



# Prospective cost implications with a clinical decision support system for pediatric emergency head computed tomography

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Received: 14 December 2020 / Revised: 11 June 2021 / Accepted: 23 July 2021 / Published online: 25 August 2021  
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## Abstract

**Background** Unnecessary imaging is a potential cost driver in the United States health care system.

**Objective** Using a clinical decision support tool, we determined the percentage of low-utility non-contrast head computed tomography (CT) examinations on emergency patients and calculated the prospective cost implications of providing low-value imaging using time-driven activity-based costing at an academic quaternary pediatric hospital.

**Materials and methods** A clinical decision support tool for imaging, CareSelect (National Decision Support Co., Madison, WI), was integrated in silent mode into the electronic health record from September 2018 through August 2019. Each non-contrast head CT order received a score from the clinical decision support tool based on the American College of Radiology Appropriateness Criteria. Descriptive statistics for all levels of appropriateness scores were compiled with an emphasis on low-utility exams. A micro-costing assessment was conducted using time-driven activity-based costing on head CT without contrast examinations.

**Results** Within the 11-month time period, 3,186 head CT examinations without contrast were ordered for emergency center patients. Among these orders, 28% (896/3,186) were classified as low-utility studies. The base case CT pathway time was 43 min and base case total cost was \$193.35. The base case opportunity cost of these low-utility exams extrapolated annually amounts to \$188,902 for our institution.

**Conclusion** Silent mode implementation of a clinical decision support tool resulted in 28% of head CT non-contrast exams on emergency patients being graded as low-utility studies. Prospective cost implications resulted in an annual base case cost of \$188,902 to Texas Children's Hospital.

**Keywords** Appropriateness criteria · Children · Clinical decision support · Computed tomography · Cost analysis · Neuroradiology

## Introduction

In 2018, health care expenditures in the United States (U.S.) grew by 4.6% and constituted approximately 18% of the national gross domestic product [1, 2]. Advances in medical technology, despite providing lifesaving care, are associated with inappropriate use and overutilization. It is estimated that \$210 billion is spent on unnecessary services such as medications, diagnostic imaging tests and procedures that do not result in the marginal utility of expected health improvement [3].

In response to escalating health expenditures and the significant growth of medical imaging, national policies have been authorized that concentrate on the appropriateness of advanced diagnostic imaging. Appropriateness criteria is an ongoing effort by the American College of Radiology (ACR)

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to critically analyze and categorize the appropriateness of imaging modalities used in both the diagnosis and management of more than 170 specific clinical conditions. Central to the appropriateness criteria is the idea of necessity, meaning that imaging exams should have a reasonable chance of providing a benefit to the patient [4]. Mandated in 2014, the Protecting Access to Medicare Act (PAMA) was an attempt to transition to a value-based care reimbursement model where quality is rewarded over the volume of services performed in regard to diagnostic imaging [5]. The PAMA mandate included a provision requiring referring clinicians to consult appropriate use criteria to receive reimbursement when ordering advanced diagnostic imaging services, defined as computed tomography (CT), magnetic resonance imaging (MRI), nuclear medicine and positron emission tomography (PET) for Medicare part B patients [5, 6].

While PAMA does not broadly apply to pediatric institutions given their relatively low number of Medicare patients, it is assumed that private insurers transitioning toward a value-driven reimbursement model will adopt similar requirements and will use appropriate use criteria utility scores as a basis for reimbursement [7].

As a means to improve imaging appropriateness and reduce low-value imaging, clinical decision support software has been developed to incorporate appropriate use criteria directly into the electronic health record, allowing for real-time feedback at the point of image ordering. When a clinician places an advanced diagnostic imaging order through the electronic health record system, a clinical decision support module displays appropriate examinations for the indication selected. Previous studies in adults have shown that such feedback reduces the rate of inappropriate scored exams being performed [8–10].

