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Brief Communications

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Effect of a behavioral nudge on adoption of an electronic health record-agnostic pulmonary embolism risk prediction tool: a pilot cluster nonrandomized controlled trial

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Abstract

Objective: Our objective was to determine the feasibility and preliminary efficacy of a behavioral nudge on adoption of a clinical decision support (CDS) tool.

Materials and Methods: We conducted a pilot cluster nonrandomized controlled trial in 2 Emergency Departments (EDs) at a large academic healthcare system in the New York metropolitan area. We tested 2 versions of a CDS tool for pulmonary embolism (PE) risk assessment developed on a web-based electronic health record-agnostic platform. One version included behavioral nudges incorporated into the user interface.

Results: A total of 1527 patient encounters were included in the trial. The CDS tool adoption rate was 31.67%. Adoption was significantly higher for the tool that included behavioral nudges (39.11% vs 20.66%; $P < .001$).

Discussion: We demonstrated feasibility and preliminary efficacy of a PE risk prediction CDS tool developed using insights from behavioral science. The tool is well-positioned to be tested in a large randomized clinical trial.

Trial Registration: Clinicaltrials.gov (NCT05203185)

Lay Summary

Overuse of CT imaging in the diagnosis of pulmonary embolism (PE) exposes patients to unnecessary radiation risk. Professional guidelines recommend the use of validated clinical prediction rules for PE risk stratification before imaging. Their use reduces CT testing by 25%. Incorporating behavioral nudges into clinical decision support (CDS) with clinical prediction rules for PE risk provides a potential avenue for increasing the adoption of these tools.

Our objective was to determine the feasibility and preliminary efficacy of a behavioral nudge on adoption of a PE risk CDS tool. We conducted a pilot trial in 2 Emergency Departments at a large academic healthcare system in the New York metropolitan area. We tested 2 versions of a CDS tool for PE risk assessment developed on a web-based electronic health record-agnostic platform. One version included behavioral nudges incorporated into the user interface.

A total of 1527 patient encounters were included in the trial. Tool adoption was significantly higher for the tool that included behavioral nudges (39.11% vs 20.66%; $P < .001$). We demonstrated feasibility and preliminary efficacy of a PE risk prediction CDS tool developed using insights from behavioral science. The tool is well-positioned to be tested in a large randomized clinical trial.

Key words: clinical decision support; pulmonary embolism; computed tomography; pulmonary angiogram; behavioral economics.

Introduction

Overuse of computerized tomography pulmonary angiography (CTPA) in the diagnostic management of pulmonary embolism (PE) exposes patients to unnecessary risk of contrast induced nephropathy, radiation induced malignancy, and cardiovascular disease.[1–3] As such, professional society guidelines recommend the use of validated clinical prediction rules for PE risk stratification before imaging.[4]

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Their use reduces CTPA testing by 25% without any missed PEs.[5,6] PE risk stratification clinical decision support (CDS) tools have also been shown to reduce unnecessary imaging without missing PEs.[7–13] However, providers do not use these tools, or use them incorrectly, in up to 80% of patients.[14–16] It is estimated that one third of all CTPA studies for PE are avoidable and cost the healthcare system more than $100 million annually.[17]

Incorporating behavioral nudges into CDS with validated clinical prediction rules for PE risk prediction provides a potential avenue for increasing the adoption of these tools and improving care. Nudges are defined as positive reinforcement and indirect suggestions that have a non-forced effect on decision making.[18] For example, "opt-out" options for organ donation consent lead to striking differences in enrollment.[19] Nudges have emerged as a novel and promising avenue for impacting provider behavior as they have a non-forced effect on decision making, preserving autonomy. They additionally incorporate ease as a key principle in design, minimizing negative impacts on clinical workflow and cognitive load.

We applied insights from behavioral science to design, develop, and pilot test a CDS tool for PE risk prediction that incorporated behavioral nudges to reduce the rate of unnecessary CTPA testing in the Emergency Department (ED) setting in a pilot cluster nonrandomized controlled trial. Our objective was to determine the feasibility and preliminary efficacy of the use of nudges and their impact on CDS adoption and provider ordering behavior.

