Original Investigation

Dissecting Costs of CT Study: Application of TDABC (Time-driven Activity-based Costing) in a Tertiary Academic Center

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Rationale and Objectives: The lack of understanding of the real costs (not charge) of delivering healthcare services poses tremendous challenges in the containment of healthcare costs. In this study, we applied an established cost accounting method, the time-driven activity-based costing (TDABC), to assess the costs of performing an abdomen and pelvis computed tomography (AP CT) in an academic radiology department and identified opportunities for improved efficiency in the delivery of this service.

Materials and Methods: The study was exempt from an institutional review board approval. TDABC utilizes process mapping tools from industrial engineering and activity-based costing. The process map outlines every step of discrete activity and duration of use of clinical resources, personnel, and equipment. By multiplying the cost per unit of capacity by the required task time for each step, and summing each component cost, the overall costs of AP CT is determined for patients in three settings, inpatient (IP), outpatient (OP), and emergency departments (ED).

Results: The component costs to deliver an AP CT study were as follows: radiologist interpretation: 40.1%; other personnel (scheduler, technologist, nurse, pharmacist, and transporter): 39.6%; materials: 13.9%; and space and equipment: 6.4%. The cost of performing CT was 13% higher for ED patients and 31% higher for inpatients (IP), as compared to that for OP. The difference in cost was mostly due to non-radiologist personnel costs.

Conclusions: Approximately 80% of the direct costs of AP CT to the academic medical center are related to labor. Potential opportunities to reduce the costs include increasing the efficiency of utilization of CT, substituting lower cost resources when appropriate, and streamlining the ordering system to clarify medical necessity and clinical indications.

Key Words: Healthcare costs; medical imaging; computed tomography; activity-based costing.

INTRODUCTION

The growing pressure to reduce the overall healthcare expenditure and to improve coordination of care has led to transformation of the Medicare payment model. The US Department of Health and Human Services announced the goal that 30% of Medicare payments are tied to alternative payment models by the end of 2016 and 50% by the end of 2018 (1). This value-based payment models reward quality and value of care over quantity of services, clearly shifting from the traditional fee-for-service model (1). Bundled payment, one approach of alternative payment models, facilitates improved coordination and integration of care and holds the provider team accountable for the full cycle of care to achieve better outcomes (2).

The healthcare expense of medical imaging has dramatically increased over the past several decades (3,4). Most of the growth in imaging expenditures has been driven by increased utilization of advanced imaging, including computed tomography (CT), magnetic resonance imaging, and positron emission tomography (PET). Efforts to reduce healthcare costs have had impact on the reduction of imaging-related expense. For example, from 2009 to 2010, the imaging volume among Medicare beneficiaries declined by 3.5% (5). Nevertheless, as of June 2012, medical imaging remains 11.9% of the total Medicare charges (MedPAC Report on March 2014; www.medpac.gov).

To contain potential overutilization and reduce healthcare expenditures (6), recent reimbursement models have shifted from the traditional fee-for-service toward bundled payments or capitation models, incentivizing physicians and

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hospitals to deliver more effective care and reduce wasteful practice. In shifting the financial risk from insurers or other payers to the hospitals and providers, imaging has a risk of transforming from a profit center to a cost center for the organization. Although decreased utilization is one approach to reducing imaging expenses, improving the efficacy of delivery to reduce costs of service is an alternative and complementary strategy (7). Under the healthcare payment transformation, accurate costing will be a critical competency to survive and thrive in the value-based payment models. Implementation of Value Driven Outcomes, a homegrown data analytic tool, was recently reported to reduce cost of care and improve quality by informing physicians' actual costs of care, variations of costs among the care team, and quality measures (8).

Abdomen and pelvis CT (AP CT) is one of the most frequently performed radiological examinations. For example, one study from integrated multispecialty group practice showed that AP CT represents 50% of all CT examinations (9). Utilization of AP CT is unlikely to decrease significantly as AP CT plays a central role in clinical diagnosis across a range of conditions, such as trauma, cancer, and acute abdomen. To reduce the costs of delivering this service, the specific components or cost drivers need to be understood (10). A cost accounting method known as time-driven activity-based costing (TDABC) provides an actionable process and costing data to redesign delivery of care effectively (10–14).

The following are the objectives of this study: (1) map the process for performing an AP CT study in an academic institution using the TDABC, (2) identify the component costs to conduct an AP CT, and (3) consider, in light of costing and process data, opportunities to reduce the costs of AP CT.

MATERIALS AND METHODS

The study was exempt from an institutional review board approval at our institution. None of the authors had direct or indirect financial conflicts related to this study.

Setting

The setting is an urban level I trauma academic medical center. In the main general hospital, two state-of-the-art CT scanners are open and fully staffed 24 hours a day 7 days a week to accommodate outpatients (OP), inpatients (IP), and emergency department (ED) patients.

Time-driven Activity-based Costing (TDABC)

Detailed elsewhere (11,15), TDABC uses two proven management tools—process mapping from industrial engineering and activity-based costing from accounting (16). The process map outlines every step of the care process. For each step, the time to carry out each activity is estimated. Next, the costs of resources required for each step (15) are calculated by determining the cost per unit of capacity. By multiplying the cost per unit of capacity by the required task time for each step of the process and summing each component cost, the total cost of the process is estimated. The TDABC method uses a bottoms-up approach to measure the human and capital costs expended throughout an entire episode of care (11,17).