Cost estimation resulting from clinical decision support and improved awareness of appropriateness of advanced diagnostic imaging examinations for particular clinical conditions is an important aspect of institutional and health system level analysis. Despite a recent trend toward reducing pediatric emergency department CT use [11] and the Image Gently [12] and ALARA (as low as reasonably achievable) [13] campaigns, emergency physicians still view overuse of CT scans as a problem with the potential for improvement [14]. Head CT exams are the most commonly ordered CT scan in pediatric emergency departments [15]. The purpose of this study was to use a clinical decision support tool to determine the percentage of low-utility non-contrast head CT examinations in emergency patients and to calculate the prospective cost implications of providing low-value imaging using time-driven activity-based costing at Texas Children's Hospital, an academic quaternary pediatric hospital that sees more than 150,000 emergency room patients annually and has more than 950 patient beds.

## Materials and methods

The study was submitted to the institutional review board (IRB) and was classified as exempt from IRB approval at Texas Children's Hospital.

### Clinical decision support implementation

CareSelect (National Decision Support Co., Madison, WI) was integrated by imaging modality and ordering location in phases into the electronic health record (Epic version 2015 initially, followed by version 2018; Epic Systems Corporation, Verona, WI) with the CT integration occurring in the emergency department from September 2018 through August 2019. The clinical implementation consisted of mapping structured indications for each CT scan to appropriateness scores based on the ACR Appropriateness Criteria. The clinical decision support tool was implemented in silent mode. The provider orders an imaging study in this mode by using the structured indications provided by the clinical decision support tool rather than entering in free text for the reason for the exam. Upon order placement, an appropriateness score is stored for subsequent analysis only. The appropriateness criteria used the following grades: 1–3, low utility or usually not appropriate; 4–6, marginal utility or may be appropriate; and 7–9, high utility and usually appropriate. In addition, the clinical decision support tool provided structured indications that did not have associated scores as well as a non-scored custom indication of “indication not found” and the opportunity for the ordering provider to enter a free text indication. The ordering provider remained blinded to the score and received no feedback as to the appropriateness of the order per the clinical decision support system. Descriptive statistics for the appropriateness scores were compiled and the proportion of low-utility exams was calculated for head CT without contrast examinations.

### Time-driven activity-based costing

Micro-costing was conducted using a time-driven activity-based costing approach. This method calculates the cost from an institutional perspective of producing an output, in this case, non-contrast head CT examinations. This method consists of establishing process maps through direct process shadowing, deriving time estimates for each sub-step, calculating capacity cost rates for resources, assigning appropriate resources to process steps, summing all the steps together for a true cost, and analyzing the impacts of cost with both a volume assessment and sensitivity analysis [16, 17]. We followed the reporting guidelines that stipulate a standardized criteria for time-driven activity-based costing analysis [18].

### Process mapping

The process map for the non-contrast head CT exam begins with order placement by an emergency department referring physician and concludes with the radiologist dictating a report (Fig. 1). Process maps were constructed through direct shadowing of 20 head CT exams (13 male, 7 female; mean patient age: 6.7 years, standard deviation [SD]: 7.5 years). For each step in the process, details such as personnel, resources used and duration of the sub-step were recorded. The process map was validated by a multidisciplinary team that consisted of CT technologists, registered nurses, radiologists and technical assistants in the CT department.

Time durations for each sub-step were collected through direct shadowing of the procedure and time stamps derived from the electronic patient records during a 6-month period ( $n=172$ ; 102 male, 70 female; mean age: 9.1 years). If the time stamps were not available for a sub-step, the time duration was derived by surveying the personnel involved.

### Cost calculation

Cost calculation for each sub-step consisted of calculating the capacity cost rates of personnel (cost of capacity supplied ÷ practical capacity of resources supplied) and capital equipment, and multiplying the respective capacity cost rates by the duration of each step. The total cost of each step was then summed to calculate a time-driven cost for the entire process.

