Cost and Resource Utilization Associated With Use of Computed Tomography to Evaluate Chest Pain in the Emergency Department

The Rule Out Myocardial Infarction Using Computer Assisted Tomography (ROMICAT) Study

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Background—Coronary computed tomographic angiography (cCTA) allows rapid, noninvasive exclusion of obstructive coronary artery disease (CAD). However, concern exists whether implementation of cCTA in the assessment of patients presenting to the emergency department with acute chest pain will lead to increased downstream testing and costs compared with alternative strategies. Our aim was to compare observed actual costs of usual care (UC) with projected costs of a strategy including early cCTA in the evaluation of patients with acute chest pain in the Rule Out Myocardial Infarction Using Computer Assisted Tomography I (ROMICAT I) study.

Methods and Results—We compared cost and hospital length of stay of UC observed among 368 patients enrolled in the ROMICAT I study with projected costs of management based on cCTA. Costs of UC were determined by an electronic cost accounting system. Notably, UC was not influenced by cCTA results because patients and caregivers were blinded to the cCTA results. Costs after early implementation of cCTA were estimated assuming changes in management based on cCTA findings of the presence and severity of CAD. Sensitivity analysis was used to test the influence of key variables on both outcomes and costs. We determined that in comparison with UC, cCTA-guided triage, whereby patients with no CAD are discharged, could reduce total hospital costs by 23% (P<0.001). However, when the prevalence of obstructive CAD increases, index hospitalization cost increases such that when the prevalence of ≥50% stenosis is >28% to 33%, the use of cCTA becomes more costly than UC.

Conclusions—cCTA may be a cost-saving tool in acute chest pain populations that have a prevalence of potentially obstructive CAD <30%. However, increased cost would be anticipated in populations with higher prevalence of disease.

Clinical Trial Registration—URL: http://www.clinicaltrials.gov. Unique identifier: NCT00990262.


Key Words: acute coronary syndrome ■ chest pain ■ multidetector computed tomography ■ economics

Coronary artery disease is the leading cause of death in the United States, and emergency evaluation of acute coronary syndrome (ACS) alone accounts for $10 billion annually in the United States.¹ Contributing to this cost is the fact that a misdiagnosis involving ACS is the number 1 cause of litigation for emergency department (ED) practitioners.²

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WHAT IS KNOWN

• Previous studies demonstrate that coronary computed tomographic angiography (cCTA) more rapidly triages emergency department chest pain patients compared with usual care and results in emergency department cost savings.
• No previous study has compared actual hospital cost incurred by usual care (if cCTA was not available) with modeled cost based on actual cCTA results, which were blinded to patients and caregivers.

WHAT THE STUDY ADDS

• cCTA offers hospital cost savings among emergency department chest pain patients who by CCTA have no coronary artery disease or mild coronary artery disease (<50% worst coronary stenosis).
• cCTA may increase cost for patients with inconclusive examinations or ≥50% stenosis because of the need for additional testing.
• Thus, the cost savings of cCTA is dependent on the prevalence of coronary artery disease (pretest probability) among the patients tested. In particular, once the prevalence of ≥50% or indeterminate stenosis increases beyond ≈30%, the cost of cCTA exceeds that of usual care.

Current clinical practice or usual care (UC) for evaluating patients with suspected ACS typically involves an ≈12-hour stay in a hospital ward or chest pain unit to allow serial evaluation of cardiac biomarkers and ECG, often followed by an array of diagnostic tests. Coronary computed tomographic angiography (cCTA) is an accurate noninvasive diagnostic test for assessment of symptoms of possible angina, which has proven prognostic value in thousands of patients. Recently, several studies, including 1 single-center and 3 multicenter trials, have suggested that use of cCTA in the ED represents a rapid and efficient method to evaluate patients with acute chest pain.

When examining the cost of care, the Coronary Computed Tomographic Angiography for Systematic Triage of Acute Chest Pain Patients to Treatment (CT-STAT) trial demonstrated that cCTA reduced time to diagnosis and was associated with a 38% lower ED (not total) cost. When total hospital cost was examined in a subset of patients from the Rule Out Myocardial Infarction Using Computer Assisted Tomography I (ROMICAT I) study, the mean cost of care between the cCTA group and usual care was similar, although there was a trend toward more downstream testing among patients randomized to cCTA. Thus, although cCTA evaluation of acute chest pain may reduce ED cost and hospital stay, concern exists that cCTA may increase posttest resource utilization and downstream costs.

