



The direct costs of coronary CT angiography relative to contrast-enhanced thoracic CT: Time-driven activity-based costing

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ABSTRACT

Background: Coronary CT angiography (CCTA) and contrast-enhanced thoracic CT (CECT) are distinctly different diagnostic procedures that involve intravenous contrast-enhanced CT of the chest. The technical component of these procedures is reimbursed at the same rate by the Centers for Medicare and Medicaid Services (CMS). This study tests the hypothesis that the direct costs of performing these exams are significantly different.

Methods: Direct costs for both procedures were measured using a time-driven activity-based costing (TDABC) model. The exams were segmented into four phases: preparation, scanning, post-scan monitoring, and image processing. Room occupancy and direct labor times were collected for scans of 54 patients (28 CCTA and 26 CECT studies), in seven medical facilities within the USA and used to impute labor and equipment cost. Contrast material costs were measured directly. Cost differences between the exams were analyzed for significance and variability.

Results: Mean CCTA duration was 3.2 times longer than CECT (121 and 37 min, respectively, $p < 0.01$). Mean CCTA direct costs were 3.4 times those of CECT (\$189.52 and \$55.28, respectively, $p < 0.01$). Both labor and capital equipment costs for CCTA were significantly more expensive (6.5 and 1.8-fold greater, respectively, $p < 0.001$). Segmented by procedural phase, CCTA was both longer and more expensive for each ($p < 0.01$). Mean direct costs for CCTA exceeded the standard CMS technical reimbursement of \$182.25 without accounting for indirect or overhead costs.

Conclusion: The direct cost of performing CCTA is significantly higher than CECT, and thus reimbursement schedules that treat these procedures similarly undervalue the resources required to perform CCTA and possibly decrease access to the procedure.

Introduction

Coronary CT Angiography (CCTA) is gaining acceptance as a primary, and in some cases, preferred diagnostic test for assessing coronary artery

disease.¹ Recent meta-analyses and large prospective randomized clinical trials have demonstrated among other favorable qualities a decrease in subsequent myocardial infarctions and hospital visits compared with functional stress testing in evaluating chest pain in the setting of

Abbreviations: APC, Ambulatory payment classification; CCR, Cost-to-charge ratio; CCTA, Coronary CT angiography; CECT, Contrast-enhanced chest CT; CPT, Current procedural terminology; CMS, Centers for Medicare & Medicaid Services; OPPS, Outpatient Prospective Payment System; RVU, Relative Value Unit; TDABC, Time-driven activity-based costing.

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suspected CAD.^{2–4} In spite of these results, CCTA is underutilized relative to functional stress testing. To facilitate wider adoption of CCTA, payment amounts should reflect the total cost of providing the test.

CCTA and contrast-enhanced chest CT (CECT) are both widely used diagnostic tests in the assessment of thoracic disease. Because of the greater complexity in achieving diagnostic quality images for assessing coronary artery disease, CCTA is a more resource-intensive exam to perform. This primarily relates to pre-scan pharmacologic preparation for heart rate control, differences in personnel involved, greater complexity of ECG-gated CT acquisition, and post-processing required for optimal assessment of the coronary arteries. In addition, CCTA requires the use of more sophisticated (and costly) scanners, specially-trained technologists, and the use of additional nursing staff to monitor patients before and during image acquisition. Currently, the Centers for Medicare & Medicaid Services (CMS) national outpatient prospective payment system (OPPS) global facility price without modifiers for CECT (CPT 71260) is \$246.13, while the global price for CCTA without modifiers (CPT 75574) is \$303.15.⁵ Global payment without modifiers is inclusive of both the professional and technical components of performing a procedure. However, because these tests both fall under the same ambulatory payment classification (APC), the technical components of these procedures start from the same national baseline of \$182.25 under the OPPS schedule. In calculating final reimbursement, a portion of this national baseline payment is adjusted by the hospital wage index for the area in which the scan was performed, as well as by a variety of other factors such as pass-through drugs and biologics, rural adjustments, and adjustments for certain cancer hospitals among others.⁵ Note that this APC-based payment system is applied only to hospitals, not to non-hospital outpatient centers. The technical component of a service refers to the labor, supplies, and equipment related to performance of the exam itself. When considering the relative complexity of performing the procedures, our hypothesis is that these technical reimbursement figures undervalue the direct cost of CCTA relative to CECT.

