Advanced Imaging Reduces Cost Compared to Standard of Care in Emergency Department of Triage of Acute Chest Pain

Pamela S. Noack , Jhanna A. Moore, and Michael Poon

Objective. To evaluate medical costs of novel therapies in complex medical settings using registry data.

Data Source/Study Setting. Primary data, from 2008 to 2010. We used patient registry data to evaluate cost and quality performance of coronary computed tomography angiography (CCTA) in triaging chest pain patients in our tertiary care emergency department and to model financial performance under Medicare's two midnight rule.

Study Design. Using generalized linear modeling, we retrospectively compared estimated expenditures for evaluation of low-to-intermediate-risk chest pain for demographic and medically risk matched samples of 894 patients each, triaged with CCTA or local standard of care (SOC) using Medicare reimbursement as a proxy.

Data Collection/Extraction Methods. Predefined data elements were downloaded from the hospital mainframe into the CCTA registry, where they were validated and maintained electronically.

Principle Findings. We found that predicted standard of care costs were 2.5 times higher on the initial visit and 1.98 times higher over 30 days ($p < .001$) than those using CCTA. Predicted cost was 1.6 times higher when we applied our two midnight rule model ($p < .001$).

Conclusion. Rapid assessment of treatment using registry data is a promising means of analyzing cost performance in complex health care environments.

Key Words. CCTA, registry data, cost of care, innovation, evaluation

As we move toward a value-based health care system, improvements in health information technology offer researchers and providers opportunities to advance toward innovative, patient-centered care. Historically, medical innovation has relied heavily on randomized controlled clinical trial (RCT) data to assess safety and efficacy of novel medical interventions. While essential for initial validation, these trials may leave many questions concerning applicability and cost effectiveness unanswered, because of their necessarily narrow

focus and need to carefully control the environment and homogeneity of the sample (Marko and Weil 2010; Krumholz 2014). In addition, as RCTs rely on prospective, random assignment to control for bias, they can be very expensive and may require several years to acquire adequate evidence.

Recently, advances in the storage, security, and accessibility of patient medical information have given observational study designs the power to generate very large sample sizes with enough medical detail to risk-adjust effectively. These designs can generate information on outcomes concerning medical utilization, cost, and downstream patient experience in a variety of settings. Also critically important, these observational studies allow researchers to work without disrupting the standard health care delivery model. Researchers can observe patients' reactions to actual care received in real-world settings. This information can be instrumental in formulating policies and managing financial incentives to change health care delivery.

The important role that the emergency department (ED) plays in the U.S. health care system has been well documented. Although ED physicians account for only 4% of U.S. physicians, they manage 38% of U.S. acute care visits and make 50% of hospital admission decisions (Barish, McGauley, and Arnold 2012; Sabbatini, Nallamothu, and Kocher 2014). Centers for Medicare and Medicaid Services (CMS) recently projected hospital spending for 2015 at \$3,093 billion (Centers for Medicare and Medicaid Services, 2014; Sabbatini, Nallamothu, and Kocher 2014). Nearly one-third of this projected cost is from hospital admissions only. In addition, many EDs face crowding conditions. In 2010, 50% of U.S. urban EDs and 51% of U.S. teaching EDs reported that they operated at or beyond their capacity. ED visits have grown from 351 per 1,000 population in 1991 to 415 per 1,000 population in 2009 (Barish, McGauley, and Arnold 2012). Crowding in EDs has been linked to increased inefficiencies, poor patient outcomes, higher costs, and increased mortality rates (Bernstein et al. 2009; Bhuiya, Pitts, and McCaig 2010; Guttman et al. 2011; Edmondson et al. 2013; Sun et al. 2013; Sabbatini, Nallamothu, and Kocher 2014).

Recently, Sabbatini, Nallamothu, and Kocher (2014) reported findings of an inverse relationship between risk-adjusted mortality rates and variability

Address correspondence to Pamela S. Noack, Ph.D., M.B.A., Northwell Health, Non-Invasive Cardiology, Lenox Hill Heart and Vascular Institute, 100 East 77th Street, 2East, New York, NY 10075; e-mail: psnoack@gmail.com. Jhanna A. Moore, M.D., is with the Department of Radiology, Mount Sinai St. Luke's and Mount Sinai West, New York, NY. Michael Poon, M.D., is with the Northwell Health, Non-Invasive Cardiology, Lenox Hill Heart and Vascular Institute, New York, NY.

of admission rates for ED patients. The authors concluded that the variability might indicate an opportunity for cost reduction. The diagnosis with the highest level of variability and the largest volume was chest pain. Chest pain accounts for 6 million U.S. ED visits annually and generates a cost of \$13 to \$15 billion. Two-thirds of these costs are for negative workups (Rubinshtein et al. 2007; Niska, Bhuiya, and Xu 2010; Owens et al. 2010; Priest et al. 2011). Observation chest pain units have been shown to improve clinical outcomes (Furtado et al. 2011) but, historically, have not been well adopted, (Venkatesh et al. 2011) perhaps due to prohibitive operating cost.

Several centers have conducted clinical trials on the use of coronary computed tomography angiography (CCTA) to triage low-risk chest pain. They concluded that CCTA is a safe alternative to stress tests for ruling out acute coronary syndrome (ACS) (Hoffman et al. 2009, 2012; Goldstein et al. 2011; Litt et al. 2012). However, estimated costs from the trials were not generalizable because they did not control for the complexity of medical settings found routinely in ED and inpatient hospital operations.

Our Medical Center Experience

In 2009, our tertiary care medical center introduced CCTA as an alternative to our standard of care (SOC) for triage of patients presenting with acute chest pain in the ED. Our SOC at the time of introduction was using enzyme testing or nuclear stress testing with hospital admission, depending on physician assessed patient risk. In the new protocol, CCTA was offered 7 days per week from 8:00 A.M. to 8:00 P.M.

Concurrently, the medical center commenced a registry for all CCTA patients, to monitor any changes in medical and costs outcomes at a micro level resulting from the new CCTA protocol. In addition, the ED trained staff on the appropriate use of CCTA for chest pain triage based on guidelines from 2006 (Hendel et al. 2006) at the time of program implementation, and updated to the new guidelines when published in 2010 (Taylor et al. 2010).