Within healthcare, TDABC has been applied to several medical care pathways (18,19), including endoscopic sinus surgery (20), tonsillectomy (21), arthroplasty (22), head and neck surgery (23), heart valve surgery (13), anesthesiology care (14), and complex neurosurgery procedures (24). The team performing the TDABC for AP CT consisted of a business manager for the department of radiology, value (industrial) engineers, financial analysts, physicians, technologists, and the CT manager. A research team from Harvard Business School (D.H., R.K.) provided the process map template and guided the project.

Development of Process Maps

The process maps require frontline practicing clinicians and the team members to use their clinical knowledge to describe all the clinical and administrative process steps—each activity, duration, clinical resources, personnel, and equipment involved in a patient's complete cycle of care. The starting point for the care cycle is defined as the time when the order for the AP CT was placed, and the ending point was the approval of the final interpretation of the study by the radiologist.

Information was collected through direct observations (workflow for radiologists, residents, CT technologists, and nurses), as well as the time stamps in the radiology information system (RIS) (percentages of AP CT with contrast or oral contrast, duration of examinations, and referral sources), and surveys to physicians, CT technologists, and nurses (frequency of additional imaging study, protocol changes, and contrast reaction).

Financial Accounting

The radiology financial administrator (K.M) determined a cost-per-minute "capacity cost rate" for each clinical resource involved in the care cycle. This refers to the fully loaded cost of supplying a resource divided by the amount of time that resource was available for productive work. The capacity cost rate was calculated for personnel, space, and equipment.

Personnel costs include compensation, costs of office space, technology, training, supervision, and other indirect expenses incurred to support that person. The practical full capacity was calculated to be 80%–85% of the time each personnel type was on average scheduled to work, allowing for 15%–20% of personnel time for breaks, lunch, communication, meeting, and training. To determine the capacity cost rate for personnel ($/min), the full expense ($/year) is divided by the practical full capacity (total number of minutes/year).

Space and equipment costs include depreciation or rental expense, the costs of space occupied, utilities, consumable supplies, and maintenance and repair. The denominator is the estimated total capacity, measured in hours or minutes, that each resource is available for productive work in the TDABC model. Using the 24 hours 7 days a week staffing model, the total duration of time the equipment is available was 525,600 minutes a year (365 × 24 × 60). The maintenance (annual service contract) and obsolescence (annual depreciation) costs are included. All material costs (syringe, needle, tubing, and contrast material) are derived from the actual supply costs.

Process Mapping

Five total process maps were required to describe the performance of an AP CT. Figure 1 demonstrates an overview of the five process maps that reflect three distinct components: the ordering process (only mapped for OP, Fig 2), performance of imaging (mapped for IP, OP, and ED, Figs 3–5), and the interpretation of the examination (Fig 6). The OP examination has an additional series of steps for scheduling outpatient service specialist (OSS) (Fig 2). The orders for examinations that originate in the IP and ED settings are communicated directly to the CT technologist via a computerized physician order entry system (Epic Radiant, Verona, WI).

The most complex process maps are the ones that generate the diagnostic images (CT technologist workflow). The

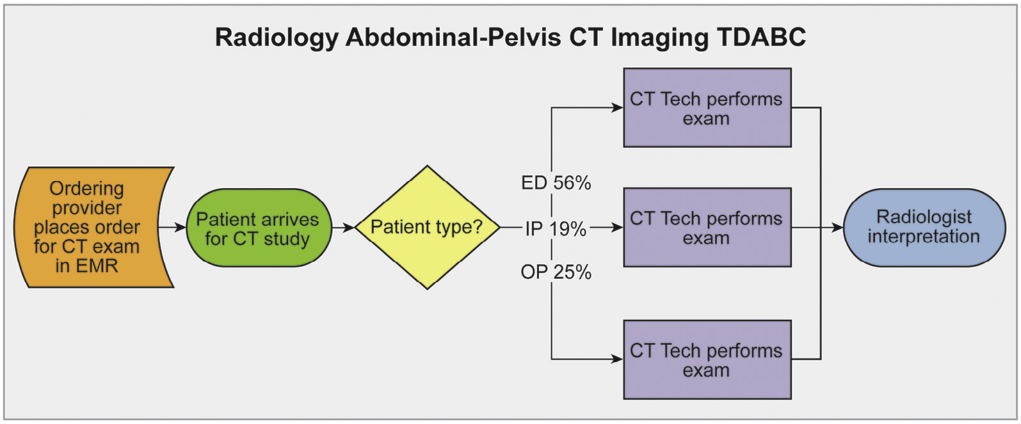

Figure 1. TDABC workflow. An *oval shape* indicates the starting and ending point of the workflow process. A *yellow diamond shape* indicates a decision point. The percentage reflects the distribution across different categories. Each personnel-based activity is shown in a *rectangular shape* with different color for different roles (eg, purple for CT technologist and blue for radiologist). CT, computed tomography; ED, emergency department; EMR, electronic medical record; IP, inpatient; OP, outpatient; TDABC, time-driven activity-based costing. (Color version of figure is available online.)