The Rule Out Myocardial Infarction Using Computer Assisted Tomography I (ROMICAT I) study used a unique design by which all patients and caregivers were blinded to cCTA results; thus, actual observed patient care and costs were based on UC and were not influenced by cCTA results. This design, which has not been used in any other cCTA studies, provides actual UC costs yet contains real cCTA data for each patient that can be used to simulate the effect of various cCTA-guided algorithms on costs, length of stay (LOS), and resource utilization. Therefore, our aim was to compare actual costs of UC (if cCTA was not available) with projected costs of a strategy of early cCTA in the evaluation of patients with acute chest pain.

Methods

Study Population

The study design and results of the ROMICAT I study have been described in detail previously. The study was approved by the Partners Healthcare Institutional Review Board, and all subjects enrolled in the ROMICAT I study provided informed consent. Briefly, this single-center, double-blinded, observational cohort study enrolled 368 consecutive patients with acute chest pain, unremarkable initial troponin and ECG, and no known coronary artery disease (CAD) who were awaiting hospital admission between May 2005 and May 2007. All patients underwent 64-slice contrast-enhanced cCTA before hospital admission, with caregivers and patients blinded to the results of the examination. Immediate (within the index hospitalization) and long-term (2-year) outcomes included the following: additional noninvasive imaging tests during the index hospitalization, invasive coronary angiography, percutaneous coronary intervention, coronary artery bypass grafting, ST-segment—elevation myocardial infarction, non–ST-segment—elevation myocardial infarction, and cardiovascular death. ACS was defined as either an acute myocardial infarction (ie, patients developed a positive troponin during serial testing or 6 or 9 hours after ED presentation) or unstable angina pectoris according to the American Heart Association/American College of Cardiology/European Society of Cardiology guidelines. Unstable angina pectoris was defined as clinical symptoms suggestive of ACS (unstable pattern of chest pain at rest, new onset, or crescendo angina), optimally with objective evidence of myocardial ischemia such as a positive stress test. Clinical events were ascertained using a standardized phone interview at 6 months and 2 years. In addition, records were reviewed. A combined end point of major adverse cardiac events (cardiac death, myocardial infarction, or coronary revascularization) was adjudicated by 2 physicians blinded to the cCTA data. Disagreements were resolved by consensus with a third experienced clinician.

Cost Data

To determine all hospital-related costs for each patient in our study, we used the Eclipsys Sunrise Decision Support Manager system (Eclipsys, Boca Raton, FL). The Sunrise Decision Support Manager is a cost accounting system that tracks all costs associated with each patient’s hospital admission at a line-item level. From this system, we obtained detailed costs for all services provided to the patient except for the actual physician fees. Compared with an approach based solely on Medicare reimbursement values, this approach is more accurate in describing actual hospital costs of all direct and indirect services provided and thus allows a valid comparison between different treatment strategies.

Cost and Resource Utilization Under UC Strategy

For each of the 368 patients included in the ROMICAT I study, cost under UC was derived by adding all line-item costs for the entire hospital admission. Costs included costs in all units (ED, observation unit, and inpatient wards). For each patient, total cost was calculated by adding all direct and indirect costs incurred by each department. Direct costs represent all expenses that can be traced directly back to direct patient care (ie, procedure, medications, nursing care); indirect costs represent overhead costs that are associated with each charge (eg, equipment). Such costs are important to consider because they are used during the treatment of patients although they may not necessarily relate to any one procedure. Cost of all cardiac imaging tests for each admission was calculated by adding the cost of each test that the patient underwent. All costs were converted to 2007 US dollars using the consumer price index.

LOS was calculated as the time difference from presentation to the ED until discharge and thus included ED LOS, observation unit LOS (when applicable), and ward LOS.
Estimated Cost and Resource Utilization Using Coronary CT Strategy

On the basis of the results of cCTA, patients were divided into the following groups:

- Negative coronary CT: no plaque and no stenosis (n=183)
- Plaque with no significant stenosis (n=117)
- Indeterminate stenosis (n=34): stenosis could not be excluded
- Significant stenosis (n=34)

The presence of any plaque and the presence of significant coronary stenosis, which was defined as ≥50% luminal narrowing, were determined in a consensus reading by 2 experienced cardiac imaging investigators. All patients with the presence of stenosis were further assessed using semiautomated software and subdivided into those with <70% and those with ≥70% luminal narrowing.23

Proposed management and subsequent projected costs were determined for each subgroup as detailed in Figure 1. Key underlying assumptions with supporting literature are summarized in Table 1.