Using the detailed registry data, our center evaluated CCTA medical performance during the initial 16 months of implementation, comparing the performance of CCTA to the SOC for triaging ED patients for coronary artery disease (CAD) in our region. The assessment of medical outcomes and utilization of services was published in the *Journal of The American College of Cardiology* in August, 2013 (Poon et al. 2013). This study concluded that the CCTA protocol was associated with reduced resource utilization and improved medical outcomes. Fewer patients were admitted to the hospital or

underwent invasive coronary angiography (ICA). Readmissions and returns to the ED related to chest pain were significantly lower. ED average length of stay (ALOS) was significantly lower. There were no major adverse cardiovascular events (MACEs). Median radiation exposure of CCTA (5.88 mSv) was less than half of that of stress MPI (12 mSv)—the most common alternative test for chest pain evaluation. The study validated the safety, admission avoidance, reduced time spent in the ED, and clinical feasibility of using CCTA routinely without potential investigational bias commonly associated with RCTs (Poon et al. 2013).

Our Study

We now report on our program's cost assessment; completing the efficacy analysis for the use of CCTA; and illustrating the important contribution that retrospective evaluation utilizing detailed data registries can offer.

METHODS

Study Sample

Our patient population was drawn from 3,630 non-CCTA and 1,061 CCTA patient visits recorded in our registry from January 2009 to April 2010. We used propensity scoring followed by nearest neighbor matching to derive a balanced and evenly matched sample of 894 cases in each category.

Prior Standard of Care (non-CCTA). Prior to introduction of CCTA, our standard evaluation of chest pain patients included serial ECGs for detection of ischemic changes and repeated cardiac enzyme testing to rule out acute coronary syndrome (ACS). Patients were either discharged from the ED or admitted for cardiac stress testing, at the recommendation of the ED physician or attending cardiologist (Poon et al. 2013). Cardiac stress testing provided a functional assessment of the patient's coronary status, from which a decision for invasive angiography was made.

Introduction of Coronary Computed Tomographic Angiography. Beginning in 2009, the attending physician chose between the former SOC or CCTA workup for non-ACS chest pain patients (with normal ECG and having had at least one negative biomarker test result). CCTA was offered 7 days per week from 8:00 A.M. to 8:00 P.M. Patients with kidney failure (estimated glomerular

filtration rate <50 ml/minute/ 1.73 m^2), body mass index > 50 , and for whom iodinated contrast was not indicated were not eligible for CCTA (see Poon et al. 2013 for details of CCTA prep.). CCTA results provided an anatomical image of the patient's coronary vessels from which the level of coronary obstruction was evaluated, and recommendation for further workup with invasive coronary angiography was made.

Primary Outcome Measures

Our primary outcome measure was cost to society when CCTA is used versus when SOC is applied to diagnose coronary artery disease (CAD). We defined cost to society as expenditures used caring for chest pain patients in their initial ED visit triaged by SOC versus CCTA including any 30-day follow-up visits. Patient status (inpatient vs. outpatient) and severity of illness drive hospital costs. Therefore, we categorized patients treated as inpatients and those treated in the ED. We then explored expected severity and cost based on final diagnosis for the inpatients. Using Medicare reimbursement as a proxy for costs, we calculated reimbursement for each patient visit using appropriate fee for service FY 2013 base operating rates, prior to adjustments for regional variations, teaching, and capital expenses (Centers for Medicare and Medicaid Services 2013a, 2013b; Department of Health and Human Services Centers for Medicare and Medicaid Services, 2013; MedPac, 2013; American Medical Association, 2014) for all services utilized (see Appendix S1: Reimbursement Definitions, for details). We used base operating rates before adjustments, so that readers can apply applicable adjustments based on characteristics of their own provider region. We categorized patients into one of the following diagnoses: (1) chest pain (MS DRG 313) (2) cardiovascular excluding chest pain (all other MS DRGs assigned to MDC 5), and (3) other. Using these categories, we compared SOC to CCTA costs for all services utilized by the hospital and physicians. Finally, we reviewed CCTA results to determine the incidence of coronary artery disease (CAD) present in our population.

Secondary Outcome Measures

Subsequent to the treatment of our patient population, in October 2013, CMS implemented its two midnight rule. To ensure our analysis was of timely and practical importance, we also modeled Medicare reimbursement using this time-based rule for determining inpatient status in acute care hospitals, as a sensitivity analysis (Centers for Medicare and Medicaid Services 2013b;

Department of Health and Human Services Centers for Medicare and Medicaid Services, 2013). We reviewed all hospital admissions and assumed admissions would have converted from inpatient to observation status if the length of stay was 2 days or less (based on recorded hospital experience). We assumed patients who remained in the hospital for 9 hours but less than 2 days would have been billed as observation to meet CMS criteria for observation status. Remaining patients were classified as outpatient.

Statistical Methods

Initial Risk Matching. Our null hypothesis was that cost of care for patients evaluated with the former SOC and those evaluated using CCTA would be significantly different.

We analyzed our CCTA and non-CCTA registry patients' cardiac risk factors that are routinely evaluated as part of the ED triage for coronary artery disease, including patient age, sex, BMI, and medical status for kidney failure, hypertension, hyperlipidemia, diabetes, smoking history, family history of heart disease, and number of cardiac risk factors.

We found that our non-CCTA patient population had significantly higher proportions of patients with hypertension, hyperlipidemia, and diabetes. We controlled for these risk factors using a logistic regression analysis to calculate propensity scores of receiving CCTA, using the risk factors discussed above. Next, we matched propensity scores for SOC and CCTA cohorts, using nearest neighbor matching to derive a severity matched sample. Analysis was performed using Stata PScore (software written by A. Becker and A. Ichino) and PSMATCH2 (software written by E. Leuven and B. Sianesi) (see Poon et al. 2013 for further details.).

Assessment of Costs. We used independent *t*-tests with Sidak adjustments for repeated measures and ANOVA testing, as appropriate, to compare patient status and case mix index categories between the SOC and CCTA cohorts.

