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Clinical Decision Support Increases Diagnostic Yield of Computed Tomography for Suspected Pulmonary Embolism

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Abstract

Objective—Determine effects of evidence-based clinical decision support (CDS) on the use and yield of computed tomographic pulmonary angiography for suspected pulmonary embolism (CTPE) in Emergency Department (ED) patients.

Methods—This multi-site prospective quality improvement intervention conducted in three urban EDs used a pre/post design. For ED patients aged 18+ years with suspected PE, CTPE use and yield were compared 19 months pre- and 32 months post-implementation of CDS intervention based on the Wells criteria, provided at the time of CTPE order, deployed in April 2012. Primary outcome was the yield (percentage of studies positive for acute PE). Secondary outcome was utilization (number of studies/100 ED visits) of CTPE. Chi-square and statistical process control chart assessed pre- and post-intervention differences. An interrupted time series analysis was also performed.

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Results—Of 558,795 patients presenting October, 2010–December, 2014, 7,987 (1.4%) underwent CTPE (mean age 52 $\pm$ 17.5 years, 66% female, 60.1% black); 34.7% of patients presented pre- and 65.3% post-CDS implementation. Overall CTPE diagnostic yield was 9.8% (779/7,987 studies positive for PE). Yield increased a relative 30.8% after CDS implementation (8.1% vs. 10.6%; $p=0.0003$). There was no statistically significant change in CTPE utilization (1.4% pre- vs. 1.4% post-implementation; $p=0.25$). A statistical process control chart demonstrated immediate and sustained improvement in CTPE yield post-implementation. Interrupted time series analysis demonstrated the slope of PE findings versus time to be unchanged before and after the intervention ($p=0.9$). However, there was a trend that the intervention was associated with a 50% increased probability of PE finding ($p=0.08$), suggesting an immediate rather than gradual change after the intervention.

Conclusions—Implementing evidence-based CDS in the ED was associated with an immediate, significant and sustained increase in CTPE yield without a measurable decrease in CTPE utilization. Further studies will be needed to assess whether stronger interventions could further improve appropriate use of CTPE.

Keywords

pulmonary embolism; clinical decision support; computed tomography

INTRODUCTION

A common and potentially fatal disease, pulmonary embolism (PE) may present with nonspecific symptoms such as chest pain, palpitations, or dyspnea. Clinical decision rules for suspected PE have been developed and validated for emergency department (ED) patients,^{1–3} yet their implementation and use are variable.⁴ As a result, patients may be subjected to inappropriate medical imaging. Over time, the use of imaging and specifically computed tomography (CT) in the ED has increased,⁵ and many of these studies may be unnecessary or of marginal clinical benefit.⁶ Unnecessary imaging results in increased resource utilization, avoidable healthcare costs, and risks from exposure to ionization radiation¹ and contrast-induced nephropathy.⁷

Inappropriate computed tomographic pulmonary angiography for suspected PE (CTPE) in patients presenting to the ED may be avoided through the use of validated clinical decision rules.⁸ An evidence-based electronic clinical decision support (CDS) tool based on the Wells criteria has been shown to significantly improve documented adherence to a national quality measure for PE without adversely affecting the use or yield of CTPE.⁹ In addition, decision support tools can decrease imaging order volume and may increase the appropriateness of medical imaging in certain clinical circumstances.^{10, 11} In a single center study, CDS based on the Wells criteria was associated with a decrease in the use of CTPE and an increase in the yield of CTPE in ED patients.¹² These outcomes have not been externally validated in other institutions so their generalizability remains uncertain.

The primary goal of this multi-site prospective quality improvement intervention was to determine the effect of evidence-based CDS on the use and diagnostic yield of CTPE in ED

patients. We hypothesized that CDS would result in increased yield and decreased utilization of CTPE.

METHODS

Study Design

This was a Health Insurance Portability and Accountability Act-compliant, Institutional Review Board-approved, multi-site, single health care system prospective quality improvement intervention using a pre/post design of clinical decision support at the time of CTPE order for ED patients 18 years or older.