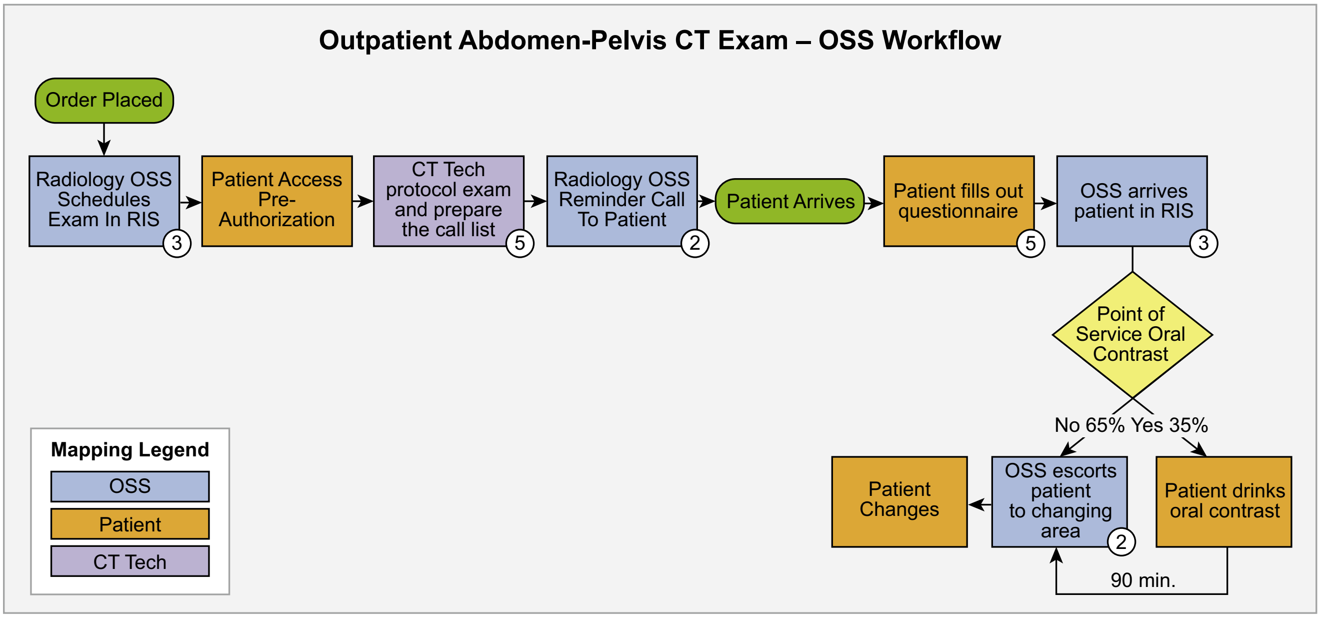

Figure 2. OSS workflow (Map 1). Prior to arrival of a patient, OSS schedules the examination and obtains preauthorization for the examination. Once the patient arrives, the patient needs to fill out a questionnaire, and the OSS escorts the patient to a changing room if no oral contrast is required. When the patient needs oral contrast, the patient spends 90 minutes drinking oral contrast in the waiting room. CT, computed tomography; OSS, outpatient service specialist; RIS, radiology information system.

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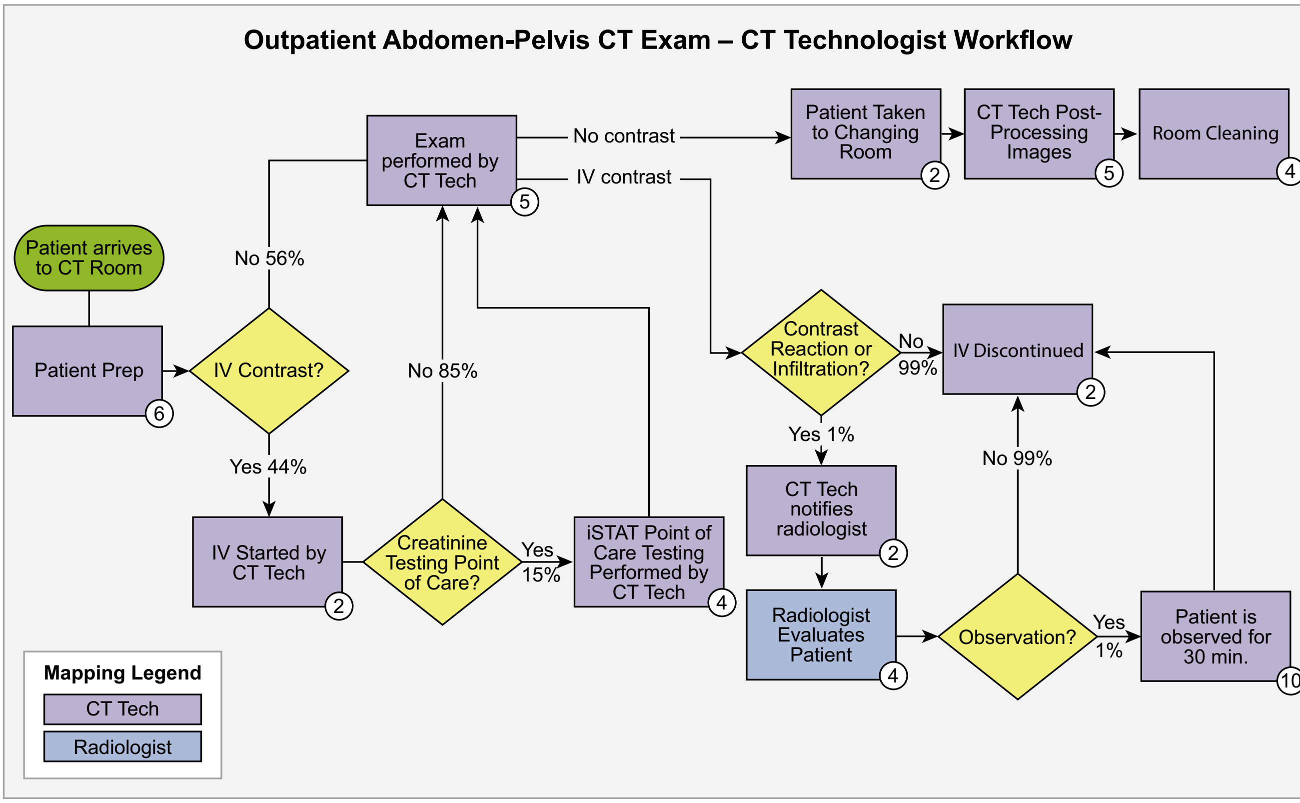