According to the previously published medical outcomes comparative analysis (Poon et al. 2013), patient evaluation by CCTA was associated with fewer hospital admissions and returns compared to patient evaluation of similar cardiac risk by SOC. This association is likely due to the accurate anatomical information CCTA makes accessible to physicians. Because patients' medical conditions were similar, the primary driver of cost and reimbursement was patient status. Patients admitted to the hospital generated the highest costs, which are reflected in the reimbursement. Hence, patient status as

inpatient, observation, or outpatient mediated cost of care (Baron and Kenny 1986). We hypothesized that provision of CCTA in the initial workup of chest pain informed physicians on patients' risk of a heart attack, thereby moderating their decision to admit patients. Also, we recognized that CCTA added to the direct cost of care for the population, because of the resources expended and time required to deliver the imaging service. We assessed this relationship by applying a generalized structural equation model using quasi-maximum likelihood approach with robust variances (Besag 1975; Baron and Kenny 1986). Then, we estimated the total effect CCTA had on cost.

In this two-step process, we first ran a logistic regression model to predict patient status based on whether or not the patient received CCTA, the patient's propensity score (as described above under *Initial Risk Matching*), and the additional variables: patient's minority status, stroke, peripheral vascular disease, comorbidity count, angina, circulatory disorders, minority status, sub-acute ischemia, ischemia, atherosclerosis, aneurysm, and year of visit. We note that while the additional variables were not deemed likely to determine whether the patient received CCTA, based on the hospital's chest pain protocol, we did believe they might influence the likelihood of being admitted to the hospital, regardless of whether the patient had undergone a CCTA. We then predicted total cost of the patient's initial visit using the patient status, and the patients diagnosis categories (inpatient chest pain, inpatient cardiology other than chest pain, inpatient other diagnosis, outpatient chest pain, outpatient cardiology, and outpatient other diagnosis), and whether or not the patient had CCTA.

Sensitivity Analysis. To evaluate the effect of the two midnight rule on costs, we added observation as a patient status using the time definitions discussed under Secondary *Outcome Measures* to assign observation status and reran the analysis (see Appendix S2: Details of Statistical Analyses).

Stata/MP version 13.1 (StataCorp, College Station, TX) was used for all data analyses. The study was approved by our institutional review board.

RESULTS

Propensity Score and Matching Results

The results of the analysis using propensity score and matching are presented in Table 1. The process resulted in a well-balanced sample of 894 patients each undergoing treatment with CCTA and SOC.

Table 1: Cardiac Risk Factors

Propensity Score Factors	PreMatch Population		PostMatch Population		p Value	p Value
	SOC (n = 3,630)	CCTA (n = 1,061)	SOC (n = 894)	CCTA (n = 894)		
Demographic						
Patient age mean/(median)	51 ± 16 (50)	49 ± 11 (47)	49 ± 12 (47)	49 ± 11 (48)	≤0.001	.802
Patient sex (male)	1,673 (46)	503 (47)	430 (48)	430 (48)	0.448	>.999
Number cardiac risk factors						
Mean/(median)	1.14 (1)	0.92 (1)	0.84 (1)	0.84 (1)	<0.001	>.999
0-1 Cardiac risk factors	2,372 (65)	786 (74)	690 (77)	690 (77)	<0.001	>.999
2-3 Cardiac risk factors	1,195 (33)	268 (25)	200 (22)	200 (22)	<0.001	>.999
>3 Risk factors	63 (2)	7 (1)	4 (<1)	4 (<1)	0.011	>.999
Cardiac risk factors (ICD9 code)						
Hypertension (401.XX to 405.XX)	1,506 (41)	355 (33)	294 (33)	294 (33)	<0.001	>.999
Hyperlipidemia (472.XX)	957 (26)	186 (18)	141 (16)	141 (16)	<0.001	>.999
Diabetes (249.XX-250.XX)	508 (14)	97 (9)	56 (6)	56 (6)	<0.001	>.999
Smoking history (301.5, V15.82)	1,190 (33)	335 (32)	257 (29)	257 (29)	0.460	>.999
Family history cardiac disease (V17.3, V17.4)	121 (11)	392 (11)	118 (13)	103 (12)	>0.999	.316
Other risk factors						
Obese (BMI ≥ 30.0-39.9 kg/m ²)	1,050 (30)	297 (31)	279 (31)	279 (31)	0.511	>.999
Morbidly obese (BMI ≥ 40.0 kg/m ²)	295 (8)	78 (8)	66 (7)	66 (7)	0.798	>.999
Severe kidney disease (eGFR 0-30)	152 (4)	3 (<1)	1 (<1)	1 (<1)	<0.001	>.999

Notes. Values are *n* (%), unless otherwise noted. Any numeric value recognized in the ICD-9 coding system may be substituted for “XX.” BMI, body mass index; CCTA, coronary computed tomography angiography; eGFR, estimated glomerular filtration rate. ICD9, International Classification of Diseases Version 9; SOC, standard of care.

Table 2: Estimated Costs

<i>Case Category</i>	<i>SOC</i>	<i>SOC</i>	<i>CCTA</i>	<i>CCTA</i>	<i>p</i>
	<i>Est.</i> <i>Medicare</i> <i>Cost</i> <i>(n = 894)</i>		<i>Est.</i> <i>Medicare</i> <i>Cost</i> <i>(n = 894)</i>		
		<i>95% Confidence Interval</i>		<i>95% Confidence Interval</i>	<i>Value</i>
Inpatient	\$5,177	\$4,765 to \$5,590	\$6,926	\$5,740 to \$8,113	<.001
Inpt chest pain	\$3,736	\$3,724 to \$3,749	\$3,810	\$3,781 to \$3,840	<.001
Inpt cardiology (excl chest pain)	\$8,996	\$7,201 to \$10,791	\$10,758	\$7,954 to \$13,563	.269
Inpt intervention (PCI/CABG)	\$15,563	\$13,539 to \$17,586	\$14,640	\$11,353 to \$17,927	.640
Inpt cath with no intervention*	\$6,326	\$5,916 to \$6,736	\$6,425	\$5,886 to \$6,964	.801
Inpt cardiology other	\$7,130	\$2,891 to \$11,369	\$8,155	\$2,050 to \$14,261	.767
Inpt other	\$5,323	\$4,817 to \$5,829	\$5,380	\$4,623 to \$6,146	.896
ED total (includes imaging)	\$321	\$299 to \$344	\$545	\$537 to \$553	<.001
ED chest pain	\$325	\$298 to \$352	\$540	\$531 to \$548	<.001
ED cardiology other	\$284	\$154 to \$413	\$516	\$377 to \$617	.280
ED other	\$314	\$271 to \$356	\$565	\$541 to \$590	<.001
Total	\$2,266	\$2,038 to \$2,493	\$1,438	\$1,218 to \$1,656	<.001