The personnel cost for each staff type involved in the process was calculated by totaling the median personnel’s effective gross salary plus fringe benefits per year, per the cost analysis standardized reporting guidelines [18] (Table 1). Practical capacity was calculated, starting with total days averaged to work per year, minus standard vacation days, weekends, holidays and training/meeting allowances. Similarly, hours per day were adjusted for practical capacity to only

include hours specifically dedicated to clinical care (hours for meetings and breaks were subtracted). Because our institution is an academic center, we estimated practical capacity at 75–85% of the total average time a personnel type is scheduled to work, as radiologists have research and educational roles that reduce the amount of time devoted clinically [19]. By holding salary constant, the capacity cost rate increases as less time is available for clinical activities. Derived personnel costs were divided by practical capacity to determine per-minute costs for each personnel type. All capacity cost rates were calculated using 2019 values and do not reflect any salary adjustments during the 2020 coronavirus disease 2019 (COVID-19) pandemic.

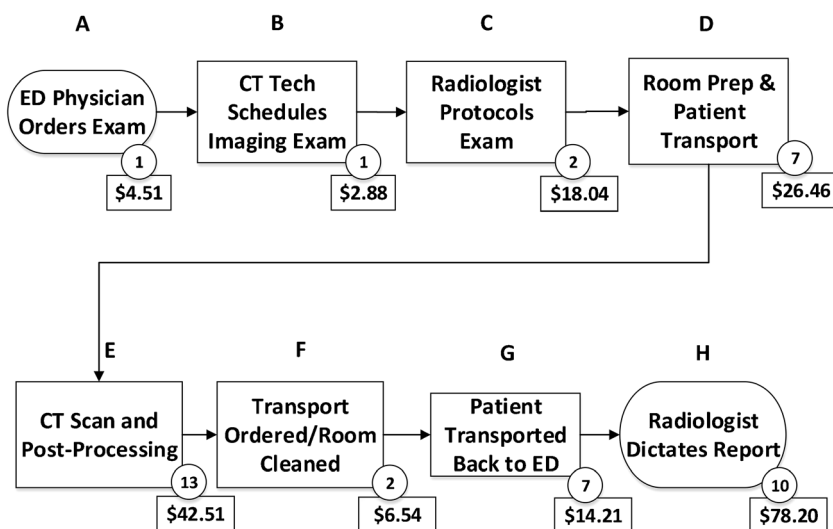
Capital equipment costs were calculated for the CT unit used for the procedure. Total cost for the CT unit was calculated by adding depreciation, maintenance and service costs. The CT unit life cycle was calculated at 7 years and was determined by institutional accounting policy. The CT unit capital equipment costs per minute were multiplied by the number of minutes used in the procedure. Square footage was obtained for the CT suite. Operational facility costs per square foot were multiplied by the relevant square footage obtained and included the overhead of environmental services for the facility. The added costs of all steps yielded a total cost for the procedure and the ranges were analyzed in a sensitivity analysis.

## Results

### Clinical decision support

Within the 11-month time period, 3,186 non-contrast head CT examinations were performed in the emergency department (mean age: 7.2 years, SD: 6.1 years; 1,419 female, 1,767 male). Of the 3,186 examinations, 28% (896/3,186) were

**Fig. 1** A head computed tomography (CT) process map. Letters represent individual steps. Circled numbers represent the average amount of time spent (in min) within each step and the corresponding rectangles represent cost per step. ED emergency department



**Table 1** Baseline case capacity cost rates for producing a head computed tomography (CT) exam without contrast in emergency department (ED) patients at Texas Children’s Hospital

Description	Capacity cost rate (per minute) <sup>a</sup>
Personnel	
CT technologist	\$0.94
CT assistant	\$0.51
ED nurse <sup>b</sup>	\$1.17
ED physician	\$4.12
Radiologist	\$6.69
Equipment	
CT scanner	\$1.13
Facilities	
CT room	\$0.81

<sup>a</sup> Capacity cost rate = [base salary (\$) + fringe and technology (\$) / [annual total days worked × (daily total # hours – daily average # nonclinical hours)]

<sup>b</sup> For emergency department nurses in the cost calculation, we used \$0.39 (\$1.17/3) capacity cost rate to reflect a 3:1 patient-to-nurse ratio

classified as low utility, 14% (444/3,186) as marginal utility and 51% (1,639/3,186) as high utility. The remaining 7% (207/3,186) had no score or “indication not found” (Table 2). Non-contrast head CT studies accounted for 57% (3,186/5,564) of all CT examinations ordered in the emergency department and 75% (896/1,192) of the low-utility examinations (Table 3).

