitted to the hospital because of greater than 50% lesion on the coronary CT angiography (20 [47%]), isolated increased calcium score (8 [19%]), or isolated troponin or CK-MB increase (3 [7%]). The remainder were admitted because of medical indications unrelated to the coronary CT angiography results (12 [28%]).

Observation unit cohort. The observation unit cohort consisted of 283 patients, of whom 262 (93%) were discharged to home from the observation unit. Two hundred forty-seven of the 254 patients (97%) with a maximal stenosis less than 50% and a calcium score less than 100 were discharged home from the observation unit. None of these patients sustained a cardiovascular death or nonfatal myocardial infarction within 30 days. Fifteen patients had further testing (7 as outpatients), but none had a positive stress test or cardiac catheterization result. The length of stay from triage until ED disposition for the patients in the observation unit cohort was a median of 5.8 hours (IQR 4.2 to 7.3 hours), and the overall time from triage until observation until disposition was 20.8 hours (IQR 15.1 to 25.5 hours).

Table 1. Demographic, historical and presenting characteristics of study patients.

Characteristic	Delayed CTA, n=283	Immediate CTA, n=285	Whole Cohort, n=568
Age, mean (SD)	46.3 (8.5)	47.6 (9.3)	47.0 (8.9)
Male (%)	112 (40)	140 (49)	252 (44)
Race (%)			
Black	191 (67)	169 (59)	360 (68)
White	65 (24)	75 (26)	140 (26)
Asian	9 (3)	7 (2)	16 (3)
Hispanic	3 (1)	6 (2)	9 (2)
Other/unknown	15 (5)	28 (10)	43 (8)
Cardiac risk factors (%)*			
Hypertension	137 (48)	114 (40)	251 (44)
Hypercholesterolemia	53 (19)	55 (19)	108 (19)
Family history of CAD	48 (17)	56 (20)	104 (18)
Diabetes mellitus	45 (16)	32 (11)	77 (14)
Current tobacco use	103 (36)	97 (34)	200 (35)
Cocaine use in last week	26 (9)	15 (5)	41 (7)
Number of cardiac risk factors (%)			
0	64 (23)	73 (26)	137 (24)
1	106 (37)	109 (38)	215 (38)
2	71 (25)	75 (26)	146 (26)
3	30 (11)	20 (7)	50 (9)
≥4	12 (4)	8 (3)	20 (4)
Past medical problems (%)*			
Undiagnosed chest pain	14 (5)	30 (11)	44 (8)
Myocardial infarction	3 (1)	5 (2)	8 (1)
Congestive failure	3 (1)	2 (1)	5 (1)
Arrhythmias	9 (3)	5 (2)	14 (3)
Chest pain characteristics (%)			
Location			
Substernal	149 (53)	133 (37)	282 (50)
Left chest or arm	99 (35)	110 (39)	209 (37)
Right sided	13 (5)	15 (5)	28 (5)
Epigastrium	5 (2)	3 (1)	8 (1)
Other/unknown	17 (6)	24 (8)	41 (7)
Quality			
Crushing/pressure/tightness	147 (52)	140 (49)	287 (51)
Sharp/stabbing	57 (20)	65 (23)	122 (21)
Aching/dull	29 (10)	26 (9)	55 (10)
Burning/indigestion	19 (7)	17 (6)	36 (6)
Tearing	2 (1)	0	2 (<1)
Other/unknown	29 (10)	37 (13)	56 (10)
Associated symptoms (%)			
Shortness of breath	145 (51)	123 (43)	268 (47)
Diaphoresis	57 (20)	48 (17)	105 (18)
Palpitations	35 (12)	30 (11)	65 (12)
Nausea	75 (27)	61 (21)	136 (24)
Vomiting	12 (4)	17 (6)	29 (5)
Syncope	7 (2)	4 (1)	11 (2)
Vital signs at presentation (%)†			
Systolic blood pressure, mm Hg			
>139	144 (51)	125 (44)	269 (48)
>91–139	136 (48)	157 (56)	293 (52)
<90	3 (1)	0	3 (<1)
Diastolic blood pressure (%)			
>90 mm Hg	95 (34)	78 (28)	173 (31)
Pulse, beats/min (%)			
>100	37 (13)	21 (7)	58 (10)
60–100	224 (79)	250 (88)	474 (84)
< 60	22 (8)	13 (5)	35 (6)
Respiratory rate, breaths/min (%)			
>25	2 (1)	2 (1)	4 (<1)
10–25	281 (99)	282 (99)	563 (99)
Temperature >38°C (100.4°F)	1 (0.4)	0	1 (<1)
Presenting ECG (%)			
Normal	167 (59)	178 (62)	345 (61)
Nonspecific	89 (31)	85 (30)	174 (31)
Nondiagnostic	18 (6)	16 (6)	34 (6)
Ischemia known to be old	2 (1)	2 (1)	4 (1)
Ischemia not known to be old infarction	6 (2)	3 (1)	9 (2)
	1 (0.4)	1 (0.4)	2 (<1)
TIMI risk score (%)			
0	173 (61)	170 (60)	343 (60)
1	83 (29)	83 (29)	168 (29)
2	22 (8)	28 (10)	50 (9)
3 or 4	5 (2)	4 (1)	9 (2)