Figure 3. CT technologist process map for the OP encounter (Map 2). CT technologist process map starts when a patient arrives at the CT room. A point-of- care serum creatinine check is performed for those patients requiring intravenous contrast without recent laboratory tests. The CT technologist performs the examination, takes the patient back to the changing room, performs necessary post processing, and cleans the CT room. The CT technologist contacts a radiologist in the event of a contrast reaction. CT, computed tomography; OP, outpatient.

CT technologist workflow varied considerably based on whether the patient initiated an event as an OP, IP, or ED, necessitating three separate process maps (Figs 3–5). Finally, the radiologist workflow for interpretation was partitioned as a unique component of the process (Fig 6).

Based on the RIS data, 56% of patients initiate the AP CT examinations from ED, 19% from IP wards, and 25% from an OP setting (Fig 1).

Part I: Outpatient Service Specialist Workflow

The OSS workflow is initiated when an imaging order is placed and ends when a patient arrives at the CT room. The OSS workflow includes time for scheduling a CT examination, obtaining preauthorization, verifying that the correct examination has been ordered, and confirming appointments with the patient or patient's caregivers. In addition, the OSS escorts the OP to a changing room and then to the CT examination room (Fig 2).

Most AP CT studies are performed with both oral and intravenous (IV) contrast materials. Oral contrast requires approximately 90 minutes for the contrast to reach the large intestine. For ED patients, the oral contrast is mixed and administered by an ED nurse. For IP, the pharmacy mixes and delivers the contrast material and a nurse administers the contrast to a patient. The time for a pharmacist to mix and an ED nurse to administer oral contrast was included in the cost calculation, as the study was performed from the institutional perspective (not department perspective). However, the time a patient spent in drinking oral contrast (90 minutes) was not included in the cost calculation as no personnel was directly involved in the activity.

Part II: CT Technologist Workflow

The workflow for the CT technologist is initiated when a patient arrives at the CT scan room (Fig 3). The technologists' activities include confirming that the examination scheduled is the correct study and troubleshooting any incorrect examination order by contacting the radiologists. The CT technologist explains the procedure to the patient and places an IV catheter after verifying the serum creatinine. For 85% of the patients, recent laboratory values are available in the electronic medical record (EMR). For the remaining 15%, the CT technologist performs a point-of-care serum creatinine check (iStat, Abbott, Princeton, NJ), which typically takes less than 5 minutes and is factored into the cost accounting.

The next major step for the CT technologist is the performance of the CT examination. Then, the technologist performs any necessary image post processing and communicates with the radiologist to ensure that the examination