ABG, coronary artery bypass graft; cath, catheter; CCTA, coronary computed tomography angiography; ED, emergency department; Est, estimated; excl, excluding; Inpt, inpatient; PCI, percutaneous coronary intervention; SOC, standard of care.

Primary Study Outcomes

The average cost per case was \$2,266 when SOC was used, as compared to \$1,438 for CCTA ($p < .001$), representing a savings of \$740,000 for the population studied (Table 2). Our risk-adjusted regression model predicted the mean cost to evaluate and treat chest pain patients with SOC at 2.5 times greater than with CCTA ($p < .001$). When 30-day emergency and inpatients costs were added, our risk-adjusted model predicted SOC costs at 1.98 times greater than CCTA costs ($p < .001$), with actual (nonrisk adjusted) values at \$1,950, as compared to \$2,828 for SOC ($p < .001$).

This savings was driven by admission rates for patients evaluated by CCTA that were slightly more than one-third of those for SOC (14% vs. 40%, $p < .001$). The primary reason for this difference was that fewer patients were admitted for chest pain in the CCTA group (4.3% vs. 21.0%, $p < .001$). In addition, a higher proportion of SOC admitted patients were discharged with low-weighted diagnoses, after being evaluated for CAD (Table 3, Figures 1 and 2). The number of patients undergoing stenting or coronary bypass procedures

Table 3: Traditional Fee for Service: Patient Status by Category, Patient Intensity of Illness, and Patient Returns

Case Category	Cases (Percent)		
	CCTA (n = 894)	SOC (n = 894)	p Value
Inpatient	125 (14.0)	358 (40.0)	<.001*
Test of diagnosis category			<.001**
(chest pain, cardiology Not DRG chest pain, other)			
Inpatient chest pain	38 (4.3)	188 (21.0)	<.001***
Inpatient cardiology excluding chest pain	47 (5.3)	67 (7.5)	.196***
Inpatient intervention (PCI/CABG)	21 (2.3)	17 (1.9)	.884***
Inpatient ICA with No intervention	8 (0.9)	27 (3.0)	.003***
Inpatient cardiology other	18 (2.0)	24 (2.7)	.724***
Inpatient other	40 (4.4)	103 (11.5)	<.001***
ED total	769 (86.0)	539 (60.0)	<.001*
ED chest pain	617 (69.0)	410 (45.9)	<.001***
ED cardiology other	25 (2.8)	18 (2.0)	.737***
ED other	127 (14.2)	108 (12.1)	.557***
Total	894 (100.0)	894 (100.0)	

	Inpatient Intensity		
	CCTA (n = 125)	SOC (n = 358)	p Value
Inpatient	1.143	0.850	<.001*
Inpatient chest pain	0.599	0.599	
Inpatient cardiology excluding chest pain	1.794	1.500	.660***
Inpatient intervention (PCI/CABG)	2.418	2.587	.940***
Inpatient ICA with No intervention	1.038	1.029	1.000***
Inpatient cardiology other	1.402	1.224	.990***
Inpatient other	0.886	0.894	1.000***

	Patient Returns		
	CCTA	SOC	p Value
Returns In 30 days	12 (1.3)	32 (3.8)	.009*
Discharge from ED	7 (0.8)	17 (1.9)	.080***
Admitted	5 (0.6)	15 (1.7)	.050***

Notes. CABG, coronary artery bypass grafting; CCTA, coronary computed tomography angiography; ED, emergency department; ICA, invasive coronary angiography; Inpt, inpatient; PCI, percutaneous coronary intervention; SOC, standard of care.

* TTest.

** Anova Test.

*** TTest with Sidak Adjustment for Repeated Measures.

Figure 1: Comparison of Costs by Percentile [Color figure can be viewed at wileyonlinelibrary.com]

Notes. CCTA, coronary computed tomography angiography; SOC, standard of care.

Figure 2: Distribution of Patient Status [Color figure can be viewed at wileyonlinelibrary.com]

Notes. Pie slice shaded in dark blue represents patients categorized as inpatient status (14% of CCTA cohort and 40% of SOC cohort). “Non-Chest Pain Cardiology” includes all diagnoses that fall under cardiology (MS DRG System Major Diagnostic Category 5), except chest pain.

CCTA, coronary computed tomography angiography; ED, emergency department.

was similar; however, significantly more SOC patients (3.0% compared to 0.9%, $p = .003$) received invasive coronary angiography without subsequent intervention, driving up the cost of care and placing the patients at greater risk. Medicare case mix index, a measure of severity of illness, was 1.143 for CCTA and 0.850 for SOC ($p < .001$). This difference in case mix index indicated that patients admitted after CCTA evaluation were more severely ill on average and provided evidence of the need for a hospital stay.

Two Midnight Rule

Our two midnight rule model results were similar. Our predicted (risk adjusted) cost of care was 1.57 times higher for SOC than for CCTA ($p < .001$). Modeled costs (non-risk adjusted) were \$1,238 per case for CCTA as opposed to \$1,633 when SOC was used (see Appendices S3 and S4: Details of Observation Model Outcomes). Based on our model results, 31% of CCTA and 51% of SOC patients were cared for as observation. Twelve percent of the SOC and 4% of the CCTA cases remained inpatient.

CCTA Results

About one-third of the population had coronary artery disease, including obstructive or nonobstructive CAD (see Electronic Content 4, Appendix S5: CCTA Results on Level of Obstructive Disease).