CTA, CT angiography; *SD*, standard deviation; *CAD*, coronary artery disease.
*Cardiac risk factors and past medical problems were self-reported. Cardiac risk factors include hypertension, hypercholesterolemia, family history of coronary artery disease, diabetes mellitus, and tobacco use.
†The following information was not recorded at presentation, before evaluation: pulse, 1 patient; temperature, 14 patients; systolic blood pressure, 3 patients; diastolic blood pressure, 4 patients; respiratory rate, 1 patient.

Main Clinical Outcomes

Thirty-day survival data were available by direct contact or record review for 525 patients (92%). The remaining 43 patients did not appear in the Social Security Death Index, and no deaths or cardiovascular complications were detected through records review of these patients. None of these patients had outpatient diagnostic testing at our institution or the hospital closest to our institution (a health system partner).

There were no cardiovascular deaths (0%; 95% CI 0% to 0.8%); 1 patient died in a motor vehicle crash. No patients had an adverse event during index hospitalization or at 30-day follow-up (0%; 95% CI 0% to 0.8%). Death or nonfatal myocardial infarction did not occur in any patient during the 30-day period either in the immediate group (0%; 95% CI 0% to 1.6%) or the observation unit group (0%; 95% CI 0% to 1.6%).

Coronary CTA Results

Of the total cohort of 568 patients, there were 6 patients with calcium scores greater than 400 who did not receive contrast injection (Figure). Four patients were in the immediate CT angiography cohort and 2 were in the observation unit cohort. All 6 patients received further diagnostic testing. One patient had a positive stress test result, and subsequent cardiac