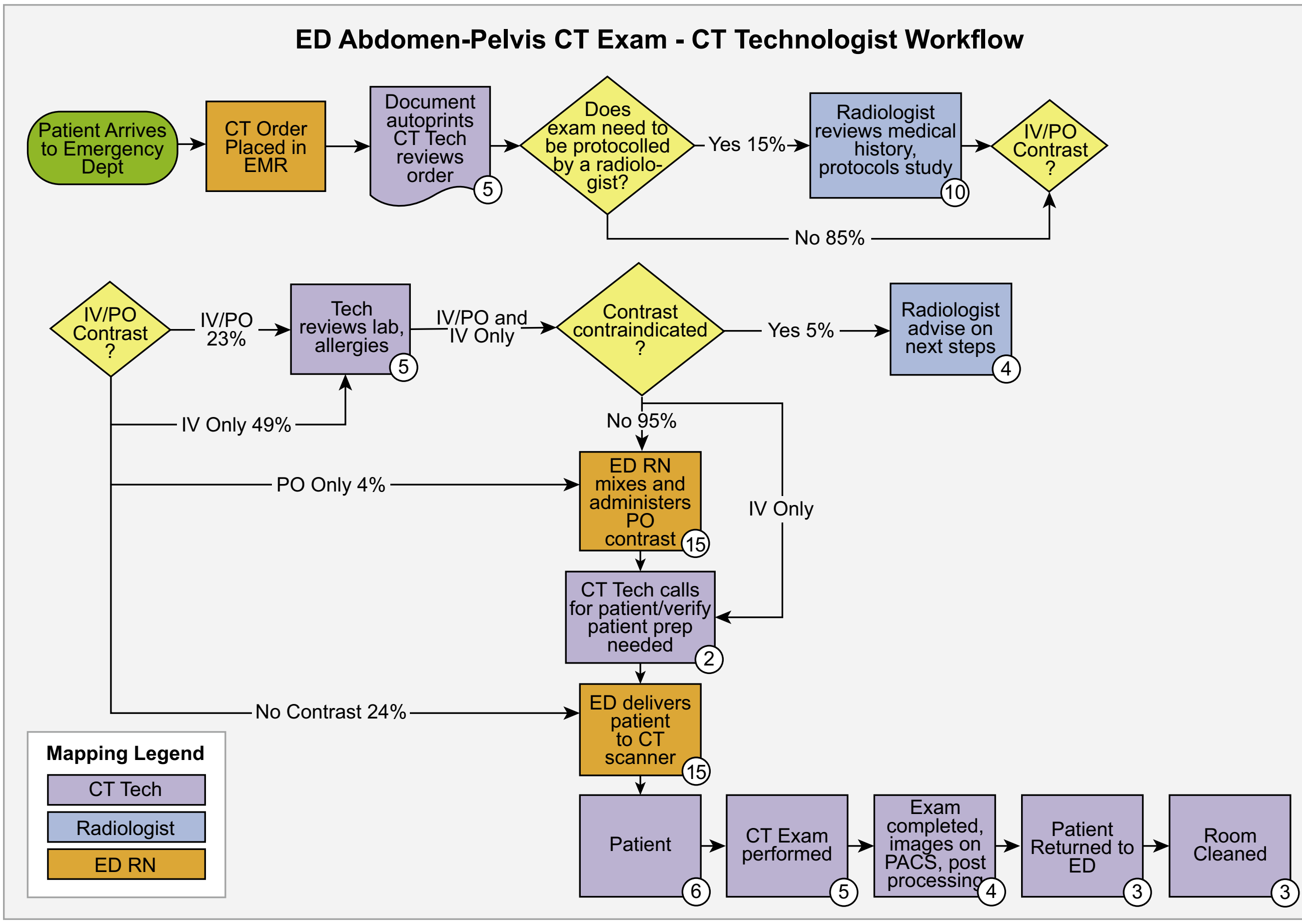

Figure 4. CT technologist process map for the ED encounter (Map 3). The ED nurse administers oral contrast to the ED patient and also delivers the patient to the CT room. The CT technologist returns the patient to the ED after the examination is complete. CT, computed tomography; ED, emergency department; EMR, electronic medical record.

requires physician's attention, when necessary. Finally, the CT technologist returns the patient to the location where he or she started. Between patients, the CT technologist cleans and prepares the room to be ready for the next patient. Some patients (approximately 1%) experience an adverse reaction to the contrast material. The percentage of the probability of contrast reaction is incorporated into the model to estimate the weighted additional time necessary for the workflow.

Significant differences in the CT technologist process for ED patients resulted from the shift of much of the allocated space and activities for preparation from the radiology department to the ED (Fig 4). For example, an ED nurse is responsible for administering oral contrast material, placing an IV, and transporting the patient to the CT scanner. The time needed for the ED nurse to complete these tasks was included. The CT technologist brings the patient back to the ED after completion of the examination.

Similarly, the workflow for the inpatient AP CT is considerably more complex and involves more personnel resources than the outpatient AP CT. The process relies on the pharmacist to mix and deliver the oral contrast material, the floor nurse to administer oral contrast, and a patient transporter to bring a patient to CT scanners. These activities were added to the base model of the OP workflow (Fig 5). Approximately 30% of the IP studies are performed on intensive care unit (ICU) patients. The transport of an ICU patient requires the presence of an ICU nurse due to the severity of the illness. The additional time for the ICU nurse was added to the IP model.

Part III: Image Interpretation

The final process relates to a radiologist generating an interpretation of the imaging study (Fig 6). The radiologist workflow starts when the CT study appears on the PACS (picture archiving and communication system) worklist. Because this process models the imaging encounter in a teaching hospital, it was estimated that 60% of cases were initially reviewed by a trainee and then verified by an attending radiologist, and the remaining 40% of the examinations were interpreted by an attending alone. The time for reviewing images, dictation, and report signing were all included in this workflow. The model assumed that there was no difference in the time required to interpret AP CT study from ED, IP, or OP (Fig 6), and also that 15% of all CT cases required additional radiologist's attention, including requiring additional