Methods

Study design, setting, and enrollment

We conducted a cluster nonrandomized controlled trial in 2 EDs at a large academic healthcare system in the New York metropolitan area. The study took place between October 1, 2021, and March 3, 2022. The tool was launched with behavioral nudges in one ED and without behavioral nudges in the other. EDs were chosen based on comparable size and acuity levels. Emergency Medicine leadership at each department consented to participate. ED providers (ie, physicians, physician assistants, and nurse practitioners) were trained before the tool launch and automatically enrolled in the trial if they ordered a CTPA for the evaluation of PE during the study period. All study procedures were approved by the Northwell Health Institutional Review Board.

Data abstraction and outcome measures

All study data were extracted from the enterprise electronic health record (EHR) (Sunrise Clinical Manager; Allscripts) reporting database. As this was a pragmatic clinical trial, all data used were routinely collected during the provision of clinical care. Data collected included patient demographic information and Charlson Comorbidity Index (CCI). The CCI predicts 10-year survival in patients with multiple comorbidities and was used as a measure of total comorbidity burden.[20] Race and ethnicity data were collected by self-report in prespecified fixed categories.

For each patient encounter, the patient's final Wells' Score was collected as was d-dimer order and test results, CTPA order and test results, and 3-month ED or inpatient readmission along with CTPA order and test results for readmission. CTPA testing results (PE vs no PE) are specified in discrete categories by the reading radiologist as a part of routine care. Provider information was collected including age, provider type (physicians, physician assistants, or nurse practitioner), and employment type (part vs full time). Tool display, finalization, and adoption metrics were collected. The tool was considered finalized if an order was placed for either d-dimer or CTPA and it was not cancelled. The primary study outcome was concordance between CDS tool order recommended and the provider order placed (*provider tool adoption*). The safety outcome was a missed PE, defined as provider tool adoption on index visit, no CTPA order placed and readmission to the ED or inpatient within 3 months with CTPA positive for PE.

Intervention: EHR-agnostic PE risk prediction tool and behavioral nudge

Description of the tool's development is summarized below and presented in detail in a previous publication.[21] The design and development processes were grounded in user-centered and behavioral design principles and guided by a well-established behavioral framework, the Behavior Change Wheel.[22] Specific behavioral nudges were chosen to target barriers to tool use for PE risk stratification identified during development work.[23] The tool was developed on an EHR-agnostic web-based platform, designed for dissemination to work with any EHR using the open communication protocol Fast Healthcare Interoperability Resources (FHIR) (Figure 1).

The CDS tool was triggered by any order for "CT Chest w/ IV contrast for Pulmonary Embolism" (CTPA) placed at a study site. This triggered an automated backend PE risk assessment. The tool calculated the *Wells' Criteria for Pulmonary Embolism* using patient-specific information from the EHR and the health information exchange. The validation study for this assessment was previously published, finding an accuracy of 92.1% for this method in correctly identifying patients in "PE Unlikely" and "PE Likely" categories using the 2-tiered approach, when compared with manual chart review.[24] The subjective criterion of Wells' Score (PE is #1 diagnosis OR equally likely) was considered positive for all patients as the assessment is triggered only by a provider

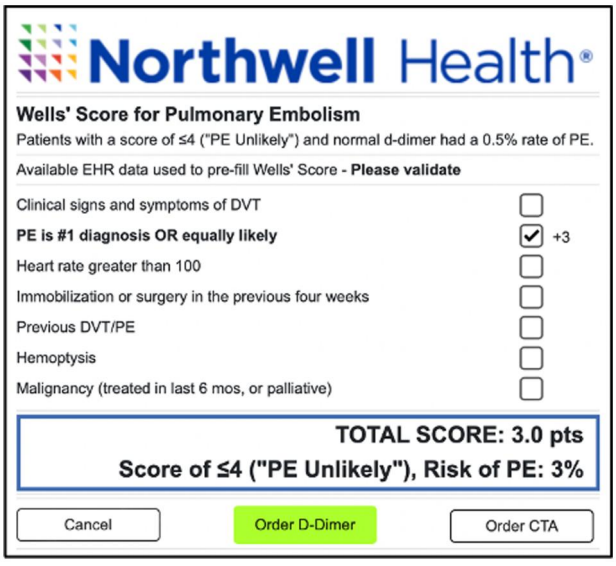

Figure 1. Pulmonary embolism risk prediction clinical decision support tool.

order for imaging. The tool only displayed for the provider if the Wells' Score was ≤4, classified as "PE Unlikely" by the 2-tiered score. All Wells' Score criteria were then modifiable by the provider. The tool recommended ordering a d-dimer for patients with a Wells' Score ≤4 ("PE Unlikely") and a CTPA for patients with a Wells' Score >4 ("PE Likely"). Patients with a Wells' Score ≤4 ("PE Unlikely") and a normal d-dimer test have a 0.5% rate of PE.[25] CTPA testing is unnecessary for these patients. The tool recommended order was highlighted in green and could be placed with one click. The order not recommended could be placed with 2 clicks.