## Costs

The process for a non-contrast CT head exam was initiated by the emergency department physician’s order and concluded with finalization of the report by the radiologist. As contrast was not indicated, these exams followed an efficient process map, without redundant loops in the care cycle. The greatest contributor to the cost of the CT procedure was labor (65% of the overall base case cost). Space and equipment costs contributed 35% to the overall cost of the non-contrast head CT exams.

**Table 2** Clinical decision support (CDS) scores of head computed tomography (CT) exams without contrast ordered for emergency department patients at Texas Children’s Hospital

CDS score	Number of orders	% of orders
Indication not found	119	3.7%
No score	88	2.8%
Low utility	896	28.1%
Marginal utility	444	13.9%
High utility	1,639	51.4%
Total	3,186	100%

The base case total non-contrast head CT pathway time was 43 min, with a production cost of \$193.35 (Table 4). The base case volume assessment was established from the number of non-contrast head CT examinations ( $n=896$ ) ordered during the 11-month period that were graded as low utility and was extrapolated to a 12-month period (977 exams) for an annual cost of \$188,902. Multivariate sensitivity analyses applying all minimum labor and time inputs and maximum labor and time inputs to the cost function yielded a total minimum cost of \$146.25 and maximum cost of \$315.95 per head CT exam. In applying the sensitivity analysis to the volume assessment, the total cost ranged from \$142,866 (minimum) to \$308,683 (maximum) for a 12-month period.

## Discussion

As health care expenditures in the U.S. have escalated, clinical decision support for imaging is one attempt to alleviate the

**Table 3** Clinical decision support (CDS) scores of all computed tomography (CT) exams ordered for emergency department patients at Texas Children’s Hospital

CDS score	Number of orders	% of orders
Indication not found	426	7.7%
No score	270	4.9%
Low utility	1,192	21.4%
Marginal utility	759	13.6%
High utility	2,917	52.4%
Total	5,564	100%

**Table 4** Baseline case times and costs for head computed tomography (CT) exams without contrast in emergency department patients at Texas Children's Hospital

Description	Head CT without contrast
Baseline case time (min)	43
Time range (min)	32–73
Baseline case cost	\$193.35
Total cost range	\$146.25–\$315.95

expenses by focusing on clinical efficiency and reducing the amount of inappropriate imaging exams. While most studies on low-value imaging demonstrate costs from a patient or societal prospective and concentrate on out-of-pocket costs of unnecessary imaging exams, we demonstrate an alternative cost perspective in providing low-value care. This study sought to calculate the annual cost of providing low-value imaging as defined by appropriate use criteria as low-utility exams on the most commonly ordered CT exam, a head CT without contrast, at a quaternary pediatric academic institution.

Our calculation of cost incorporates a time-driven activity-based micro-costing method and represents the cost to the institution of producing a non-contrast head CT exam. Cost per exam affects multiple parties such as patients, insurance companies, and state and federal governments, and these costs can vary depending on insurance coverage and deductibles. The payer perspective is complex as it is affected by the negotiated amount the insurance company pays to the health care institution based on specific contracts or a Centers for Medicare and Medicaid Services (CMS) fee schedule. A major goal of PAMA is shared responsibility of health care costs between providers and payers, and as it becomes fully implemented, it is hypothesized that low-utility exams will no longer be reimbursed by Medicare, rendering the institutional cost of producing these exams non-reimbursable.

While this study focuses on the prospective cost implications of providing low-value imaging, for certain indications there is a cost trade-off between the costs of imaging versus the cost of observing the patient in the emergency department for several hours (without imaging). While for some indications, it is plausible that observing the patient in the emergency department and not performing a CT could extend the patient's stay, on the whole this has not been proven. Conversely, there is some evidence that the use of CT, for instance in the case of mild head trauma, can extend the length of stay for patients [20]. A large prospective study of clinical decision rules for the use of CT for a minor head injury found that patients who did not undergo a CT spent 2.5 fewer hours in the emergency department than patients who had a CT [20].