Historically, the cost of medical procedures has most commonly been estimated using relative value unit (RVU) based costing or a cost-to-charge ratio (CCR), which generally impute departmental cost and an institutional overhead on the basis of risk-adjusted RVUs or a standardized charge schedule, respectively. Unfortunately, such top-down approaches suffer from the fact that true resource use is not captured and substantial cost distortions are introduced.⁶ Activity-based costing is a bottom-up cost measurement tool that derives cost from resource consumption and has been widely used to measure direct costs.⁷ Time-driven activity-based costing (TDABC) models time as the fundamental driver of cost for all resources consumed except supplies, which are applied directly to the process. With collection of the necessary time data, TDABC models can be used to analyze individual procedures, episodes of care, or entire care pathways.^{6,8,9} Such analyses have been previously used to model varying aspects of the radiology value-chain.^{7,10,11}

The aim of this study was to assess the direct cost of performing the technical components of CCTA and CECT in the outpatient setting, and to examine whether Medicare technical reimbursement as listed in CMS payment schedules aligns with the relative direct cost of performance.

Materials and methods

This study was reviewed and granted exempt status by the institutional review board. The procedures to be analyzed were identified as CCTA (CPT code 75574) and CECT (CPT code 71260). Only direct costs associated with the technical component of these procedures were considered for this analysis. The scheduling, interpretation, and post-exam follow-up components of workflow were excluded from this study. Inclusion criteria for both CCTA and CECT included outpatient assessment and a patient age of 50 years or greater. The primary indication for all CCTA was evaluation for suspected coronary artery disease. Patients with prior cardiac surgery, coronary artery stents, structural

heart disease, or congenital heart disease were excluded from this study to limit exam complexity. Data were collected from 28 CCTA and 26 CECT procedures performed at seven medical centers (Brigham and Women's Hospital, Cardiovascular Management Institute of Illinois, Duke University Medical Center, Loyola University Hospital of Chicago, Massachusetts General Hospital, Miami Cardiac & Vascular Institute, and Scripps Clinic Medical Group) located in California, Florida, Illinois, Massachusetts, and North Carolina during February 2020.

Four major workflow phases for the performance of CCTA and CECT were defined as follows (Fig. 1):

- 1 **Patient Preparation** encompassed all activities after initial admission to a pre-procedural area until the patient transfers to the CT scan room. This phase included the administration of beta blockers, long-acting nitrates, and vital sign monitoring.
- 2 **CT Exam** encompasses all activities between the moment the patient enters the CT scan room and the moment that they leave after completing the scan. It includes the planning and acquisition of the CT scan and associated administration of intravenous iodinated contrast material and short-acting nitrates, when appropriate.
- 3 **Post-Exam Monitoring** begins when the patient leaves the CT scan room and ends when the patient leaves the imaging department and encompasses post-scan monitoring to ensure safe discharge after receiving beta blockers and nitrates.
- 4 **Post-Processing** encompasses the preparation of specialized visualizations, including multi- and curved planar reformations, maximum intensity projections, and volume renderings. Note that this excluded interpretation and activities captured by the professional component of reimbursement.

Data collection

A single observer was designated at each site to collect the data through direct observation of the procedures. The total time required to complete each step of the workflow was measured to the nearest minute. Effort was measured for all personnel involved in each step of the procedure including nurses, radiology technologists, aides, MDs, or MD trainees involved in each study. MD effort was largely consultative to support nurses or technologists as needed and thus not billable professionally. MD trainees supplemented nursing effort at some sites. Effort was recorded to the nearest minute or estimated as closely as possible based on direct observation when encounters involved rapid entry and exit during the procedure. The resulting time-based effort data were multiplied by cost per minute figures specific to the type of personnel, inclusive of both wages and benefits, to calculate the cost of physician and non-physician labor.

Labor cost rate determination

To estimate the hourly cost of non-physician labor, May 2018 Bureau of Labor Statistics (BLS) data in the Occupational Employment Statistics Query System was used.¹² The categories queried by state to estimate mean hourly wages for radiology technologists, nurses, and other non-MD staff were “radiologic technologists and technicians”, “registered nurses”, and “healthcare support workers, all other,” respectively. Benefits were calculated using BLS data from December 2019 by multiplying the ratio of national average hourly benefits to national average hourly wages from the “non-physician health care and social assistance” category of labor by estimated hourly wage.