No Plaque, No Stenosis on cCTA

In the ROMICAT I population,19,22 the absence of plaque and stenosis by cCTA had a 100% negative predictive value for ACS and was associated with no major adverse cardiac death after 2 years. From these results and the findings from others,2,28–30 one may confidently conclude that this subgroup of patients can be safely discharged home and do not require any further testing.

For each patient who had a negative cCTA, total cost (direct and indirect) was estimated from Sunrise Decision Support Manager data and with the following adjustments: (1) shorter LOS as discussed below and (2) elimination of any costs related to cardiac imaging tests (exercise ECG stress tests, nuclear perfusion imaging studies, echocardiography, cardiac catheterizations). Therefore, costs for patients with normal cCTA results were calculated by using the real-world costs from Sunrise Decision Support Manager and subtracting any additional imaging or catheterization cost. Estimated LOS was determined from the following constraints and assumptions: (1) cCTA service was available at the time of ED triage, and (2) patients modeled as being safe for discharge after cCTA would have a 54% reduction in LOS, similar to the time reduction seen in cCTA trials.8

Presence of Plaque but No Stenosis on cCTA

Given the results of ROMICAT I, patients who have plaque on their cCTA—even if this does not result in significant stenosis—cannot completely be ruled out for ACS (eg, spasm, lysis of thrombus spontaneously or because of medical therapy). For the purposes of estimating resource utilization and cost, we modeled this subgroup by assuming they would undergo UC. Subsequent decisions on testing and patient management would then be based on actual care that took place without knowledge of the cCTA results.

Presence of Stenosis on cCTA

Among patients with stenosis and acute chest pain, clinical reasoning would suggest that if positive enzymes are identified or if there are any other high-risk features (eg, persistent symptoms, hemodynamic instability), then the patient should be referred for invasive coronary angiography (ICA) with possible percutaneous coronary intervention (Figure 1). If, however, cardiac markers are negative, further imaging testing should be obtained. An underlying assumption, which is supported by results from all studies to date, is that among patients with significant stenosis, some at lower risk may be evaluated with noninvasive testing, whereas those at higher risk would proceed to invasive angiography. One potential strategy is to offer invasive angiography to all patients who are found to have a stenosis on the basis of CT. The limitation of this approach is that patients with stenosis that is not hemodynamically significant would be referred for angiography/interventions. Such a strategy is unlikely to be economically attractive because it may result in increased use of coronary angiography compared with UC.7 Therefore, the present study assumes that there will be a mix of both invasive angiography and noninvasive functional testing, as described by the following scenarios (Figure 1).

Baseline Scenario

- All patients undergo cCTA, and those with normal scans (ie, no plaque and no stenosis) are discharged home without additional testing and accordingly with a decreased LOS.
- All patients with plaque but no stenosis remain in the ED/observation unit for a total of 3 sets of cardiac biomarkers (12 additional hours in hospital). If biomarkers are normal, patients are discharged home with cost determined by UC (any real-world non-cCTA imaging costs are applied). If positive (n=3), the patients are admitted for ICA with additional costs determined by UC.
- All patients with ≥50% but <70% stenosis undergo myocardial perfusion imaging (MPI). If MPI is abnormal, ICA is performed and cost is determined by UC.
- All those with ≥70% stenosis undergo selective ICA at a rate of what was performed in the CT-STAT1 trial (9 of 13 patients with ≥70% stenosis were referred to ICA; 4 patients were medically managed per physician’s discretion; these data have not been published for the American College of Radiology Imaging Network-Pennsylvania (ACRIN-PA) or ROMICAT II study).

Figure 1. Alternate scenarios. CAD indicates coronary artery disease; cCTA, coronary computed tomographic angiography; D/C, discharged; ICA, invasive coronary angiography; MPI, myocardial perfusion imaging; Neg, negative; and Trp, troponin.
Table 1. Evidence From Prior cCTA Studies That Provides the Basis for Modeled Scenarios and Assumptions