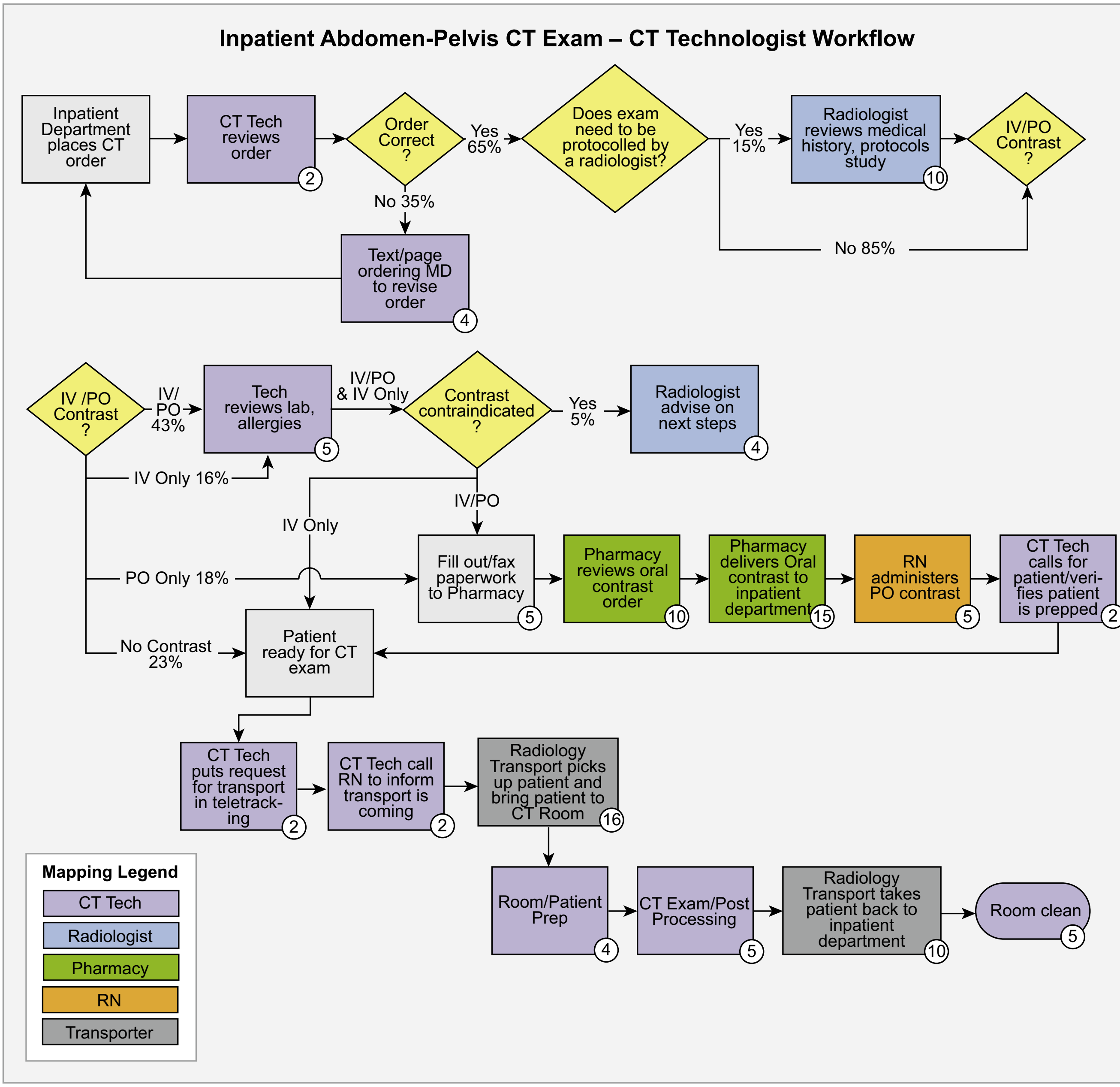

Figure 5. IP CT technologist process map for IP encounter (Map 4). For the IP study, the CT technologist orders oral contrast material to a pharmacy. The pharmacy mixes the contrast and delivers the contrast material to the IP. The IP nurse administers the oral contrast material. Once the patient is ready to come down to the CT suite, a patient transporter delivers the patient to the CT room. For ICU patients, an ICU nurse accompanies the patient to the CT room and stays for the duration of the examination. CT, computed tomography; ICU, intensive care unit; IP, inpatient.

imaging or contacting referring physicians for examination findings.

RESULTS

Direct Costs of AP CT

The components of direct costs to a healthcare institution to perform an outpatient AP CT study were as follows: 45.4% for radiologist interpretation, 35% for other personnel (technologist, nurse), 18.1% for materials (IV line, syringes, needle, and contrast), and the remaining 7.4% for space and equipment.

The components of direct costs for ED patients were 40.1% for radiologist interpretation, 40% for non-radiologist personnel (technologist, ED nurse), 13.2% for materials, and 6.7% for space and equipment. For IP, the cost distributions were 34.6% for radiologist, 47.9% for non-radiologist personnel, 11.6% for materials, and 5.9% for space and equipment.