DISCUSSION

Previous Challenges Assessing Costs

Coronary computed tomography angiography multicenter clinical trials (Hoffman et al. 2009, 2012; Goldstein et al. 2011; Litt et al. 2012) reported inconsistent cost findings because RTC study designs did not account for variability of operations encountered daily in real-life clinical settings. Institutional study operating hours varied. Resources reserved for patients during clinical trials may not have been routinely available in the ED. For example, rapid access to cardiologist and nuclear SPECT imaging may not be financially feasible for routine ED operations during off hours. Multicenter trials can add to the confusion, because hospital costs and medical practices vary geographically, making overall performance less generalizable and more difficult to interpret (Fisher et al. 2003). Moreover, the major clinical trial studies measured costs inconsistently. Goldstein et al. applied a site-specific Medicare ratio of costs to charges (RCCs) but did not include inpatient costs once a diagnosis was made (Goldstein et al. 2011). Variations in hospital charging systems, pricing, and charge capture have been well documented and yield inconsistencies in Medicare RCCs across hospitals. Omitting inpatient costs incurred after diagnosis from cost analysis does not reflect the true costs of treating patients. Hoffman et al. measured costs using individual hospital's cost accounting systems but included only 65% of the patients. The SOC varied among study hospitals, so comparisons reported by the trial are less meaningful. The financial impact of the change in inpatient/outpatient mix from using CCTA was not clearly assessed: 47% of CCTA and 12% of SOC were discharged from the ED. As the cost of admitted patients was significantly higher than for those treated and released, we would have expected the overall cost per case to be lower for CCTA than for SOC. Longer stays carrying significantly higher labor costs appear not to have been recognized because no adjustment for inpatient/outpatient mix was presented or discussed (Hoffman et al. 2012).

Understanding Costs

Recently the American College of Cardiology and the American Heart Association formally recognized the importance of assessing both cost and quality of medical outcomes, when establishing clinical practice guidelines (Anderson et al. 2014). A key economic principle was recognizing resource scarcity.

Introduction of new medical interventions involves opportunity cost. We must maximize the value of our medical expenditures and recognize the societal cost of care. Simply shifting costs from one party to another (e.g., insurer to provider) does not decrease societal cost of health care.

Medicare reimbursement is a reasonable starting point for assessing societal cost. National pricing policy strongly influences private payer pricing; indeed, many private insurers apply models developed and used by CMS. Medicare reimbursement is a benchmark from which most financial managers can reliably estimate private insurance pricing; and using Medicare rates eliminates variability resulting from using multiple U.S. hospital cost accounting systems. Our study's assessment of societal cost begins with traditional care and progresses to changes in reimbursement policy. Value-based reimbursement with risk sharing will increase the benefit of CCTA, because providers will no longer have financial incentives to admit or observe patients unnecessarily.

CCTA Reduced Costs by Increasing Certainty

Coronary computed tomography angiography reduced costs by stabilizing health care utilization patterns, applying a consistent workup with strong evidence base, and improving the understanding of patient status. Most CCTA patients were discharged from the ED after one imaging examination: CCTA (see Figure 2). Many SOC patients received multiple imaging examinations, and 40% were admitted. Final diagnoses of chest pain accounted for more than half of the SOC admissions.

Most SOC patients were admitted due to uncertainty of cardiac status. CCTA reduced admissions by providing a rapid, definitive diagnosis. Low-risk patients' incidence of heart attack is small, but the consequences for affected patients are disastrous. Many hospitals that are unable to offer routine stress testing admit patients when there is not any definitive explanation of their chest pain (Berstein et al. 2009; Winchester et al., 2012; Sun et al. 2013; Edmondson et al. 2013). But this defensive approach is no longer encouraged.

CCTA and Impact of Two Midnight Rule: Societal Cost Shifts

In 2010, CMS expanded the Recovery Audit Contractor (RAC) Program, as required by Section 6411 of the Affordable Care Act. According to AHA

surveys with 1,233 hospital respondents in the fourth quarter of 2012 (American Hospital Association 2014), RAC audits adopted a strong focus on denials of short-stay inpatient cases. Sixty-eight percent of the denials (\$143 million) were from care provided in the wrong setting, that is, inpatient. The most frequently denied inpatient cases from this group were Medicare DRG 247, percutaneous cardiovascular procedure with drug-eluting stent. The third most common was Medicare DRG 313, chest pain. In 2013, CMS introduced the two midnight rule to redefine criteria for inpatient stay. Physicians were required to predict and document that a patient stay of two or more midnights was necessary to qualify for inpatient care. Patients who are expected to stay for fewer than two midnights would be billed as outpatient or observation cases (Department of Health and Human Services Centers for Medicare and Medicaid Services 2013).

Implementation of the two midnight rule posed challenges for many hospitals. EDs experiencing crowding cannot consistently observe patients for the 8–48 hours often necessary for SOC protocol. Because many hospitals are not equipped to perform stress testing during the weekend or in the evening, patients' hospital stays are extended when they present to the ED during these "off hours." Hospitals with limited or no ED observation units may choose to use inpatient accommodations to observe patients until assessment is completed. When this occurs, insurers benefit from the reduction in cost if the two midnight rule is applied, even as patients' out-of-pocket costs increase due to changes in copayment; and providers, who must still offer safe care, receive reduced reimbursement with no change in expense. Changing only the method of reimbursement does not reduce societal cost.

Coronary computed tomography angiography decreased hospital financial losses in our two midnight rule model because the majority of CCTA patients were already classified as outpatient. CCTA limited the cost-shifting effects, from the insurer to the provider and patient, by reducing the real cost of evaluating patients.

Application to a Larger Population

Although reform is moving aggressively toward changing the infrastructure of the U.S. health care delivery model, there is a lack of focus on reducing costs of treatment. Seventy percent of annual health care cost growth can be attributed to rising cost of treatment, as opposed to increase in the proportion of chronically ill in our aging population (Starr, Dominiak, and

Aizcorbe 2014). Therefore, innovations that reduce cost of treatment are arguably just as important, or more so, as restructuring the delivery system to reduce health care costs. Using CCTA to triage chest pain is an example of an innovation that efficiently addresses an expensive and common symptom that is evaluated inconsistently.