To calculate the costs of attending physician labor, 2019 average annual salaries from Medscape 2019 physician compensation reports were used.¹³ Sites used both cardiologists and radiologists in different proportions; the applicable salary figures were applied in proportion to the division of labor for each site. To calculate trainee physician labor,

Outpatient CCTA and CECT Technical Workflow

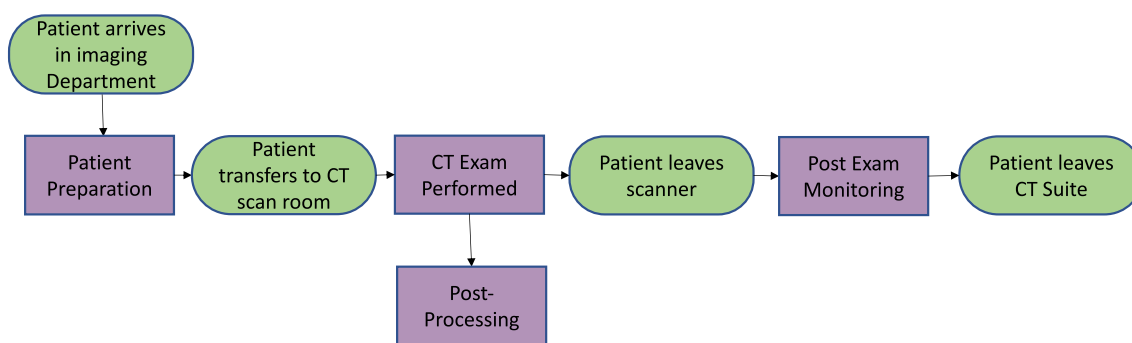


Fig. 1. CCTA and CECT workflow. Ovals represent patient movement, and rectangles represent activity at each step of the exam.

national average annual trainee salaries in radiology and cardiology from the Medscape Residents Salary & Debt Report 2018 were used.¹⁴ As state-level figures for attending and trainee compensation were not available, these national-level figures were chosen instead. A single source was chosen for trainees in both fields to ensure that the methodology of collecting data for both types of trainees was consistent. Both attending and trainee positions assumed a 2,080 h work year (52 weeks at 40 h per week) to calculate the hourly figure, and both used a standard overhead of 26% of wages to calculate hourly benefits cost. The resulting hourly benefits cost and wage estimates were summed to arrive at a total cost per hour figure for each physician and trainee. Physician and non-physician efforts were summed to calculate total labor cost per procedure.

Equipment and service cost rate determination

CT scanner depreciation cost was calculated using data from Becker's Hospital Review.¹⁵ As all CT scanners used for this study were late-model devices, vendor quoted equipment prices and annual service costs for premium CT scanners approximated the basis for actual equipment and service costs. Time-based equipment costs were derived using straight-line depreciation with an estimated useful life of ten years and residual value of \$300,000. To estimate an hourly cost, each machine was assumed to be active for fifty-two weeks per year, five days per week, and an average of 10 h per day. Depreciation cost was allocated by multiplying the estimated depreciation per minute by the number of minutes that the patient was in the CT scan room.

Annual service cost was likewise calculated using an hourly estimate based on fifty-two active weeks per year at five days per week with an average of 10 h per day. The cost of contrast used in each procedure was calculated for each site using institutional payment data and included in the cost each case.

One site used an offsite contractor for image processing, and the cost of that service was included in the total cost of processing for that stage of the site's total.

Total direct procedural cost determination

The total direct cost of each procedure was calculated by adding CT depreciation, service cost, contrast material, and labor cost as described previously. Of the 28 CCTA scans, nitroglycerin was used in all 28. Beta blockers were used in 15 scans, and intentionally not used in 6 scans. In the remaining 7 scans, patient identifying information was not logged with data collection and thus beta blocker use could not be determined. The cost of any beta blockers and nitrates used was presumed to be de minimis, so was not included in calculations of total cost.

Analysis

Due to the skewed distribution of the data collected, Mann-Whitney U-tests were performed to evaluate the statistical significance of cost differences between the 28 CCTA and 26 CECT studies included in this analysis. These comparisons include the total cost of equipment per procedure including both depreciation and service cost, the cost of contrast, and labor costs associated with pre-exam preparation, scan performance, post-exam monitoring, and image post-processing. Additionally, Mann-Whitney U-tests were performed to compare the total expense of each labor subcategory such as technologists, nurses, etcetera. A final set of tests was performed comparing the total cost of the whole procedure including both labor and equipment for CCTA and CECT. All tests used a significance cutoff value of $p < 0.05$. Arithmetic means were calculated for the purpose of illustrating and presenting data. Due to the use of nonparametric statistical tests for significance, data dispersion, where indicated, is presented as the interquartile range (IQR).