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Rationale/References</th>
<th>Limitations/Counterpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients with no plaque or stenosis after cCTA can be safely discharged home and do not require any further testing.</td>
<td>Low event rate among normal cCTA; see Table 2.</td>
<td>N/A</td>
</tr>
<tr>
<td>Patients with nonobstructive (&lt;50%) plaque can be safely discharged home if negative cardiac biomarkers.</td>
<td>Hollander et al(^2): Among 481 patients with nonobstructive CAD (ie, stenosis &lt;50%) who were discharged home from ED, no patients had any cardiac death, MI, or coronary revascularization at 1-y follow-up. Goldstein et al(^8): CT-STAT trial (multicenter, randomized, clinical trial comparing cCTA and MPI) used a study design that encouraged patients to be discharged home if stenosis &lt;25%. Litt et al(^4): In the ACRIN-PA trial, 0 of 640 patients with cCTA 0% to &lt;50% stenosis had a cardiac event during 30-d follow-up.</td>
<td>A small proportion of patients with nonobstructive plaque may have ACS. Notably, among patients with negative serial cardiac enzymes in ROMICAT I, all such events are the result of unstable angina.</td>
</tr>
<tr>
<td>Patients with moderate stenosis (50%–70%) will undergo noninvasive myocardial perfusion imaging to determine whether it is a flow-limiting disease; patients with ischemia will then be referred for invasive angiography.</td>
<td>Hollander and Blankstein et al(^14,25): Moderate stenosis on cCTA may be associated with ischemia and the presence of an ACS. MPI would be useful for further risk stratification.</td>
<td>N/A</td>
</tr>
<tr>
<td>Among patients with moderate stenosis referred for MPI, 30% will have ischemia and will require further invasive testing; of those referred for invasive angiography, 70% will undergo coronary revascularization.</td>
<td>Goldstein et al(^8): In CT-STAT, 4 of 37 (11%) patients with intermediate/nondiagnostic cCTA were abnormal; 3 of them had invasive angiography. In the present study, 18 of the 33 referred for invasive angiography underwent coronary revascularization; however, when excluding the 6 patients who had no disease on cCTA, 18 of 27 (67%) patients referred for ICA required coronary revascularization.</td>
<td>Blankstein et al(^25): The number of patients with moderate stenosis who will have ischemia is variable in trials. Hachamovitch(^26) and Tonino(^27): Not all patients with ischemia require further invasive assessment because individuals with only mild ischemia may benefit from optimization of medical therapies.</td>
</tr>
<tr>
<td>All patients with severe stenosis (&gt;70%) will be referred for invasive angiography.</td>
<td>Most patients with stenosis &gt;70% will benefit from further testing. Goldstein et al(^8): In CT-STAT it was recommended that patients with severe stenosis undergo invasive angiography (although only 9 of 13 patients with stenosis ≥70% were actually referred.</td>
<td>Reffing all patients with &gt;70% stenosis may result in overutilization of invasive angiography and possibly PCI(^9); some of these patients may benefit from initial MPI testing followed by selective use of invasive angiography.</td>
</tr>
<tr>
<td>50% of patients with stenosis on cCTA &gt;70% who are referred for invasive angiography will undergo coronary revascularization.</td>
<td>In the present study, 8 of the 9 patients with stenosis on cCTA &gt;70% referred for invasive angiography underwent coronary revascularization.</td>
<td></td>
</tr>
<tr>
<td>Patients with uninterpretable cCTA will be treated as having &gt;50% stenosis.</td>
<td>Consistent with analysis of ROMICAT I(^19). Patients with lesions uninterpretable for stenosis will require at least some additional testing and are likely to undergo ICA or MPI.</td>
<td>Will be compared with usual care.</td>
</tr>
</tbody>
</table>

ACS indicates acute coronary syndrome; CAD, coronary artery disease; cCTA, coronary computed tomographic angiography; CT-STAT, Coronary Computed Tomographic Angiography for Systematic Triage of Acute Chest Pain Patients to Treatment; ED, emergency department; ICA, invasive coronary angiography; MPI, myocardial perfusion imaging; PCI, percutaneous coronary intervention; and ROMICAT I, Rule Out Myocardial Infarction Using Computer Assisted Tomography I.

Alternate Scenario A

- All patients undergo cCTA, and those with normal or <50% stenosis are discharged home without additional testing and accordingly with a decreased LOS.
- Management of ≥50% and ≥70% stenosis follows the baseline scenario.

Alternate Scenario B

- All patients undergo cCTA, and those with normal scans (ie, no plaque and no stenosis) are discharged home without additional testing and accordingly with a decreased LOS.
- All patients with <50% stenosis remain in the ED/observation unit for a total of 3 sets of cardiac biomarkers (12 additional hours in hospital). If biomarkers are normal, patients are discharged home with cost determined by UC (any real-world non-cCTA imaging costs are applied). If positive (n=3), the patients are admitted for ICA with additional costs determined by UC.
- All patients with ≥50% stenosis remain in the ED/observation unit for a total of 3 sets of cardiac biomarkers (12 additional hours in hospital). If biomarkers are normal, patients undergo MPI. If MPI is normal, patients are discharged home. If MPI or biomarkers are abnormal, ICA is performed and cost is determined by UC.