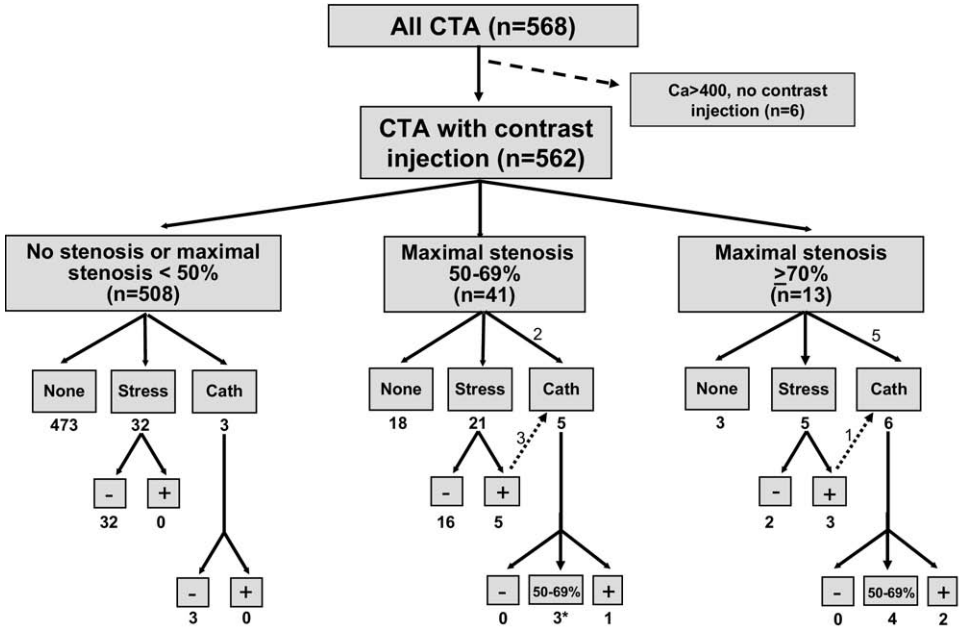

Figure. Relationship between results of CT coronary angiography and other diagnostic testing. None, no further diagnostic testing; Stress, noninvasive testing, including pharmacologic and stress imaging; Cath, cardiac catheterization. Dotted arrows represent patients who had a positive stress test result and then also received cardiac catheterization.

*One additional patient had a 60% lesion on coronary CT angiography and received a stent at an outside hospital, but we were unable to determine whether the lesion was above or below 70% stenosis.

catheterization found 3 90% lesions. He received 3 stents. Three patients had negative stress test results and 2 patients were admitted to the hospital but were managed medically without further diagnostic testing. None of these 6 patients sustained a cardiovascular death or nonfatal myocardial infarction within 30 days.

Of the remaining 562 patients, 508 (89%) had a coronary CT angiography result that did not reveal coronary stenosis of 50% or greater (Figure), of whom 9 had a calcium score greater than 100. Four hundred sixty-one (91%) of the 508 patients were discharged home after the coronary CT angiography testing. None of these patients sustained a cardiovascular death or nonfatal myocardial infarction within 30 days. There were 18 patients who received further diagnostic testing as inpatients (15 stress tests, 3 cardiac catheterizations), and 17 patients had outpatient stress tests. All 35 patients had negative test results, confirming the findings on the coronary CT angiography.

Overall, 54 patients (9.6%) had stenosis 50% or greater (Figure), of whom 24 also had a calcium score greater than 100. Thirteen of these 54 patients had a stenosis of 70% or greater, 8 of whom had a calcium score greater than 100. Seven of these 13 patients were in the immediate CT angiography cohort and all were admitted to the hospital. Ten of the 13 patients were referred for further testing. One patient had a coronary CT angiography lesion of 80% and received a stent during catheterization. Four received cardiac catheterization alone and were found to have lesions between 50% and 60%. Five patients received stress tests, and 3 had positive results. One patient with a positive stress test result received cardiac catheterization, which confirmed the 80% lesion found on coronary CT angiography, and he was medically managed. Two of the patients with positive stress test results had maximal coronary CT angiography lesions of 70% and were medically managed. One patient had a normal electrocardiographic portion of the stress test and refused the imaging portion. He had a maximal stenosis of 70% on coronary CT angiography and was medically managed. One patient was referred for an outpatient cardiac catheterization but never returned for the test.

There were 41 patients who had a maximal stenosis of 50% to 69% (Figure), of whom 15 (37%) also had a calcium score greater than 100. Twenty-one of these 41 patients received stress tests. Sixteen stress test results were negative, and the patients received no further diagnostic evaluation. Of the 5 patients with positive stress test results, 3 received cardiac catheterization. All 3 patients with a maximal stenosis of 50% to 69% on coronary CT angiography were found to have coronary lesions with the same degree of stenosis on cardiac catheterization. One patient had a 60% eccentric lesion in the proximal left anterior descending artery on both coronary CT angiography and cardiac catheterization and he was managed with placement of a stent. The other 2 patients were managed medically. Two patients with a 60% maximal lesion on coronary CT angiography received cardiac catheterization (without previous stress test). One was found to have a 70% lesion on cardiac catheterization and was managed medically. The other received stent placement, but details of the cardiac

Table 2. Relationship between degree of coronary stenosis on coronary CT angiography and composite outcome.*

Maximal Coronary Stenosis, %	Composite Outcome Present	Composite Outcome Absent
>50	7†	47
<50	0	508

*The composite outcome was based on a composite of diagnostic testing and clinical follow-up. If a patient received an objective assessment of coronary artery disease (stress test or cardiac catheterization), it was considered the criterion standard. When a patient received both tests, the cardiac catheterization was considered the criterion standard. For this analysis, the catheterization result was considered positive if the patient had greater than a 70% stenosis. In the absence of either test, 30-day death or nonfatal myocardial infarction was considered to be the criterion standard.
†One patient who had a 60% lesion on coronary CT angiography received a stent at an outside hospital, but we were unable to determine whether the lesion was above or below 70% on cardiac catheterization. We used the most conservative approach and considered her lesion to be below 70%. In either case, our sensitivity would remain 100%. Specificity would be slightly improved.

catheterization were not available. None of these patients sustained a cardiovascular death or nonfatal myocardial infarction within 30 days.