Results

Performing CCTA required significantly more time than CECT with a median duration of 107 (IQR = 87–148) minutes compared to 30 (IQR = 17–36) minutes, respectively ($p < 0.0001$). Moreover, each of the four exam phases were significantly longer for CCTA than for CECT ($p < 0.0001$). Median durations of CCTA by phase were 64.5, 28, 10, and 19 min for pre-CT prep, CT scan time, post-exam monitoring, and post-processing, respectively. The same four phases for CECT had median durations of 7, 15, 0, and 0 min, respectively. The pre-procedure stage was significantly longer for CCTA than CECT because of the need to assess heart rate and blood pressure and subsequently administer oral beta blockers with further vital sign monitoring for at least 15 of the 28 subjects. Post-scan monitoring was all but eliminated in CECT, and post-processing activity was likewise minimal for CECT. Fig. 2 presents the mean duration of each phase for the two procedures and the relative contribution of each type of labor to effort for each phase.

The greater duration of CCTA was accompanied by greater labor effort required in all exam phases. Median and mean labor effort in minutes by phase and each personnel type can be seen in Table 1. CCTA required consistently more effort for almost every category of labor time analyzed. The pre-procedure phase involved periods where the patient was waiting for transfer to the scanner suite and was unaccompanied by labor. For CCTA these periods included time required for oral beta blockers to sufficiently reduce heart rate. For both procedures, these time periods were considered “downtime” and thus no direct costs were applied.

Compensation values for non-physician labor in each state represented by sites in this study are presented in Table 2.¹⁶ To construct the

Duration and Labor Utilization for Major Phases of CCTA and CECT

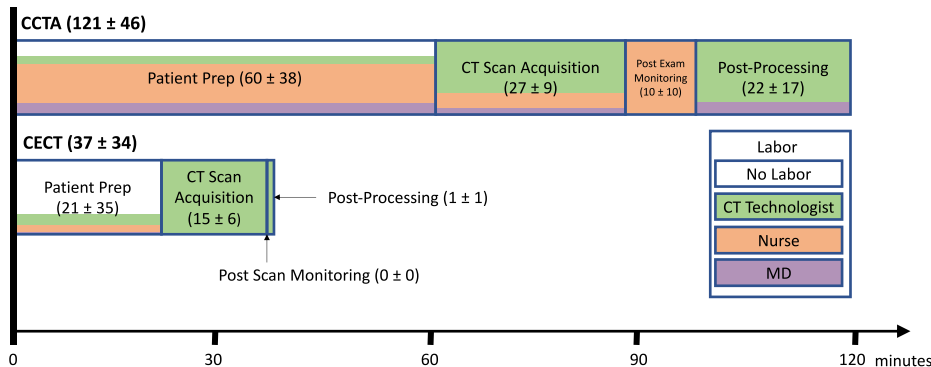


Fig. 2. Mean ($\pm$ s.d.) duration in minutes of four major phases of CCTA and CECT exams across all sites. Colors within each box indicate the mean fractional contribution amongst three major types of labor. “No Labor” (white regions) indicates the minimum amount of time, on average, that no personnel were directly interacting with the patient. This minimum assumes that there is no overlap between staff effort: e.g. given a hypothetical 30 min prep duration, if a nurse works for 10 min and a technologist for 2 with no overlap, at least 18 min of the total prep time was spent without labor effort that would contribute to direct cost. Discrepancies between the sum of the phases for each scan type and the total duration reflect rounding to the nearest minute in each phase.

Table 1

Mean and (median, IQR) labor effort data in minutes for each position and phase of CCTA and CECT. Significance figures reflect results from a Mann-Whitney *U* test, with asterisks indicating statistically significant differences.