Alternate Scenario C

- All patients undergo cCTA, and those with normal or <50% stenosis are managed according to the baseline scenario. Those with no CAD are discharged home without additional testing and accordingly with a decreased LOS.
- All patients with indeterminate or >50% stenosis undergo MPI. Cost is determined by subtracting non-cCTA imaging cost from UC except the cost of MPI.
- Those with >70% stenosis undergo ICA, and cost is determined by adding catheterization cost to UC, if not performed.
Sensitivity Analyses
In ROMICAT I, the prevalence of indeterminate or ≥50% stenosis was 18.5% (68 of 368). A sensitivity analysis was performed to assess the impact of cost on each scenario after varying the prevalence of ≥50% stenosis from 0% to 100% in 1% increments.

Because some patients had a prolonged hospital stay for reasons not related to their chest pain or heart disease, a separate sensitivity analysis was performed to exclude patients with hospital LOS greater than the 95th percentile for the cohort (5.083 days). Among these 18 patients, there were 5 patients with no CAD, 5 patients with <50% stenosis, and 8 patients with indeterminate or ≥50% stenosis.

Statistical Analysis
Continuous variables were compared with ANOVA. Categorical variables were compared with the \( \chi^2 \) test. \( P \) values are 2 sided, with an \( \alpha \) of 0.05. All statistics were performed with Stata 12.0 (College Station, TX).

Costs were indexed as a percent of total cost observed under UC (real world) as determined from the line-item hospital costs discussed above. The purpose of indexing costs to UC was to evaluate how differences in the management strategies compare with UC. Actual cost data were not reported as per institutional policies. Costs were compared by medians (Kruskal-Wallis test).

Results

cCTA Examination Results
CCTA findings in the ROMICAT I study included 183 (50%) possible ACS patients with normal cCTA, 117 (32%) with <50% stenosis, 34 (9%) with indeterminate stenosis, and 34 (9%) with ≥50% stenosis. Among the 34 patients with ≥50% stenosis, 18 had ≥70% stenosis. Patients without significant CAD were younger and had fewer cardiac risk factors (Table 2).

Observed Resource Utilization Under UC
Under UC in the ROMICAT I study, providers (who were blinded to cCTA findings) performed 68 single-photon emission computed tomography (SPECT) scans, 20 transthoracic echocardiograms, and 6 ICAs on those (n=183 patients) with no CAD by cCTA; 50 SPECTs, 34 exercise tolerance tests, 9 transthoracic echocardiograms, and 10 ICAs on those (n=117) with <50% stenosis by cCTA; and 35 SPECTs, 11 exercise tolerance tests, 15 transthoracic echocardiogram, 1 transesophageal echocardiogram, 1 exercise stress echocardiograms, and 17 ICAs on those with ≥50% stenosis or indeterminate scans. Table 3 summarizes the actual use of diagnostic testing according to cCTA finding versus the modeled use (only baseline scenario shown).

Projected Costs Based on cCTA
Figure 2 compares modeled cost indexed as a percentage of actual spending based on different patterns of testing while holding LOS unchanged. Compared with real-world costs, total costs for the baseline scenario were 92%; alternative scenario A, 92%; alternative scenario B, 91%; and alternative scenario C, 93% (all scenarios differed significantly from actual cost, \( P<0.001 \); all scenarios differed from each other, \( P<0.001 \)).

When cost savings that are expected to result from decreased LOS are added to each model (Figure 3), more pronounced differences in cost are observed. Specifically, the cost of the baseline scenario was 85%; alternative scenario A, 77%; alternative scenario B, 84%; and alternative scenario C, 85% (all scenarios differed significantly from actual cost, \( P<0.001 \); all scenarios differed from each other, \( P<0.001 \); Figure 3).