As our volume of AP CT is mostly from ED and OP (56% from ED and 25% from OP), the average component direct

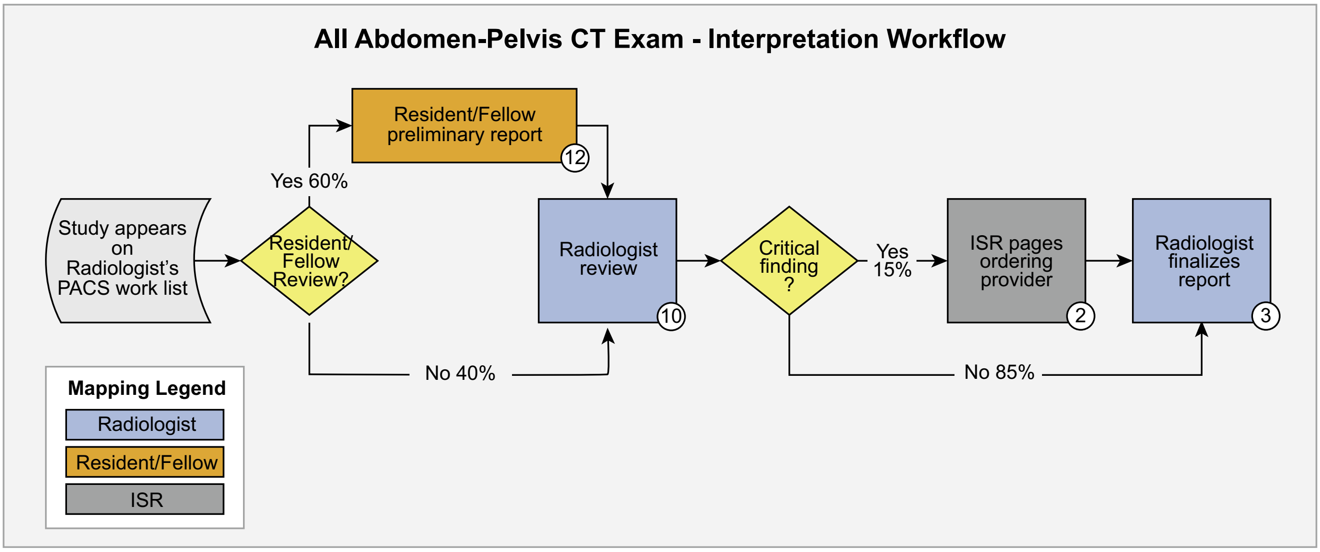

Figure 6. Radiologist process map for imaging interpretation (Map 5). The radiologist workflow starts when an imaging study appears on the PACS worklist. In this model, 60% of cases are interpreted initially by a trainee and the remaining 40% are read by attending radiologist alone. A subset of 15% of the cases is associated with critical findings that require verbal communication to an ordering physician or require additional images, as directed by the radiologist, at the time of the examination. PACS, picture archiving and communication system.

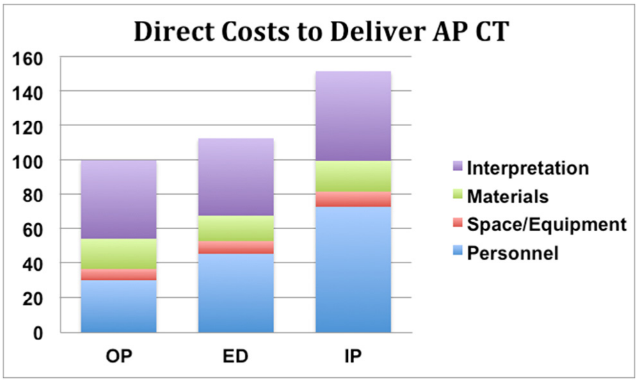

Figure 7. Costing data for AP CT. Tiered bar graphs represent the costing data with the OP costs pegged to 100%, and the cost for ED and IP expressed in a percentage as compared to the OP costs. A percentage of cost in each bar graph is adjusted with respect to the OP cost of AP CT. AP CT, abdomen and pelvis CT; ED, emergency department; IP, inpatient; OP, outpatient.

costs to the healthcare institution were as follows: 40.1% for radiologist interpretation, 39.6% for other personnel, 13.9% for materials, and the remaining 6.4% for space and equipment. The weighted average costs of IP, OP, and ED patients, as well as the composites of the total direct costs for each referral source, are shown in Figure 7.

The cost of the AP CT to the institution was lowest for the OP. Compared to the cost for OP, the costs were 13% higher for ED patients and 31% higher for IP. The difference in costs was mostly attributable to the costs of non-radiologist personnel, with significantly higher resources required for imaging an IP as expected based on the process map. The costs of non-radiologist personnel for an inpatient AP CT study were more than double for IP (109% higher) than for than an outpatient CT study.

In this study, we estimated that 60% of examinations were interpreted initially by a trainee and verified by the attending. If an attending were to interpret all examinations and it takes the same amount of time for the attending to review and finalize report with or without a trainee, this would have resulted in 5.5% savings of the direct cost for an OP study, which would be equivalent to 13.4% of the costs of imaging interpretation.

If we were to have a transporter deliver an ED patient to CT scan and bring the patient back to ED, instead of ED nurse or CT technologist, non-radiologist personnel costs would be reduced by 19.2%. Potential other strategies also include maximization of the room utilization by improved scheduling, such as blocking time to scan inpatients and making the rest of scan times available for ambulatory care patients. Having a detachable CT table to prepare a patient next in the line might facilitate the efficiency of room utilization.