Labor Effort by Position and Phase				
Procedure Phase	Position	CCTA	CECT	Significance
Pre-CT Preparation	Nurse	31 (17.5, 6.5–39.5)	1 (0, 0–3.25)	$p < 0.0001^*$
	Technologist	6 (0, 0–16.5)	3 (0, 0–6.25)	$p = 0.9237$
	MD	1 (0, 0–0.75)	0 (0, 0–0)	$p = 0.0104^*$
	MD Trainee	8 (0, 0–2)	0 (0, 0–0)	$p = 0.0648$
	Aide	0 (0, 0–0)	0 (0, 0–0)	$p > 0.9999$
	Other	0 (0, 0–0)	1 (0, 0–0)	$p = 0.0208^*$
CT Scan	Nurse	8 (0, 0–17)	0 (0, 0–0)	$p = 0.0006^*$
	Technologist	28 (25.5, 15–35)	15 (15.5, 9.5–21.25)	$p = 0.0007^*$
	MD	0 (0, 0–0)	0 (0, 0–0)	$p = 0.0235^*$
	MD Trainee	3 (0, 0–0)	0 (0, 0–0)	$p = 0.0519$
	Nurse	10 (10, 0–19.25)	0 (0, 0–0)	$p < 0.0001^*$
	Technologist	20 (15.5, 10–30.25)	1 (0, 0–3.25)	$p < 0.0001^*$
Post-Scan Monitoring Image Processing	MD	1 (0, 0–0)	0 (0, 0–0)	$p = 0.4913$
	MD Trainee	2 (0, 0–0)	0 (0, 0–0)	$p = 0.0519$
	Nurse	51 (51.5, 6.5–75)	3 (2.5, 0–6)	$p < 0.0001^*$
	Technologist	55 (48.5, 38.5–73.75)	20 (19, 14.75–26.25)	$p < 0.0001^*$
	MD	3 (0, 0–5)	0 (0, 0–0)	$p = 0.0045^*$
	MD Trainee	13 (0, 0–2)	0 (0, 0–0)	$p = 0.0648$
Entire Exam (all phases)	Aide	0 (0, 0–0)	1 (0, 0–0)	$p > 0.9999$
	Other	0 (0, 0–0)	0 (0, 0–0)	$p = 0.0208^*$

TDABC model, estimated hourly wages and benefits were summed to yield total hourly labor costs. Direct physician labor was performed by radiologists, cardiologists, radiology trainees, or cardiology trainees at an

Table 2

Hourly wage, benefits, and total cost by state and position.¹² The non-physician healthcare and social assistance category of labor has average total hourly benefits of \$10.64 and an average hourly wage is \$24.67; the ratio of these figures is approximately 0.43.¹⁶ This ratio is multiplied by each of the hourly wage columns in Fig. 3 to arrive at the hourly overhead figures, which is used to calculate the total hourly cost by position. Other healthcare support was a labor category we used for aides and other non-nurse and non-tech support staff. The figure from the corresponding state was used to calculate the labor cost from time data collected at each medical center in this study.

State	Registered Nurse			Radiologic Technologist			Other Healthcare Support		
	Hourly Wage	Benefits	Hourly Total	Hourly Wage	Benefits	Hourly Total	Hourly Wage	Benefits	Hourly Total
CA	\$51.42	\$22.18	\$73.60	\$38.97	\$16.81	\$55.78	\$21.55	\$9.29	\$30.84
FL	\$31.83	\$13.73	\$45.56	\$27.24	\$11.75	\$38.99	\$18.60	\$8.02	\$26.62
IL	\$35.53	\$15.32	\$50.85	\$31.10	\$13.41	\$44.51	\$19.82	\$8.55	\$28.37
MA	\$44.30	\$19.11	\$63.41	\$35.97	\$15.51	\$51.48	\$19.56	\$8.44	\$28.00
NC	\$31.18	\$13.45	\$44.63	\$27.91	\$12.04	\$39.95	\$16.38	\$7.06	\$23.44

estimated mean per-hour cost inclusive of benefits of \$253.82, \$264.29, \$36.77, and \$37.62, respectively.

To determine direct labor cost, labor compensation rates were multiplied by labor utilization. Hourly CT depreciation (\$46.15) and service (\$65.38) costs were multiplied by actual CT scan acquisition time for each case. The longer average CT scan acquisition time found for CCTA versus CECT resulted in higher allocated capital and service costs, despite use of the same equipment and software. Mean and median direct costs are summarized by individual cost object in Table 3.