For each scenario, significant cost savings occur in the patients with normal or <50% stenosis because of both a shorter LOS and the fact that under UC many of these patients with no or mild CAD underwent testing that could be averted under cCTA care. For example, under UC, 68 patients with no CAD (n=183) by cCTA underwent SPECT and 6 underwent catheterization. However, the cost for the patients with significant or indeterminate CAD was significantly higher in all

Table 2. Demographics

<table>
<thead>
<tr>
<th></th>
<th>No CAD</th>
<th>&lt;50% CAD</th>
<th>Indeterminate or ≥50% CAD</th>
<th>All Patients</th>
<th>( P ) Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>183</td>
<td>117</td>
<td>68</td>
<td>368</td>
<td></td>
</tr>
<tr>
<td>Age, y</td>
<td>47 (9)</td>
<td>56 (10)</td>
<td>62 (12)</td>
<td>53 (12)</td>
<td>&lt;.001</td>
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<tr>
<td>Male, %</td>
<td>55</td>
<td>66</td>
<td>71</td>
<td>226 (61)</td>
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</tr>
<tr>
<td>Hypertension, %</td>
<td>26</td>
<td>43</td>
<td>71</td>
<td>145 (39)</td>
<td>&lt;.001</td>
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<tr>
<td>Hyperlipidemia, %</td>
<td>22</td>
<td>49</td>
<td>54</td>
<td>135 (37)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Diabetes mellitus, %</td>
<td>7.1</td>
<td>7.7</td>
<td>27</td>
<td>40 (11)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Family history, %</td>
<td>21</td>
<td>22</td>
<td>35</td>
<td>89 (24)</td>
<td>0.04</td>
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<tr>
<td>Current smoker, %</td>
<td>25</td>
<td>26</td>
<td>25</td>
<td>93 (25)</td>
<td>0.87</td>
</tr>
<tr>
<td>Aspirin therapy, %</td>
<td>27</td>
<td>32</td>
<td>46</td>
<td>117 (32)</td>
<td>0.02</td>
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<td>Statin therapy, %</td>
<td>17</td>
<td>34</td>
<td>47</td>
<td>103 (28)</td>
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<tr>
<td>Antihypertensive, %</td>
<td>25</td>
<td>43</td>
<td>71</td>
<td>143 (39)</td>
<td>&lt;.001</td>
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<tr>
<td>ACS, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STEMI</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0.04</td>
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<tr>
<td>NSTEMI</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>7</td>
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<tr>
<td>UA</td>
<td>0</td>
<td>4</td>
<td>19</td>
<td>23</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

ACS indicates acute coronary syndrome; CAD, coronary artery disease; NSTEMI, non-ST-segment-elevation myocardial infarction; STEMI, ST-segment-elevation myocardial infarction; and UA, unstable angina.

*\( P \) value for trend across all groups.
scenarios because cCTA would increase test layering without reducing LOS.

After including modeled reductions in ED time (Figure 3), the relative cost for patients with no CAD was 63% of UC across all scenarios ($P<0.05$ versus UC), whereas for patients with nonobstructive CAD, the relative cost was reduced to 56% of UC ($P<0.05$) in alternative scenario A. However, among patients with obstructive CAD, cost was increased by

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**Table 3. Diagnostic Test Utilization in UC and Baseline Scenario**

<table>
<thead>
<tr>
<th>cCTA Outcome</th>
<th>UC (n=368)</th>
<th>No CAD (n=183)</th>
<th>&lt;50% CAD (n=117)</th>
<th>≥50% CAD (n=68)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac testing</td>
<td>UC</td>
<td>UC</td>
<td>Baseline</td>
<td>UC</td>
</tr>
<tr>
<td>Coronary CT</td>
<td>0</td>
<td>0</td>
<td>183</td>
<td>0</td>
</tr>
<tr>
<td>Invasive angiography</td>
<td>33</td>
<td>6</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>SPECT</td>
<td>151</td>
<td>68</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>Exercise stress test</td>
<td>117</td>
<td>72</td>
<td>0</td>
<td>34</td>
</tr>
<tr>
<td>Rest echocardiography</td>
<td>44</td>
<td>20</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Stress echocardiography</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No testing</td>
<td>74</td>
<td>36</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>Hospital stay, h</td>
<td>26.2</td>
<td>24.4</td>
<td>11.2</td>
<td>25.9</td>
</tr>
<tr>
<td>Indexed cost, %</td>
<td>100</td>
<td>100</td>
<td>82</td>
<td>100</td>
</tr>
</tbody>
</table>

CAD indicates coronary artery disease; cCTA, coronary computed tomographic angiography; SPECT, single-photon emission computed tomography; and UC, usual care.

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**Figure 2.** Coronary computed tomographic angiography cost (projected) indexed. Costs were indexed by dividing the real-world costs by the projected costs from each scenario within each subgroup (ie, no plaque/no stenosis, plaque without stenosis, plaque with indeterminate stenosis, or plaque with significant stenosis) and reporting the percent. All scenarios differed significantly from actual cost ($P<0.001$); all scenarios differed from each other ($P<0.001$). CAD indicates coronary artery disease; <50% CAD, <50% worst coronary stenosis (nonobstructive CAD); and ≥50% CAD, ≥50% worst coronary stenosis (obstructive CAD).
10% to 14% ($P < 0.05$ versus UC), depending on the modeled options for management.