Centers for Medicare and Medicaid Services Recovery Audit Contractors identified and denied many low-risk/extreme consequences short-stay admissions (frequently including diagnoses such as syncope, chest pain, transient ischemia, and esophagitis in their denials of appropriate patient status), leading up to the establishment of the two midnight rule (Winchester et al. 2012). However, lacking diagnostic tools to mitigate uncertainty when pretest probability of disease is low and consequences of misdiagnoses are grave, this policy forces providers and patients to adopt a higher level of risk or cost, as insurers' payments are reduced. Yet there is no evidence that increasing risk of poor outcomes will reduce overall societal cost. These facts justify incentivizing innovation in health care treatment, as opposed to system redesign alone. Innovation offers the potential advantage of developing diagnostic and treatment tools that may generate improved results at a lower overall cost. Such policy may also prevent unintended consequences of regulating without complete understanding of resulting financial incentives.

Healthy Populations

In 2009, the United States spent \$121.2 billion on cardiovascular disease (Venkatesh et al. 2011). About one-third of our low-to-intermediate-risk chest pain population was diagnosed with coronary artery disease. Currently, evidence is emerging that patients evaluated with CCTA do better over the longer term. For example, the promise trial documented significantly fewer deaths and nonfatal AMIs for symptomatic outpatients evaluated with CCTA, as opposed to cardiac stress tests after 1 year (Douglas et al. 2015). CCTA provides a definitive anatomical diagnosis of coronary artery disease, allowing physicians to select the most appropriate patient care and site of service after evaluation. Because CCTA promotes awareness and reduces MACE, its use for chest pain evaluation has the potential to reduce cardiovascular disease mortality, currently the leading cause of death in the United States (Hoyert and Xu 2012).

Study Limitations

Observational analyses require statistical applications to control for biases in the data. Our modeling of the two midnight rule performance left us unable to incorporate physician input. Nevertheless, the results are credible, given our experience with this patient population and adherence to CMS instructions. Our 30-day analysis captured only patients who returned for follow-up to our hospital network and therefore may not have reflected all resources utilized. This is a single center trial, although the large volume allowed us to evaluate financial performance. Finally, substituting reimbursement rates for costs masked details of cost performance that support the efficacy of the use of CCTA in the ED operations, where savings in the reduction of average length of stay are not fully quantified. While there is additional valuable information to report on CCTA efficiencies, the potential for financial efficiencies related to safely reducing inpatient stays while improving diagnostic information is of utmost importance as we transition our focus to population health.

CONCLUSION

Using new information technology can facilitate building and utilizing registry data to evaluate cutting-edge medical technologies that improve quality and lower cost. There is increasing emerging evidence that CCTA is such a technology for evaluating emergent low-risk chest pain patients.

ACKNOWLEDGMENTS

Joint Acknowledgment/Disclosure Statement: The research was prepared at Stony Brook Medicine, Department of Radiology under the supervision of Dr. Michal Poon. Dr. Poon provided access to the medical data examined. Dr. Noack provided access to the financial data examined. Drs. Noack and Moore were employees of Stony Brook Radiology for the purpose of research. This study was funded by a donation from the Dalio Center for Research and Wellness in Cardiovascular Medicine.

Disclosures: None.

Disclosure: None.

REFERENCES

- American Hospital Association. "RAC TRAC Exploring the Impact of the RAC Program on Hospitals Nationwide" [accessed on July 20, 2014]. Available at <http://www.aha.org/advocacy-issues/rac/ractrac.shtml>
- American Medical Association. "About CPT" [accessed on May 12, 2014]. Available at <http://www.ama-assn.org/ama/pub/physician-resources/solutions-managing-your-practice/coding-billing-insurance/cpt/about-cpt.page?>
- Anderson, J. L., P. A. Heindenreich, P. G. Barnett, M. A. Creager, G. C. Fonarow, R. J. Gibbons, J. L. Halperin, M. A. Hlatky, A. K. Jacobs, D. B. Mark, F. A. Masoudi, E. D. Peterson, and L. J. Shaw. 2014. "ACC/AHA Statement on Cost/Value Methodology in Clinical Practice Guidelines and Performance Measures." *Journal of the American College of Cardiology* 63: 2304–22.
- Barish, R. A., P. L. McGauley, and T. C. Arnold. 2012. "Emergency Room Crowding: A Marker of Hospital Health." *Transactions of the American Clinical and Climatological Association* 123: 304–11.
- Baron, R. M., and D. A. Kenny. 1986. "The Moderator-Mediator Variable Distinction in Social Psychological Research: Conceptual, Strategic, and Statistical Considerations." *Journal of Personality and Social Psychology* 51: 1173–82.
- Berstein, S. L., D. Aronsky, R. Duseja, S. Epstein, D. Handel, U. Hwang, M. McCarthy, K. J. McConnell, J. M. Pines, N. Rathley, R. Schafemeyer, F. Zweimer, M. Schull, and B. R. Aspin. 2009. "The Effect of Emergency Department Crowding on Clinically Oriented Outcomes." *Academic Emergency Medicine* 16 (1): 1–10.
- Besag, J. 1975. "Statistical Analysis of Non-Lattice Data." *Statistician* 24 (3): 179–95.
- Bhuiya, F. A., S. R. Pitts, and L. F. McCaig. 2010. "Emergency Department Visits for Chest Pain and Abdominal Pain: United States, 1999–2008." *National Center for Health Statistics Data Brief* 43: 1–8.
- Centers for Medicare and Medicaid Services. 2013a. "FY 2013 Final Rules Tables" [accessed on April 10, 2014]. Available at <http://www.cms.gov/Medicare/Medicare-Fee-for-Service-Payment/AcuteInpatientPPS/FY-2013-IPPS-Final-Rule-Home-Page-Items/FY2013-Final-Rule-Tables.html>
- Centers for Medicare and Medicaid Services. 2013b. "Medicare Program, Hospital Inpatient Prospective Payment Service for Acute Care Hospitals and Long-Term Care Hospitals Prospective Payment System and Fiscal Year 2014 Rates; Quality Reporting Requirements for Specific Providers; Hospital Conditions of Participation; Payment Policies Related to Patient Status" [accessed on May 15, 2014]. Federal Register. Available at www.federalregister.gov/2013-18956
- Centers for Medicare and Medicaid Service. 2014. "National Health Expenditures 2012 Highlights." Baltimore, MD: CMS [accessed on July 15, 2014]. Available at <https://www.cms.gov/research-statistics-data-and-systems/statistics-trends-and-reports/nationalhealthexpenddata/downloads/proj2012.pdf>
- Department of Health and Human Services Centers for Medicare and Medicaid Services. 2013. "Medicare Program; Hospital Inpatient Prospective Payment System for Acute Care Hospitals and the Long-Term Care Hospital Prospective