The median direct costs were \$181.00 (IQR = 124.10–236.20) and \$58.39 (IQR = 39.29–70.05) for CCTA and CECT, respectively (Table 3). Thus, the median direct cost to perform CCTA was approximately three times higher than CECT. Further, the higher cost of CCTA remains significant for total labor, total non-labor, and all more specific sub-categories of cost where a statistically significant difference was found between the two tests.

The mean cost of labor was approximately 6.5 times greater for CCTA than for CECT and was greater during each of the four exam phases as well (Fig. 4). Comparing differences in median total labor cost for statistical purposes, as well as labor cost by phase, shows that each difference is statistically significant ($p < 0.0001$).

Discussion

This TDABC study of direct technical costs for outpatient CCTA and CECT across seven health systems found 3.4-fold greater cost associated with CCTA when compared to CECT. This result stands in stark contrast to the equivalent payment for the technical portion of these exams under the OPSS schedule.

To contextualize the cost findings of this study, it is worth considering the general process by which CMS determines the reimbursement rate for a given hospital OPSS CPT code. OPSS payment provides for the reimbursement of designated hospital outpatient items and services, certain Medicare Part B services for hospital inpatients when Medicare cannot

Table 3

Mean and (median) total cost per case by labor category and non-labor expense for CCTA and CECT. The “other” category of labor costs includes contracted and outsourced post-processing. Significance values are based on non-parametric comparisons, all with $p < 0.05$. Differences with an asterisk are significant.

Direct Cost by Category				
	Expense	CCTA	CECT	Significance
Labor Costs	<i>Technologist</i>	\$43.46 (\$39.90)	\$16.17 (\$15.20)	$p < 0.0001^*$
	<i>Nurse</i>	\$47.82 (\$47.08)	\$2.97 (\$4.56)	$p < 0.0001^*$
	<i>Aide</i>	\$0.03 (\$0)	\$0 (\$0)	$p > 0.9999$
	<i>MD</i>	\$16.21 (\$0)	\$0 (\$0)	$p = 0.0045^*$
	<i>MD Trainee</i>	\$8.30 (\$0)	\$0.12 (\$0)	$p = 0.0648$
	<i>Other</i>	\$14.75 (\$0)	\$0.67 (\$0)	$p = 0.8231$
	Labor Total	\$130.57 (\$113.00)	\$19.94 (\$20.67)	$p < 0.0001^*$
Non-labor Costs	<i>CT Scanner</i>	\$51.12 (\$52.05)	\$27.88 (\$27.88)	$p < 0.0001^*$
	<i>Contrast Material</i>	\$7.83 (\$8.86)	\$7.46 (\$8.86)	$p = 0.6132$
	Non-labor Total	\$58.95 (\$61.37)	\$23.60 (\$36.93)	$p < 0.0001^*$
	Total Costs	\$189.52 (\$181.00)	\$55.28 (\$58.39)	$p < 0.0001^*$

pay Part A, and a number of other outpatient care situations.¹⁷ Both CCTA and CECT CPT codes considered in this study are reimbursed under the OPSS system in the hospital-based outpatient setting. The fundamental driver for reimbursement calculations for technical services provided under OPSS is the APC. This is a system of scaled relative weights intended to group together outpatient procedures that reflect similar clinical characteristics and resource inputs.¹⁸ Most APC's within the OPSS system package the supportive and adjunct services required to provide a given service into a single reimbursement to encourage efficient use of hospital resources. To calculate the specific reimbursement for a service, the APC is multiplied by a conversion factor to arrive at a national payment rate. This rate is then adjusted to reflect local geographic and institutional conditions. These adjustments include the local hospital wage index, urban versus rural status, adjustments for certain cancer centers, outlier payments, and many other factors. Multiple procedure modifications may reduce payment when CCTA or CECT are performed in conjunction with other imaging procedures.

When considering these many adjustment factors, those that relate to local geographic and institutional factors should apply equally to CECT and CCTA that are performed at the same institution. Thus, for this study,

while not factoring in these adjustments adds uncertainty to absolute reimbursement estimates, these factors cancel out when considering relative reimbursement between CECT and CCTA performed at the same institution.

APC assignments for CPT codes paid under OPSS are reviewed on an annual basis based on the latest claims criteria.¹⁹ The OPSS APC-based payment system applies to hospitals performing ambulatory services and not to non-hospital ambulatory centers. In performing this review, cost-to-charge ratios are applied to billed charges from providers who submit claims for procedures; these data are aggregated to estimate geometric mean cost.²⁰ It is significant to note that CCR-based data would be inclusive of overhead beyond direct costs to perform a procedure. Following proposed cuts to reimbursement for 75574 (CCTA) last year, a period of open public comment solicited a variety of arguments about the true cost of CCTA and which APC assignment best reflects actual resource use.