**Sensitivity Analysis**

Figure 4 depicts the cost of each scenario indexed versus actual cost in the ROMICAT I study (100% value). With decreasing prevalence of obstructive CAD, cost savings occur. As prevalence of ≥50% stenosis increases beyond 28% for the baseline scenario, 33% for alternative scenario A, 30% for alternative scenario B, and 28% for alternative scenario C, the triage scenarios using cCTA for initial triage of possible ACS increase cost compared with the observed UC costs from the ROMICAT I study. After excluding outliers for prolonged hospital stay (>5.083 days), there was no significant change in these findings (data not shown).

**Discussion**

In this cost analysis of the ROMICAT I study, we found that despite use of more imaging tests, initial triage of possible ACS with cCTA would be expected to result in total hospital stay cost savings of ≈15% to 23% (Figure 3). Given that $10 billion are spent each year in the United States on the evaluation of acute chest pain, on aggregate, these findings could translate into significant cost savings.

Few reports have compared the cost of a cCTA versus UC strategy in the ED for acute chest pain, and there are noteworthy limitations of these analyses. For instance, some of them only consider ED but not total hospital cost, whereas others evaluate ED and total hospital cost. Similarly, simulation models of projected cost may be limited to ER or procedural costs and not inclusive of total hospital cost. The ROMICAT I study design is uniquely suited for observing actual cost of care because physicians were blinded to cCTA findings and subsequent patient management was based exclusively on the ED and subsequent care team discretion.

Because of the lack of trials comparing cost-effectiveness of various CAD diagnostic modalities, the US National Institutes of Health has invested millions of public health research dollars in large trials comparing outcomes of different testing options. For example, the Prospective Multicenter Imaging Study for Evaluation of Chest Pain (PROMISE) trial, which has nearly completed enrollment of 10,000 outpatients with stable symptoms, is randomizing patients to a strategy of anatomic testing with cCTA.
versus functional testing (including exercise ECG, stress echocardiography, and stress nuclear myocardial perfusion imaging). The hypothesis of this study is that information derived from cCTA will lead to a lower composite end point of death, myocardial infarction, major complications from cardiovascular procedures, or unstable angina requiring hospitalizations. As a secondary end point, this study will also examine cost. However, the PROMISE trial is evaluating a population with stable angina, which is different from the acute chest pain population that is the subject of our analysis. The enrollment of the PROMISE study is expected to complete in August 2014, although the results will not be reported until at least 2016.

The anticipated cost reductions of our study are based on eliminating diagnostic tests that are unlikely to occur after cCTA (SPECT, exercise tolerance test, invasive angiography) and expected reduction in LOS, particularly among patients with no or mild CAD. A fundamental assumption of our study and of all studies conducted to date assessing the economic consequences of imaging in the ED is that testing is only performed in patients for whom further imaging is deemed clinically necessary. Although it could be argued that some patients could be triaged with no testing,33,34 given the malpractice risk of missed myocardial infarction, avoiding testing across a large proportion of patients with acute chest pain may not be realistic in all practice environments.35 When considering a strategy of no testing, one option might be to discharge all patients with 3 negative troponins. However, in the ROMICAT study, 123 of the patients (57%) with negative serial troponins had at least mild CAD and 53 (25%) had significant stenosis or indeterminate scans, suggesting that such a strategy would risk missing potentially significant CAD. Notably, 22 of these

Figure 4. Cost as a function of increasing obstructive coronary artery disease (CAD) prevalence. With increasing prevalence of obstructive CAD (x axis), the cost of care after imaging by coronary computed tomographic angiography (cCTA) increases as a result of increased diagnostic tests and medical therapies (y axis). Depicted are the projected (modeled) costs for several large studies, including the first randomized trial of cCTA for acute chest pain in the emergency department,7 Rule Out Myocardial Infarction Using Computer Assisted Tomography I (ROMICAT I),10 Coronary Computed Tomographic Angiography for Systematic Triage of Acute Chest Pain Patients to Treatment (CT-STAT),2 and ACRIN-PA8 trials. cCTA findings of prevalence of obstructive CAD have not been reported yet for ROMICAT II. As prevalence of ≥50% increases beyond 28% for the baseline scenario, 33% for alternative scenario A, 30% for alternative scenario B, and 28% for alternative scenario C, the triage scenarios using cCTA for initial triage of possible ACS increase cost compared with the actual data under usual care from the ROMICAT I study.
patients (18%) were diagnosed with unstable angina (blinded to cCTA). This strategy also would be burdened by the cost of a longer period of observation for complete assessment by serial troponins, unless highly sensitive troponins allow earlier triage time.5