- Payment System and Fiscal Year 2014 Rates; Quality Reporting Requirements for Specific Providers; Hospital Conditions of Participation; Payment Policies Related to Patient Status." *Federal Register* 78 (160): 50938–54.
- Douglas, P. S., U. Hoffmann, M. R. Patel, D. B. Mark, H. R. Al-Khalidi, B. Cavanaugh, J. Cole, R. J. Dolor, C. B. Fordyce, M. Huang, M. A. Khan, A. S. Kosinski, M. W. Krucoff, V. Malhotra, M. H. Picard, J. E. Udelson, E. J. Velazquez, E. Yow, L. S. Cooper, and K. L. Lee. 2015. "Outcomes of Anatomical versus Functional Testing for Coronary Artery Disease." *New England Journal of Medicine* 372: 1291–300.
- Edmondson, D., S. Daichi, S. Ye, P. Wyer, and K. W. Davidson. 2013. "Emergency Department Crowding During Treatment for Acute Coronary Syndrome Predicts Subsequent Posttraumatic Stress Disorder Symptoms." *Journal of the American Medical Association Internal Medicine* 173 (6): 472–4.
- Fisher, E. S., D. E. Wennberg, T. A. Stukel, D. J. Gottlieb, F. L. Lucas, and E. L. Pinder. 2003. "The Implications of Regional Variations in Medicare Spending. Part 1: The Content, Quality, and Accessibility of Care." *Annals of Internal Medicine* 138: 273–87.
- Furtado, M. V., A. Cardoso, M. C. Patricio, A. P. Rossini, R. B. Campani, C. Meotti, L. A. Nasi, and C. A. Polanczyk. 2011. "Influence on Implementation of a Chest Pain Unit on Acute Coronary Syndrome Outcomes." *Journal of Emergency Medicine* 40 (5): 557–64.
- Goldstein, J. A., K. M. Chinnaiyan, A. Abidov, S. Achenbach, D. S. Berman, S. W. Hayes, U. Hoffmann, J. R. Lesser, I. A. Mikati, B. J. O'Neil, L. J. Shaw, M. Y. Shen, U. S. Valeti, and G. L. Raff. 2011. "The CT-STAT (Coronary Computed Tomographic Angiography for Systematic Treatment of Acute Chest Pain Patients to Treatment) Trial." *Journal of the American College of Cardiology* 58 (14): 1414–22.
- Guttman, A., M. J. Schull, M. J. Vermeulen, and T. A. Stukel. 2011. "Association between Waiting Times and Short Term Mortality and Hospital Admission after Departure from Emergency Department: Population Based Cohort Study from Ontario, Canada." *British Medical Journal* 342: d2983.
- Hendel, R. C., M. R. Patel, C. M. Kramer, M. Poon, J. C. Carr, N. A. Gerstad, L. D. Gil- lam, J. M. Hodgson, R. J. Kim, J. R. Lesser, E. T. Martin, J. V. Messer, R. F. Red- berg, G. D. Rubin, J. S. Rumsfeld, A. J. Taylor, W. G. Weigold, P. K. Woodard, R. G. Brindis, P. S. Douglas, E. D. Peterson, M. J. Wolk, and J. M. Allen. 2006. "ACCF/ACR/SCCT/SCMR/ASNC/NASCI/SCAI/SIR 2006 Appropriateness Criteria for Cardiac Computed Tomography and Cardiac Magnetic Resonance Imaging: A Report of the American College of Cardiology Foundation Quality Strategic Directions Committee Appropriateness Criteria Working Group, American College of Radiology, Society of Cardiovascular Computed Tomog- raphy, Society for Cardiovascular Magnetic Resonance, American Society of Nuclear Cardiology, North American Society for Cardiac Imaging, Society for Cardiovascular Angiography and Interventions, and Society of Interventional Radiology." *Journal of the American College of Cardiology* 48 (7): 1475–97.
- Hoffman, U., F. Bamberg, C. U. Chae, J. H. Nichols, I. S. Rogers, S. K. Seneviratne, Q. A. Truong, R. C. Cury, S. Abbata, M. J. Shapiro, J. Butler, M. Ferencik, L. Hang,