Study Setting

The study was conducted between October 1, 2010 and December 31, 2014 at three urban EDs affiliated with one health system. The three EDs had a combined yearly census of approximately 137,000 patients during the study period. The first of the three sites is a large tertiary care ED with approximately 65,000 annual visits, a 4-year emergency medicine residency program, and multiple ED fellowship programs, with some fellows practicing as attending ED physicians. The other two sites are community EDs without emergency medicine training programs and yearly ED visits of 38,000 and 34,000, respectively. During the study period, the EDs utilized a shared electronic health record (EHR) and computerized physician order entry (CPOE) system (EMTRAC, Philadelphia, PA).

Data Collection

The ED EMR was queried for monthly ED patient volume, patient demographics (age, sex, and race/ethnicity), chief complaint, and ED disposition for patients who underwent CTPE during the study period. CTPE reports were obtained from the radiology information system. A natural language processing (NLP) algorithm using General Architecture for Text Engineering (University of Sheffield, South Yorkshire, England)¹³ was used to determine if a radiology report contained positive or negative findings for PE. This NLP algorithm was validated previously for CTPE reports.¹²

Intervention

An evidence-based imaging CDS (Percipio; Medicalis, San Francisco, CA) whose advice is based on a validated clinical decision rule – the Wells criteria² – was integrated into the ED EMR and CPOE system and implemented April 26, 2012. The study period prior to the intervention implementation (Oct 1, 2010 – Apr 25, 2012) was defined as the pre-intervention period, while the study period following the implementation (Apr 26, 2012 – Dec 31, 2014) was defined as the post-intervention period. The intervention system provided decision support at the time of CTPE order and required the ordering physician to choose the D-dimer level (elevated, normal, not done, unknown) and the individual clinical attributes of the Wells criteria (Figure 1a). For low or intermediate risk patients who had not undergone D-dimer testing, a CDS alert was displayed, suggesting the ordering physician obtain a D-dimer as the next step (Figure 1b). At each stage, physicians could either cancel the CTPE order or ignore the displayed alert. If a provider did not enter a variable into the CDS tool, it was considered to be absent. The treating clinicians made all evaluation and management

decisions independent of the study or study investigators and were free to ignore the evidence presented in CDS and proceed with imaging. There was no specific communication regarding the study to the radiologists at the hospital sites.

Outcomes and Measures

The primary outcome of this study was the diagnostic yield of CTPE and secondary outcome was utilization of CTPE. CTPE yield was defined as the percentage of studies positive for acute PE and CTPE utilization was defined as the number of studies per 100 ED visits.

Data Analysis

The sample size was powered to detect a 30% effect size (power=0.8, $\alpha=0.05$) with an estimated baseline yield 8%. This resulted in a desired sample size of 4554 visits (2277 in each group) for the primary outcome. Analyses were performed using Microsoft Excel 2007 (Microsoft, Redmond, WA) and JMP 10 (SAS Institute, Cary, NC). Chi-square was used to assess pre- and post-intervention differences. A two-tailed p-value of <0.05 was defined as statistically significant. As a secondary analysis, we also evaluated temporal trend in CTPE yield using a 3-sigma, p-subtype Statistical Process Control (SPC) chart, which distinguishes “noise” from “signal”.¹⁴ In addition, we performed an interrupted time series analysis to evaluate CTPE yield pre- and post-intervention. We used the following model for the interrupted time series:

$$Y_i = \beta_0 + \beta_1 * T + \beta_2 * I + \beta_3 * O + \epsilon_i$$

where Y_i is the estimated yield, T is time in months, I is intervention (denoted binary 0 or 1) and O is the interaction term of $T * I$. The interaction term allows evaluation to determine if intervention changes the slope and/or the intercept.