This study did not collect data that would permit us to quantify indirect costs attributable to each procedure. CMS estimates total costs, which represent the sum of direct and indirect (overhead) costs but does not break down total costs into overhead and direct components. In the United States, overhead costs represent 43%–45% of total hospital costs.²¹ CMS assigns 75574 to an APC on the basis of claims data with a geometric mean total cost of \$196.¹⁹ Assuming 44% departmental and hospital overhead costs, this corresponds to an estimated direct cost of \$110. Using TDABC, we find that mean and median estimates for the direct cost of performing 75574 are \$189.52 and \$181.00, respectively.

CMS reimburses \$182.25 for the technical component of 75574, which is both lower than their CCR-derived \$196 estimate of total cost and substantially lower than our TDABC-based estimates of direct cost. A technical reimbursement figure that is substantially lower than the cost of performing the exam implies that providers will experience a negative margin for each CCTA performed and is likely to result in restricted access to CCTA.

The imbalanced nature of CCTA reimbursement is further illustrated when compared to a CECT benchmark. The CMS 2020 Procedure Price Lookup Comparison File shows identical APC values for CCTA and CECT (CPT codes 75574 and 71260, respectively).²² Identical APC assignment implies comparable resource utilization as a basis for determining reimbursement. However, the large and highly significant difference in the direct costs of these two exams demonstrated by this study is at odds with the principle of cost-driven reimbursement.

To the best of our knowledge, this study represents the first published report using a TDABC model to compare specific procedures performed across multiple institutions. Obtaining TDABC measurements across

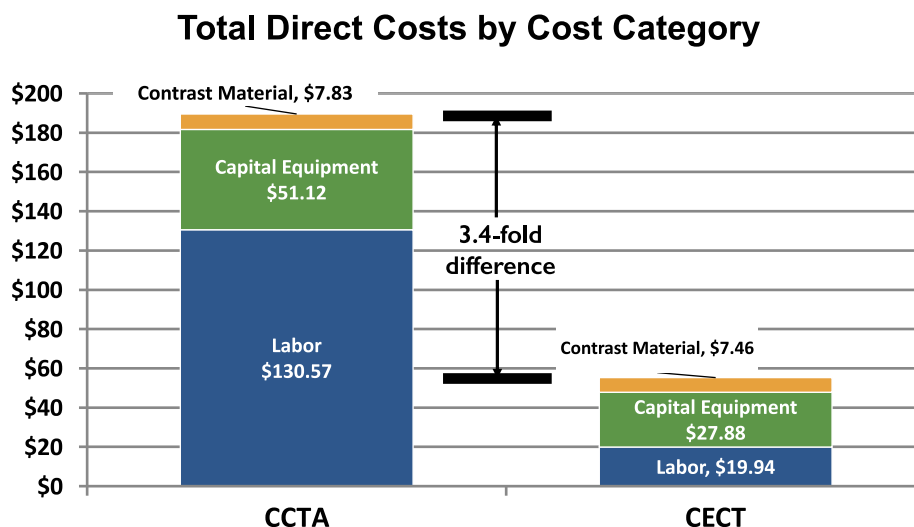


Fig. 3. Mean total direct labor, capital equipment (depreciation + service cost) and contrast material costs for CCTA and CECT procedures.