Diagnostic Accuracy

There were no patients subsequently found to have coronary artery disease, cardiovascular death, or nonfatal myocardial infarction who had an increased calcium score with normal coronary arteries on coronary CT angiography. Therefore, when we calculated diagnostic accuracy and predictive properties, we based our analysis only on the presence or absence of coronary stenosis. We excluded 6 patients with coronary calcium scores greater than 400 who did not receive contrast injection for evaluation of the coronary arteries, leaving 562 patients who had CT coronary angiography performed (Figure). Of the 508 patients without a coronary lesion of 50% or greater, none sustained a cardiovascular death or nonfatal myocardial infarction and none had subsequent diagnostic testing that revealed disease within 30 days. Using a cutoff of 50% (Table 2), the diagnostic accuracy of coronary CT angiography had a sensitivity of 100% (95% CI 59.0% to 100%), specificity of 91.5% (95% CI 88.9% to 93.7%), positive predictive value of 13.0% (95% CI 5.4% to 24.9%), and negative predictive value of 100% (95% CI 99.3% to 100%).

LIMITATIONS

Several potential limitations of our study design merit discussion. We enrolled patients according to provider comfort with clinical decisionmaking and limitations in the hours that CT technology was available (usually weekday daytime hours). For patients to be included in this study, the provider had to decide to order a coronary CT angiography test. We tried to minimize this selection bias by having a recommended approach to use of coronary CT angiography in our ED. Patients recommended for coronary CT angiography were patients with acute chest pain prompting an ECG, a TIMI score of 0 to 2, and an initial physician plan to admit the patient to rule out an acute coronary syndrome, but with the physician believing that there was a reasonable chance the patient did not actually have coronary disease. This accounts for more than 50% of patients with acute chest pain[15,16] and is typical of broad-based ED chest pain patient populations that have only a 5% to 20% risk of an acute coronary syndrome.[13-16,18] In our ED, we treat approximately 2,000 patients with chest pain syndromes annually. Coronary CT angiography was available approximately 50 hours per week (30% of the time) and could be used in the 50% of patients with acute chest pain, TIMI score 0 to 2, who would otherwise be admitted, so it is possible that nearly 1,000 patients might have qualified for this protocol during hours of availability during the study period. We did not track the patients who did not have coronary CT angiography ordered, but compared with previous studies conducted in our institution, the patient population was, on average, 4 years younger, had fewer previous cardiac events, and was more likely to have a TIMI risk score of 2 or lower.[15,16] Thus, our patient selection was representative of the low-risk cohort we targeted (Table 1).

Our 30-day outcomes were limited to cardiovascular death and myocardial infarction. We did not attempt to capture data on adverse events related to coronary CT angiography such as radiation exposure, contrast-related allergies, or clinically insignificant renal injury; however, we are unaware of the occurrence of any complications related to intravenous contrast administration for coronary CT angiography at our institution. We reviewed the death index and hospital records of the 8% of patients lost to follow-up and did not identify any adverse events; however, it is possible that these patients had an acute myocardial infarction at another institution. Although not our primary analysis, we performed an analysis of diagnostic accuracy that could be prone to workup bias. We used a composite of cardiovascular death, nonfatal myocardial infarction, and documented coronary artery disease, but the decision to perform further objective testing after coronary CT angiography was determined by the treating physician. Mandating additional diagnostic testing would have prevented us from being able to examine the actual safety of coronary CT angiography, when used for clinical decisionmaking.