RESULTS

Among 558,795 patients evaluated in the three ED sites over the study period, 7,987 (1.4%) underwent CTPE and were included for analysis; 2,771 patients (34.7%) were in the pre-intervention group and 5,216 (65.3%) in the post-intervention group. Overall, most patients were female (66.1%), black/African American (60.1%), and admitted or placed in observation status (61.7%). However, there were differences across the three hospital sites. Patients from the academic site were younger, more likely to be male, and were more often admitted when compared to the two community sites. Race also differed among the three sites with patients from the academic site and one of the community sites more likely to be black/African American (55% and 82%, respectively) while patients from the second community site were more likely to be white/Caucasian (52%) (Table 1). Across the three study sites, 154 attending physicians evaluated any patients during the study period.

Overall CTPE yield for PE was 9.8% (779/7,987 studies positive for PE). Diagnostic yield increased 30.8% post-CDS implementation from 8.1% to 10.6% ($[10.6-8.1]/8.1 = 30.8\%$; $p=0.0003$). Following CDS implementation, CTPE utilization overall did not significantly

change (1.4% pre vs. 1.4% post; $p=0.25$). When examining outcomes by site (Table 2), yield increased at all three sites but only reached significance at one community site. Utilization significantly decreased at one of the community sites and significantly increased at the academic center.

The statistical process control analysis (Figure 2) demonstrated a sustained increase in the proportion of CTPE that were positive among patients with suspected PE, which did not begin until after the intervention. Statistical significance was demonstrated by a run of greater than 8 consecutive points above the center line starting immediately after the implementation. Interrupted time series analysis demonstrated the slope of PE findings versus time to be unchanged before and after the intervention ($p=0.9$). However, there was a trend that the intervention was associated with a 50% increased probability of PE finding ($p=0.08$), suggesting an immediate rather than gradual change after the intervention.

DISCUSSION

The goal of this multi-site quality improvement intervention study was to assess the effect of evidence-based CDS, based on Wells criteria, on the use and diagnostic yield of CTPE in emergency department patients. While we found a 30.8% increase in the yield of CTPE for ED patients after CDS implementation, we did not find a concomitant decrease in utilization. The SPC analysis demonstrates that CDS implementation resulted in an immediate and sustained improvement in CTPE yield. As the study setting included both academic and community ED sites, our results are likely to be more generalizable than those previously reported in only academic sites. Our findings support the notion that implementation of CDS with embedded, validated high quality evidence¹⁵ can increase the yield of CTPE.

The increase in diagnostic yield in our study was more modest than in a prior single center study¹² that demonstrated a 69.0% increase in the yield of CTPE following implementation of CDS in the ED also based on the Wells criteria. Also, we did not observe a change in CTPE utilization post-CDS while the prior study demonstrated a 20.1% decrease in CTPE use. The more modest change in yield and the lack of significant change in utilization in our study may be due to several factors. Unlike the prior study, which was performed at a single academic institution with extensive experience with imaging CDS,^{9, 12, 16, 17} this was the first imaging CDS intervention undertaken in our EDs. In the prior study, leadership focus on reducing inappropriate imaging may have resulted in a higher level of trust in CDS alerts or a perception of a higher likelihood of consequences for ignoring evidence presented in CDS. Varied provider practices and patient populations may also have contributed to our differing results. Approximately one-half of the patients in our study were evaluated in two community EDs (without a dedicated emergency medicine training program) which may have contributed to a lower baseline CTPE utilization (1.4% in our study, compared to 2.0% utilization in the prior study). In addition, while CT utilization has increased significantly over the past two decades¹⁸, more recent data have shown a plateau in CT use over the past few years.¹⁹ This national trend may also be reflected in our study and as such, resulted in a less dramatic decrease in utilization following our CDS implementation. Additional explanations for the differences in our findings may include increasing CDS alert fatigue,

provider “gaming” of the CDS alert, and the lack of multimodal interventions such as an alert paired with provider feedback. Prior work has demonstrated a multi-modal intervention, including the addition of quarterly feedback reporting to CDS, resulting in a modest but significant increase in evidence-based guideline adherence for CTPE.²⁰ While our study showed an increase in guideline adherence, no change in CTPE utilization or yield was found.