Average Labor Costs by Exam Phase

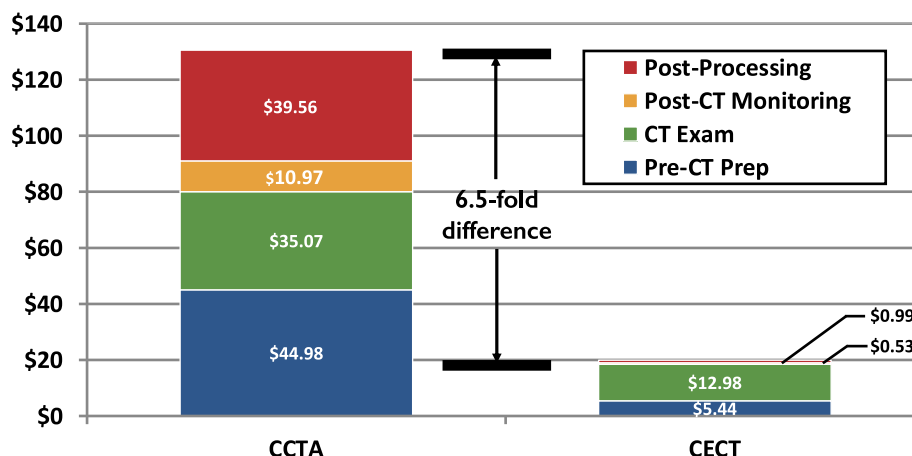


Fig. 4. Comparison of mean labor cost by exam phase.

differing geographic locations, clinical practice styles, and patient mixes reduces single-center-based biases and lends generalizability to the cost estimates. TDABC data have potential use to clinicians, managers, and policymakers. By performing similar on-site studies, health system management teams can compare their findings with these results to gauge their relative direct cost management for CCTA and CECT performance. Payors can use such information to determine fair compensation for a given procedure, and both parties will potentially benefit from the existence of data-supported cost estimates as they negotiate reimbursement schedules. Ultimately provider-payor collaborations in acquiring and utilizing activity-based costing data offer tremendous promise in support of principled and value-based reimbursement.

There are several limitations to this study. The greatest limitation is the small sample size. With only 28 CCTA and 26 CECT studies considered across 7 practice sites, there are significant limitations to our ability to analyze more granular differences between institutions, states, and practice models. Though the total cost difference between CCTA and CECT yields highly significant results, we were unable to investigate in a statistically robust fashion why certain parts of the data appeared more variable than others, such as the length of the pre-CT prep phase. Each of the sites included in this study perform moderate to high volumes of the CCTA and CECT by experienced clinicians and staff. It is possible then that the median duration measured and estimated direct costs for these procedures may be lower than a national sample that includes less experienced facilities. These pilot data support constructing a larger trial. Such a trial would also create opportunities for a deeper examination of differences in procedural protocol for both CCTA and CECT across different sites.

A second limitation is a focus restricted to direct costs associated with the technical component of the exams, excluding interpretation time or any other aspects of the professional component of the procedure. Additionally, indirect costs such as those attributable to scheduling and revenue cycle management are not included. These factors could be particularly significant if scheduling for CCTA requires more detailed intake information and greater complexity for scheduling to appropriate CT scanners. Revenue cycle management costs may differ substantially if prior authorization or more post-exam documentation is required for CCTA than CECT. Such costs would need to be considered as components of a fully comprehensive cost model independent of more general overhead such as institutional and departmental administration. Other than CT scanner costs, costs associated with hospital facilities were not addressed. However, differences in overhead costs attributable to CCTA versus CECT are likely to depend primarily on variations in site-specific cost allocation methods rather than procedure driven differences in resource utilization other than duration. Some centers may perform

CECT scans on less expensive or older generation scanners; this would reduce the relative cost of CECT at those sites, but to enable the most direct comparison possible between the procedures for this study we assumed comparable scanning equipment.

A third limitation is that data were collected by different personnel at each site. While multiple phone calls amongst the primary investigators facilitated coordination of data collection across the sites, site-based variations in data collection may have been introduced. Finally, this study examines costs exclusively and does not endeavor to assess the broader value of the information generated from the tests.

Conclusion

TDABC analysis demonstrates a significant difference in the cost between CCTA and CECT, establishing that the mean direct cost to perform CCTA is roughly 3.4 times higher than CECT. The bulk of this cost difference is driven by increased labor utilization and expense associated with performing CCTA. Despite this, CMS national OPPS facility technical reimbursement for CCTA is no higher than reimbursement for CECT, suggesting that CCTA reimbursement is currently undervalued relative to the total cost of performing each procedure and thus may limit patient access. Data from this study suggests an opportunity for a larger study to examine site-by-site cost variability and its relationship to the spectrum of clinical practice across institutions.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: **G.D.R.** is an advisor to HeartFlow, outside the submitted work. **C. B.** gave a lecture in 2019 for HeartFlow, outside the submitted work. **B.B.G.** is supported by institutional grants to his institution from Siemens Healthineers and the NIH, outside the submitted work. No interests or disclosures declared for **M.E.Z.**, **J.C.B.**, **M.G.R.**, **R.B.**, **G.E.W.**

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