- I. Jang, B. A. Parry, D. F. Brown, J. E. Udelson, S. Achenbach, T. J. Brady, and J. T. Nagurney. 2009. "Coronary Computed Tomography Angiography for Early Triage of Patients with Acute Chest Pain – The Rule Out Myocardial Infarction Using Computer Assisted Tomography (ROMICAT) Trial." *Journal of the American College of Cardiology* 53 (18): 1642–50.
- Hoffman, U., Q. A. Truong, D. A. Schoenfeld, E. T. Chou, P. K. Woodard, J. T. Nagurney, J. H. Pope, T. H. Hauser, C. S. White, S. G. Weiner, S. Kalanjan, M. E. Mullins, I. Mikati, W. F. Peacock, P. Zakrofsky, D. Hayden, A. Goehler, H. Lee, S. Gazelle, S. D. Wiviott, J. L. Fleg, and J. L. Udelson. 2012. "Coronary CT Angiography versus Standard Evaluation in Acute Chest Pain." *New England Journal of Medicine* 367 (4): 299–308.
- Hoyert, D. L., and J. Xu. 2012. "Deaths: Preliminary Data for 2011." *National Vital Statistics Reports* 61 (6): 1–51.
- Krumholz, H. M. 2014. "Big Data and New Knowledge in Medicine: The Thinking, Training, and Tools Needed for a Learning Health System." *Health Affairs* 33 (7): 1163–70.
- Litt, H. I., C. Gatsonis, B. Snyder, H. Singh, C. D. Miller, D. W. Entrikin, J. M. Leaming, L. J. Gavin, C. B. Pacella, and J. E. Hollander. 2012. "CT Angiography for Safe Discharge of Patients with Possible Acute Coronary Syndromes." *New England Journal of Medicine* 366 (15): 1393–403.
- Marko, N. F., and J. Weil. 2010. "The Role of Observational Investigations in Comparative Effectiveness Research." *Value Health* 13 (8): 989–97.
- MedPac. 2013. *Medicare Payment Basics: Outpatient Hospital Services Payment System. Payment Basics*. Washington, D.C.: MedPac [accessed on May 12, 2014]. Available at http://www.medpac.gov/documents/MedPAC_Payment_Basics_13_OPD.pdf
- Niska, R., F. Bhuiya, and J. Xu. 2010. "National Hospital Ambulatory Medical Care Survey: 2007 Emergency Department Summary." *National Health Statistics Reports* 26: 1031.
- Owens, P. L., M. L. Barrett, T. B. Gibson, R. M. Andrews, R. M. Weinick, and R. L. Mutter. 2010. "Emergency Department Care in the United States: A Profile of National Data Sources." *Annals of Emergency Medicine* 56 (2): 150–65.
- Poon, M., M. Cortegiano, A. Abramowicz, M. Hines, A. J. Singer, M. C. Henry, P. Viccellio, J. C. Hellinger, S. Ferraro, A. Poon, G. L. Raff, S. Voros, M. E. Farkouh, and P. Noack. 2013. "Association between Routine Coronary Computed Tomographic Angiography and Reduced Unnecessary Hospital Admissions, Length of Stay, Recidivism Rates, and Invasive Coronary Angiography in the Emergency Department Triage of Chest Pain." *Journal of the American College of Cardiology* 62 (6): 543–52.
- Priest, V. L., P. A. Schuffham, R. Hachamovitch, and T. H. Marwick. 2011. "The Cost Effectiveness of Coronary Computed Tomography and Cardiac Stress Imaging in the Emergency Department: A Decisional Analytic Model Comparing Diagnostic Strategies for Chest Pain in Patients at Low Risk for Acute Coronary Syndrome." *Journal of American College of Cardiology Cardiovascular Imaging* 4 (5): 549–56.
- Rubinshtein, R., D. A. Halon, T. Gaspar, R. Jaffe, B. Karkabi, M. Y. Flugelman, R. Shapira, N. Peled, and B. S. Lewis. 2007. "Usefulness of 64 Slice Cardiac Computed

- Tomographic Angiography for Diagnosing Acute Coronary Syndromes and Predicting Clinical Outcome in Emergency Department Patients with Chest Pain of Uncertain Origin." *Circulation* 115 (13): 1762–8.
- Sabbatini, A. K., B. K. Nallamothu, and K. E. Kocher. 2014. "Reducing Variation in Hospital Admissions from the Emergency Department for Low-Mortality Conditions May Produce Savings." *Health Affairs* 33 (9): 1655–63.
- Starr, M., N. Dominiak, and A. Aizcorbe. 2014. "Decomposing Growth in Spending Finds Annual Cost of Treatment Contributing Most to Spending Growth." *Health Affairs* 33 (5): 823–31.
- Sun, B. C., R. Y. Hsia, R. E. Weiss, D. Zingmond, L. J. Liang, W. Han, H. McCreath, and S. M. Asch. 2013. "Effect of Emergency Department Crowding on Outcomes of Admitted Patients." *Annals of Emergency Medicine* 61 (6): 605–11.
- Taylor, A. J., M. Cerqueira, J. M. Hodgson, D. Mark, J. Min, P. O'Gara, G. D. Rubin, C. M. Kramer, D. Berman, A. Brown, F. Chaudhry, R. C. Cury, M. Y. Desai, A. J. Einstein, A. S. Gomes, R. Harrington, U. Hoffmann, R. Khare, J. Lesser, C. McGann, A. Rosenberg, R. Schwartz, M. Shelton, G. W. Smetana, S. C. Smith, M. J. Wolk, J. M. Allen, S. Bailey, P. S. Douglas, R. C. Hendel, C. M. Kramer, J. M. Min, M. R. Patel, L. Shaw, and R. F. Stainback. 2010. "ACCF/SCCT/ACR/AHA/ASE/ASNC/NASCI/SCAI/SCMR 2010 Appropriate Use Criteria for Cardiac Computed Tomography. A Report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, the Society of Cardiovascular Computed Tomography, the American College of Radiology, the American Heart Association, the American Society of Echocardiography, the American Society of Nuclear Cardiology, the North American Society for Cardiovascular Imaging, the Society for Cardiovascular Angiography and Interventions, and the Society for Cardiovascular Magnetic Resonance." *Journal of the American College of Cardiology* 56 (22): 1864–94.
- Venkatesh, A. K., B. P. Geisler, J. J. Gibson Chambers, C. W. Baugh, S. Bohan, and J. D. Schuur. 2011. "Use of Observation Care in US Emergency Departments, 2001 to 2008." *Public Library of Science One* 6 (9): e24326.
- Winchester, D. E., P. Jois, S. M. Kraft, D. Wymer, and J. A. Hill. 2012. "Immediate Computed Tomography Coronary Angiography Versus Delayed Outpatient Stress Testing for Detecting Coronary Artery Disease in Emergency Department Patients with Chest Pain." *International Journal of Cardiovascular Imaging* 28: 667–74.

SUPPORTING INFORMATION

Additional supporting information may be found online in the supporting information tab for this article:

Appendix SA1: Author Matrix.

Appendix S1: Reimbursement Definitions.

Appendix S2: Details of Statistical Analyses.

Appendix S3: Details of Observation Model Outcomes.

Appendix S4: Distribution of Patient Status under the Two Midnight Rule.

Appendix S5: CCTA Results on Level of Obstructive Disease.