Given that the strongest influence on cost of care is LOS, it is important to recognize that assumptions of any given scenario regarding LOS will have a significant influence on cost. Furthermore, it is important to recognize that the true cost of LOS is highly variable among different hospital systems and within departments of a given hospital (ED versus intensive care unit versus observation ward). Recognizing these facts, we aimed to use a conservative method to estimate the projected LOS under cCTA care and to only estimate a percent reduction based on the actual LOS. Another option could be to use a fixed LOS (based on previous published studies or data on time to diagnosis by cCTA that are available in ROMICAT I) for patients with no CAD on cCTA who would be discharged directly from the ED. However, this technique would likely bias the analysis significantly in favor of cCTA because some patients in ROMICAT I study had noncardiac medical problems in addition to their cardiac evaluation. Thus, we chose to use a percent reduction in LOS to provide a more conservative estimate of the cost.

These findings notwithstanding, our study has inherent limitations. First, because all patients received UC, we used projected rather than actual resource utilization after cCTA to inform our cost modeling. Although our assumptions are based on real-world data from the use of cCTA in this population, as well as the results of other published trials, it is possible that even after a normal cCTA some clinicians may feel compelled to order additional testing.7,10,19 Furthermore, the results of any scenario may differ from real-world care. For instance, in the ROMICAT II trial, the potential in-hospital cost savings that would be predicted by our analysis were not realized, primarily because of a higher rate of ICA and revascularization in the cCTA arm. Second, the ROMICAT I study, like most studies of cCTA in the ED, enrolled hemodynamically stable patients with nonacute initial ECG and normal initial troponin. Importantly, these results should not be extrapolated to patients with hemodynamic instability or those patients presenting to the ED with acute chest pain who have not undergone initial ECG and cardiac biomarker laboratory testing. Third, we applied a model with 24-hour availability of cCTA, and thus, our findings are only applicable to patients who present to the hospital when cCTA is available. In systems where large numbers of patients present with acute chest pain after daytime hours, the lack of available cCTA could negate some of the potential cost savings because patients waiting to undergo cCTA would have an increased LOS. Fourth, there was a 9% rate of indeterminate cCTA, which is higher than that observed in other studies. We modeled these patients as having ≥50% disease (because many of these patients would be managed as if they have disease) although many may not have significant CAD. The net effect of this conservative assumption would be to increase cost of the cCTA strategies modeled versus UC because the prevalence of indeterminate cases is generally lower in contemporary studies. Fifth, our cost analysis does not address radiation dose, and increased use of cCTA will increase radiation exposure to patients, the public health consequences of which are not known.10 Finally, we cannot account for the potential of cCTA to affect rates of downstream testing, particularly ICA,7,19 because physicians were blinded to the cCTA results. Although a study of a large Medicare database concluded that cCTA may increase downstream catheterization compared with SPECT or exercise stress echocardiography,19 this finding occurred in a population that has a mean age of 74 years, which is older than that in the published ED trials.19 In such a population, the prevalence of CAD (and of nonevaluable scans) would be higher and, as our results demonstrate, is likely to be associated with increased cost.

Our analysis demonstrates potential for cost saving, particularly among the subgroups with no or mild CAD. However, it must be realized that there are many factors that drive hospital costs. Although our analysis (which is based on the hospital’s point of view) focuses on minimizing unnecessary expenditures as a result of potential perverse incentives of a fee-for-service system,49 some payment structures may encourage more testing, therefore creating a potential barrier to cost-effective use of cCTA.

An important consideration remains that cCTA may increase cost when implemented for populations with high prevalence of ≥50% stenosis or among groups in which stenosis cannot be excluded. As shown in Figure 4, when the prevalence of ≥50% or indeterminate stenosis increases beyond 28% to 33% (depending on which scenario is used), the cost of cCTA exceeds that of UC. Nevertheless, given that the current prevalence of obstructive CAD is low among most patients considered suitable for cCTA evaluation,41 our findings demonstrate that if used appropriately, in aggregate, cCTA is likely to be cost saving across most populations of patients with acute chest pain in whom further testing is required and who are expected to have adequate image quality.

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