Overall, SPC analysis demonstrated that CTPE yield significantly increased following CDS implementation. While yield at each of the individual three sites also increased post-intervention, we were underpowered to see a statistical significant effect at each of the sites – thus, only one of the community sites (Site 2) demonstrated a significant increase in yield. While overall utilization was not significantly changed, the same community site also demonstrated a significant decrease in utilization post-CDS intervention. This is of interest and may imply that the greatest effect of CDS occurred at this site; it began with the lowest yield and highest utilization for PE prior to CDS and was found to have significant improvements in both following implementation. Interestingly, there was a significant increase in CTPE utilization following CDS at the academic site. This may be due to different patient populations evaluated at the various sites, as the academic site has a large oncology practice while the other two sites do not. While the interrupted time series results of a 50% increase in the probability of finding a PE was not statistically significant ($p=0.08$), the SPC results imply that this was likely an issue of sample size. Further studies should include larger datasets from more institutions to verify these results.

This study had a number of limitations. As it was conducted at three urban EDs all within a single health system, the results may not be generalizable to other settings. The three hospital sites were different with respect to presence of training programs and patient demographics. We evaluated one validated clinical decision rule, the Wells criteria. However, other validated evidence-based decision rules such as pulmonary embolism rule-out criteria (PERC),¹ Pisa model,²¹ and revised Geneva score²² may have similar impact if incorporated into CDS. This study was limited to patients with suspected PE who were evaluated with CTPE and did not include patients who underwent pulmonary ventilation/perfusion scanning. This study also did not distinguish clinically significant PE, for example segmental versus subsegmental PE. As the radiology readers were not made aware of the study, it is unlikely that radiologist interpretation habits changed during the study period. It is possible there were temporal trends of improved CT yield during the study timeframe. To address this possibility, we used SPC analysis to evaluate the issue of temporal trend. Data regarding CDS implementation, such as how often alerts were ignored versus acted upon, were not available and may have helped to explain the findings.

CONCLUSIONS

In summary, our data demonstrate modest immediate and sustained increase in CTPE yield, with no demonstrated change in utilization, following evidence-based CDS implementation for patients presenting to the ED with suspected PE. Further studies will be needed to assess whether stronger interventions, compared to education-only CDS interventions, could further improve appropriate use of CT in evaluation of patients with suspected PE.

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Figure 1a.

Decision Assist

Indeterminate Appropriateness
for CTA Chest Pulmonary Embolism

Estimated radiation dose: 15 mSv

[View sources...](#)

* Select all that apply.

- ☐ Clinical signs and symptoms of DVT
- ☐ All alternative diagnoses are less likely than PE
- ☐ Heart rate greater than 100
- ☐ Immobilization at least 3 days, or surgery in the previous 4 weeks
- ☐ Previous objectively diagnosed PE or DVT
- ☐ Hemoptysis
- ☐ Malignancy (treated within 6 months, or palliative)
- ☐ None of the above

[Continue](#)

* Fields marked with an asterisk(*) are required.

Figure 1b.

Decision Assist

Alternative Suggestion
for CTA Chest Pulmonary Embolism

Estimated radiation dose: 15 mSv

Imaging is not recommended at this time. Based on the information provided, the patient is not at high risk for a pulmonary embolism. Obtaining a D-Dimer is recommended. This may exclude the need for imaging in patients with a low clinical suspicion of a pulmonary embolism. [View sources...](#)

[Cancel Order](#) [Ignore Advice](#) [Undo Answers](#) [Add Indications](#)

Figure 1.

Figure 1a. Imaging Clinical Decision Support Tool Presented at the Time of Computed Tomographic Pulmonary Angiography for Suspected PE (CTPE) Order

Figure 1b. Imaging Clinical Decision Support Alert Presented for Patients for Whom Wells Criteria Are Not Met, Based on Data Input on Prior Screen (Figure 1a)

Figure 2.