In regard to our micro-costing methodology, there have been other studies using time-driven activity-based costing to estimate the price of CT exams [21]. The relative

contribution of labor and capital components to the overall costs in our analysis are similar to available time-driven activity-based costing comparison models for CT [22]. A study by Anzai et al. [22], reported approximately 80% of abdomen and pelvis CT costs were attributed to labor costs versus 65% in our study. While the practical translation of these results into operational priorities may be different for individual institutions, the results can inform how clinical decision support implementation may impact operations. Because much of the cost of the non-contrast head CT is labor and not capital, this represents a more modifiable factor.

This study analyzed CT exam ordering practices while the clinical decision support software collected data in silent mode. Operating in silent mode allowed the institution to study CT ordering practices, providing time to analyze the anticipated effect of clinical decision support on our institutional practices. Our 11-month project functions as a baseline for future studies that analyze the effect of clinical decision support on providers' ordering habits. While this was the intent of operating in silent mode, the ordering patterns observed in silent mode may change after the clinical decision support software is active and provides feedback to ordering providers in real time. Consequently, though other studies have shown a decline in the rate of inappropriately ordered exams following full clinical decision support implementation, these results may not be generalizable to our institution. For example, as a quaternary pediatric referral center, our CT volumes compared to other non-radiation-emitting modalities is thought to be relatively lower compared to adult facilities [23]. On a separate note, it is possible that our experience with structured indications is different when compared to other institutions. If an ordering provider is made aware that their chosen indication is inappropriate, they may alter the indication selection rather than simply choosing to not order the exam or ordering a different exam. Consequently, if ordering patterns do not change following full implementation, our base case projections will overestimate expected institutional costs. Further investigations that analyze multiple institutions before and after full implementation of clinical decision support tools are needed.

Additionally, other large studies on clinical decision support implementation demonstrated an overall decrease in the number of high-cost imaging studies ordered, as opposed to a shift in modality type ordered (substitution) [24–26]. Specifically, Weilburg et al. [24], in their large cohort study of utilization management programs, found a significant reduction in the probability of physicians ordering any high-cost imaging procedure (CT, MRI, nuclear medicine and PET). Specifically, high-cost imaging use decreased by 21.33% from 0.43 exams in 2007 to 0.34 exams in 2013 [24]. The authors say this reduction was at least partly due to utilization management and its effect on physicians' ordering behavior [24].

The primary limitation of our study is that it was completed at a quaternary, academic, pediatric hospital, with access to

specialized equipment and experienced personnel; therefore, the processes and percentage of low-utility exams may not be applicable to smaller or nonacademic centers. Thus, it is uncertain at our institution whether full clinical decision support implementation will result in a higher demand for substitute imaging (e.g., brain MRI versus head CT) instead of reducing the demand for imaging altogether. Second, the time-driven activity-based costing approach lacks external validity since the labor and equipment costs may vary depending on institutional pay scales and vendor contracts, and detailed processes and resources may be institution specific. We attempted to mitigate this limitation with the sensitivity analyses. Additionally, this study only examined the prospective cost implications of providing low-value imaging and did not address outcomes related to low-value imaging. Additional studies that address either outcomes or cost effectiveness are needed. Finally, this study provides a projection based on the baseline data captured through the clinical decision support system on silent mode. It is hypothesized that the proportion of low-utility exams may change after full implementation of the clinical decision support module.

## Conclusion

With the PAMA mandate and the subsequent implementation of clinical decision support, there is need for both financial and economic evaluations of this tool on projected imaging use and the impact of this use on cost. As private insurers adopt similar policies of imaging appropriateness, the provider costs for low-utility exams would represent a sunk cost to the institution. At our institution, clinical decision support does not restrict the provider from requesting a low-utility imaging exam, but it is questionable whether payers would reimburse these exams moving forward. Nevertheless, reducing the volume of CT exams by incorporating appropriate use criteria may have major positive effects on future health expenditures.

## Declarations

**Conflicts of interest** None

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