DISCUSSION

Our data extend and prospectively validate previous work suggesting that low-risk patients with potential acute coronary syndromes and negative coronary CT angiogram results may be able to be safely discharged home without other testing such as a stress test or cardiac catheterization. In our immediate CT angiography cohort, 75% of all patients were discharged home after coronary CT angiography. Of the large subgroup of patients with a maximal coronary lesion of less than 50% and calcium score less than 100, 86% of patients were discharged home, reducing the hospital/observation unit admission rate to 14%, which compares favorably with the admission rate for

patients with potential ACS, which is typically 50% to 70% in our institution and elsewhere.[2,10,15-18]

Studies have demonstrated that coronary CT angiography can accurately identify or exclude coronary stenosis in low-,[27,28,30] intermediate-,[21-23,25,36] and high-risk[22,37,38] cohorts of patients with potential acute coronary syndrome. Most studies in high- and intermediate-risk patients have not used the test for clinical decisionmaking. In these subgroups, the test has been shown to be accurate, provide sufficient quality for diagnostic decisionmaking,[37] and provide independent prognostic information over baseline clinical risk factors.[38] However, its greatest utility may lie in identifying patients without disease because patients with acute coronary syndromes will still require further invasive testing and intervention. Studies of intermediate-risk patients also suggest that the greatest utility of coronary CT angiography may be in the subset of patients found to not have disease. Schuijf et al[36] found that coronary CT angiography provided accurate information that was complementary to myocardial perfusion imaging. Hoffman et al[29] studied 103 admitted intermediate-risk patients and found that patients without significant coronary disease on coronary CT angiography had a 100% negative predictive value for acute coronary syndrome during index hospitalization, as well as for major adverse cardiac events after 5 months. Similarly, Rubinshtein et al[31] found a 100% negative predictive value for the ED diagnosis of acute coronary syndrome in 58 patients. Thirty-five patients without obstructive coronary disease were discharged home after negative serial troponin measurement results, without any deaths or myocardial infarction during the 15-month follow-up period.[31]

At the low-risk end of the spectrum, small clinical studies have suggested the safety of coronary CT angiography for clinical decisionmaking; however, these studies did not actually follow a large cohort of patients whose management was based solely on the results of coronary CT angiography.[27-31] Gallagher et al[28] compared the accuracy of coronary CT angiography with myocardial perfusion imaging for detection of acute coronary syndrome or 30-day major adverse cardiac events after an observation unit admission to rule out an acute coronary syndrome. All patients had both rest and stress myocardial perfusion imaging and coronary CT angiography. Although the 85 patients were not managed according to coronary CT angiography results, the sensitivity of coronary CT angiography was comparable to myocardial perfusion imaging (86% versus 71%), as was the specificity (92% versus 90%).

Goldstein et al[30] studied 197 patients admitted to an observation unit. Patients were randomized to either standard evaluation or coronary CT angiography. The patients with minimal disease on coronary CT angiography were discharged home. Compared to the standard evaluation, the use of coronary CT angiography resulted in reduced length of stay and lower costs. Although this study was too small to comment conclusively on safety, no patient in either group died or had an acute myocardial infarction.

Chang et al[39] compared direct and indirect costs of 4 strategies to evaluate patients with potential acute coronary syndrome and found that immediate coronary CT angiography was more cost-effective and was associated with a shorter length of stay than observation unit management with coronary CT angiography, observation unit management with stress test, and admission with hospitalist-directed care. Although the strategy of immediate coronary CT angiography appeared to be as safe as the other strategies, the cohorts were small, preventing definitive conclusions.

Our study extends this previous work, which suggests that coronary CT angiography could be safely used to discharge low-risk patients home from the ED. Like Goldstein et al,[30] we had a cohort of patients who received coronary CT angiography after a brief observation unit stay. The low event rate, along with the larger size of our cohort, allows us to conclude that such patients will have a 1% or lower 30-day risk of cardiovascular death or myocardial infarction, thus demonstrating the utility of coronary CT angiography in rapidly identifying patients without disease.

Unlike previous studies, our work allows us to extend this approach to patients without mandating an overnight stay in the observation unit. In patients who received immediate coronary CT angiography after just an initial serum creatinine measurement, we were able to discharge the majority (75%) safely without any cardiovascular deaths or myocardial infarctions. Multiple clinical and computerized algorithms have attempted to define a group of patients safe for discharge from the ED but have not been able to identify a large subset of patients at less than 1% risk for 30-day adverse events.[5,6,9-17] Our study shows that the use of coronary CT angiography produces outcomes similar to those reported with inpatient admission and observation unit stays while avoiding the majority of admissions and shortening the duration required to determine that the patient is safe for discharge.