DISCUSSION

Unlike charges or reimbursement rates, the delivery system's "cost" of providing a service or performing a procedure should be measured by adding up the cost of resources used in all the process steps for treating a patient's medical condition (16). In the absence of accurate cost data, it is not surprising that charges or reimbursements vary widely (consumer reports, healthcare bluebook) and are disconnected from the cost of delivery of healthcare (7,25). Knowing the costs of care provides opportunities for process improvement, cost reduction, and more accurate pricing for patients who require complex imaging.

In this study, we observed that the direct costs of AP CT were mostly related to labor. Materials and equipment costs represent only about 22% of the total direct costs. In 2000, Nisenbaum et al. reported the costs of CT procedures at the academic radiology department using the traditional time and motion study. In their study, using printing images to film and using a transcriptionist to complete dictation, the radiologist's cost was 23%–42% of the total costs of CT, which is lower than that in our study. They found that all personnel costs reach 80%, similar to our study. They compared the professional cost to the 1997 Medicare Fee Schedule and found that the professional component of payment was on average $39.20 below the professional cost (26). Krug et al. reported that 73% of the costs of performing fluorodeoxyglucose (FDG)-positron emission tomography (PET) were related to clinical activities (appointment planning, preparation and injection of the radiotracer, data acquisition and reconstruction, and interpretation of FDG-PET) (27). In their study, the material cost (radiotracer) for PET was the largest (44%) for all component costs, whereas the personnel cost was only 16%.

TDABC has been applied to various medical conditions (fractures, prostate cancer, pharmacy management, arthroplasty, cardiovascular surgery, and sentinel lymph node biopsy for head and neck cancer) and proven to be a reliable method to estimate real cost of delivery of care and services (17,22,28–33). TDABC allows us to optimize the allocation of healthcare resources to provide patient care in a manner in which every member of the team is working at the "top of the license" (24) (11). The cost analysis gives us insights about the opportunities for cost reduction. Up to 40% of the total costs of performing an AP CT were related to the personnel costs for preparation of patients and actual scanning. Replacing some of the roles performed by CT technologists or nurses with medical assistants may reduce the overall costs of CT study without compromising quality of care.

For outpatient AP CT, obviating the preauthorization process with an effective radiology clinical decision support system could reduce costs and improve the efficiency of CT scheduling. Additionally, reducing delays and inefficient protocols due to incorrect orders or lack of proper clinical information can be addressed with better online ordering tools. A structured computerized physician order entry is reported to improve communication between radiologists and ordering physicians (34).

In this model, we assumed that a portion of the CT examinations would be read by a combination of radiology trainees and an attending to reflect the practice in the academic institution. This adds extra time for teaching radiology residents, as compared to the cases reviewed and dictated only by an attending. Future questions are: what are the costs of training future physicians to our healthcare system and how do we measure added value of having a resident preview a CT study on the quality of the interpretation?

The limitations of the study are as follows: Ours is a single-institution study. The practice variations do exist across the institutions. The process maps outlined in this study may need modification to fit into other institutions. The goal of this article is to illustrate the application of the TDABC method to a simple and commonly performed radiology examination, an AP CT. The scope of the study is limited to the care while a patient is receiving AP CT in a radiology department, not the entire care cycle for patients with a specific medical condition. Although the process ends at the report finalization in this study, the entire process can be extended to include the billing and coding activities and dealing with denial of payment. We did not address the appropriateness of CT examinations in this study (6,35–37). Similarly, we did not address outcomes or quality of care under CT study to estimate value of care. The study simply focused on the methodology of estimating direct cost of CT study to a health system.

We made several assumptions in our TDABC approach. To provide timely imaging for critically ill patients, holding CT scanner to accommodate emergent or urgent patients is a relatively standard practice in our institution. No wait time between patients or time holding scans for urgent cases were included in this measurement. Indirect costs were not included in this study, such as operation, maintenance, and depreciation of the hospital building and hospital administration costs.

Although TDABC has the advantage of having a detailed process mapping that can identify opportunities for cost savings, it is a labor-intensive approach. The more the measurement of time and activity can be automated using EMRs or RIS, the easier to make these measurements and monitor changes. In addition, once some of the resource capacity cost rates are determined, these values can be applied to other medical imaging technologies, such as MR or interventional radiology.

Due to regulatory and contractual reasons, we cannot express the actual cost of CT, the acquisition costs of supply or devices, or the actual cost of a CT scan. Under the current environment shifting financial risk and increasing pressures to improve efficiency, the radiology community must develop and apply techniques to understand its own cost structure. This study illustrates how the direct cost of imaging study can be estimated in the real clinical practice.

CONCLUSION

The TDABC method to measure the costs of performing an AP CT provides valuable insights into process variability and resource utilization. The vast majority of CT costs are related to personnel, such as scheduler, technologist, transporter, and radiologist. Potential opportunities to reduce costs of CT study include substituting lower cost resource when clinically appropriate, streamlining the ordering system to clarify medical necessity and clinical indications, increasing the efficiency of utilization of CT scanner, and reducing the unanticipated waiting time for the next patient.

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