Statistical Process Control Chart of CTPE Yield (number of CTPE that were positive for acute PE/number of CTPEs performed) Over Time by Quarter

CTPE = computed tomographic pulmonary angiography for suspected pulmonary embolism

Red lines = Upper and Lower Control limits, Green line = Center line, Blue line = Date intervention began

In X-axis:

Quarter	Start Date	End Date
1	10/1/2010	12/31/2010
2	1/1/2011	3/31/2011
3	4/1/2011	6/30/2011
4	7/1/2011	9/31/2011
5	10/1/2011	12/31/2011
6	1/1/2012	3/31/2012
7	4/1/2012	6/30/2012
8	7/1/2012	9/30/2012
9	10/1/2012	12/31/2012
10	1/1/2013	3/31/2013
11	4/1/2013	6/30/2013
12	7/1/2013	9/30/2013
13	10/1/2013	12/31/2013
14	1/1/2014	3/31/2014

Quarter	Start Date	End Date
15	4/1/2014	6/30/2014
16	7/1/2014	9/30/2014
17	10/1/2014	12/31/2014

Table 1

Patient Characteristics by Emergency Department Site

Characteristic	Overall N=7884 (%)	Academic Site N=3923 (%)	Community Site 1 N=2295 (%)	Community Site 2 N=1689 (%)	P value
Age (years), mean + SD	52.2 + 17.5	50.5 + 17.2	54.0 + 17.3	53.8 + 18.0	<0.01
Female sex	5224 (66.3)	2530 (64.5)	1518 (66.8)	1176 (69.6)	<0.01
Race					<0.01
Black/African American	4737 (60.1) 2738 (34.7)	2150 (54.8)	1861 (81.9)	726 (43.0)	
White/Caucasian	103 (1.3)	1518 (38.7)	339 (14.9)	881 (52.2)	
Asian/East Indian	138 (1.8)	57 (1.5)	9 (0.4)	34 (2.0)	
Arab	167 (2.1)	108 (2.8)	19 (0.8)	11 (0.6)	
Other/Unknown		90 (2.3)	43 (1.9)	34 (2.0)	
Hispanic Ethnicity	137 (1.7)	63 (1.6)	20 (0.9)	54 (3.2)	<0.01
Chief complaint					<0.01
Chest pain	1961 (24.9)	927 (23.6)	412 (18.2)	622 (36.8)	
Shortness of breath	2410 (30.6)	1289 (32.8)	590 (26.0)	531 (31.4)	
Disposition					<0.01
Admitted	3788 (48.1)	2008 (51.2)	1029 (45.3)	751 (44.4)	
Placed in observation	1087 (13.7)	487 (12.4)	433 (19.0)	158 (9.3)	
Treated and discharged	2866 (36.4)	1340 (34.1)	772 (34.0)	754 (44.6)	
Transferred	60 (0.08)	40 (0.01)	16	4	
Left AMA	44 (0.01)	22	18	4	
Left without treatment completed	10	7	1	2	
Expired in ED	2	2	0	0	

SD = standard deviation

AMA = against medical advice

ED = emergency department

Bold font indicates statistical significance

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Table 2

Outcomes by Emergency Department Site Pre- and Post- Clinical Decision Support (CDS) Implementation

Outcome	Overall N=2,771 Pre N=5,113 Post	Academic Site N=1228 Pre N=2696 Post	Community Site 1 N=909 Pre N=1362 Post	Community Site 2 N=634 Pre N=1055 Post
Yield [*] Pre-CDS Implementation	8.1%	9.4%	6.2%	8.5%
Yield Post-CDS Implementation	10.6%	11.3%	8.9%	10.8%
P value	0.0003	0.07	0.02	0.13
Utilization [^] Pre-CDS Implementation	1.39%	1.23%	1.50%	1.20%
Utilization [^] Post-CDS Implementation	1.42%	1.54%	1.32%	1.14%
P value	0.25	<.0001	0.0027	0.2557

CTPE = Computed tomographic pulmonary angiography for suspected pulmonary embolism

^{*} Yield was defined as the percentage of CTPE studies positive for acute pulmonary embolism[^] Utilization was defined as the number of CTPE studies per 100 ED visits**Bold** font indicates statistical significance