There were no patients with a maximal stenosis less than 50% on coronary CT angiography who were found to have reversible ischemia on stress test or significant coronary artery disease on cardiac catheterization. Although not all patients received further testing, none had a cardiovascular death or myocardial infarction within 30 days. Conversely, there were no patients with high-grade (>80%) lesions on coronary CT angiography with negative stress test or catheterization results. As might be expected, patients with coronary stenosis between 50% and 70% on coronary CT angiography had positive or negative stress test results confirming that anatomy alone cannot always predict physiology, particularly in patients with intermediate degrees of stenosis.

It has been stated that coronary CT angiography can be incorporated into clinical practice only after randomized controlled trials demonstrate its safety compared to other management strategies.[40] We believe that coronary CT angiography will be incorporated into clinical practice for low-risk patients with acute

chest pain before a randomized clinical trial can accrue enough patients to compare coronary CT angiography with other management strategies. We observed no cardiovascular deaths or myocardial infarction within 30 days, with an upper limit of the CI for such events of less than 1%. Immediate coronary CT angiography also appears to be more cost-effective than traditional management with observation or admission and provocative testing in both decision analysis[41] and in one actual financial analysis.[39] Randomized controlled trials are still essential to define the role of coronary CT angiography in intermediate- or high-risk patients. Larger multicenter studies should still confirm the safety of early discharge of low-risk patients, define the subset of patients most likely to benefit from coronary CT angiography, and determine the optimal strategy to manage recurrent symptoms in patients documented to have noncritical disease on coronary CT angiography. As more frequent noninvasive detailed assessment of coronary anatomy occurs, the optimal long-term management of patients with noncritical coronary disease will need to be defined.

In conclusion, coronary CT angiography can be used to identify a low-risk subset of acute chest pain patients with potential acute coronary syndromes who can be safely discharged from the ED with a very low rate of 30-day death or acute myocardial infarction. The use of coronary CT angiography provides a noninvasive accurate approach to the evaluation of coronary artery disease and may be applicable in the majority of low-risk patients who present to the ED with chest pain syndromes that would otherwise require admission. We would not recommend extension of this technology to the very-low-risk cohort of patients who do not currently receive diagnostic testing, because CT scanning is associated with a long-term radiation risk.[42,43]

Supervising editors: Deborah B. Diercks, MD; Donald M. Yealy, MD

Dr. Diercks and Dr. Yealy were the supervising editors on this article. Dr. Hollander did not participate in the editorial review or decision to publish this article.

Author contributions: JEH was responsible for overall study principal investigator. JEH collated comments from other authors, prepared the final article, and takes overall responsibility for the data. JEH had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. JEH, AMC, CMM, WGB, and HIL were responsible for data collection. JEH, AMC, FSS, CMM, WGB, and HIL were responsible for analysis and interpretation of the data. JEH, FSS, CMM, and WGB were responsible for study design. JEH, AMC, FSS, and HIL wrote sections of the article. ACC, FSS, CMM, WGB, and HIL critically reviewed the article. FSS was the overall statistician for the project. HIL oversaw the radiology component of project. JEH takes responsibility for the paper as a whole.

Funding and support: By *Annals* policy, all authors are required to disclose any and all commercial, financial, and other relationships in any way related to the subject of this article, that might create any potential conflict of interest. See the Manuscript Submission Agreement in this issue for examples of specific conflicts covered by this statement. Drs. Hollander, Chang, and Litt have received research funding from Siemens Medical Solutions. Dr. Litt has received an equipment grant (for cardiac CT processing research workstation not used in the study) and honoraria from Siemens Medical Solutions for speaking and for serving on the corporate advisory board for cardiac CT and MR. Dr. Litt has also served as a consultant for Medrad about contrast injector technology for cardiac CT (unrelated to this project). Dr. Hollander has been invited to attend an advisory board for Siemens Medical Solutions.

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Publication dates: Received for publication June 13, 2008. Revisions received August 18, 2008, and September 12, 2008. Accepted for publication September 23, 2008. Available online November 8, 2008.

Reprints not available from the authors.

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