The *peer comparison nudge* showed the individual ordering provider's CTPA yield or hit rate (% of CTPA tests done for PE that were positive for PE) in comparison to the median hit rate of ED doctors in their department (Figure 2). This was reported as an appropriate comparison by providers in development work.[21] Individual hit rates were calculated as 3-month averages and not displayed if the provider ordered less than 10 CTPAs during this period of time. If the provider's hit rate was less than the department average, it was shown in red type font. If the hit rate was above the department average, it was shown in green with a smiley face for encouragement and to minimize regression to the mean. The provider's hit rate and department median were both shown on a color-coded line showing lower hit rates as red, higher ones as green with yellow in between. The green area was chosen based on systemic review data showing that provider's using *Wells' Score for Pulmonary Embolism* improved hit rates from 9% to 12% without missing any PEs.[5,6]

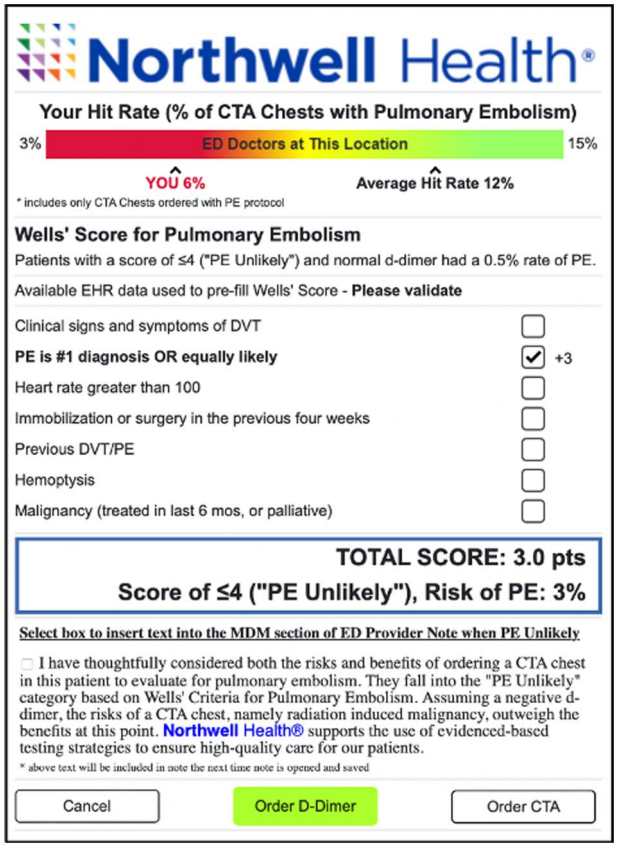

Figure 2. Pulmonary embolism risk prediction clinical decision support tool with behavioral nudge.

The *note incentive nudge* allowed the provider to input a section of pre-written text explaining that the provider had considered the risks and benefits of CTPA and that the risks outweighed the benefits for this patient into their note (Figure 2). With one click the text blurb could be inserted into the medical decision-making section of the ED Provider Note. The text was editable within the note. The text served as a channeling nudge, helping providers to begin envisioning the next steps in placing an order for d-dimer, as opposed to CTPA. The last line of the text stated that the health system supports evidence-based testing strategies for patients. This was chosen to address the provider's fear of missing a PE which emerged as a major barrier in development work.

Statistical analysis

Patient and provider characteristics were summarized descriptively using frequency and percentage for categorical variables and using mean, standard deviation, median, and interquartile range for continuous variables. Categorical characteristics were compared across control and intervention EDs using Pearson's Chi-squared test or Fisher's Exact test (if >20% of expected counts were <5), as appropriate, and continuous characteristics were compared across EDs using the Wilcoxon Rank-Sum test.

CDS tool display, finalization, and adoption, as well as CTPA yield, were summarized similarly across control and intervention EDs. The association between CTPA yield and ED was also assessed within the tool adoption and non-adoption subsets. All results were considered to be statistically significant at the $P < .05$ level of significance, and analyses were performed in R version 4.1.2 (R Project for Statistical Computing; R Foundation).

Results

Characteristics of patients and providers

A total of 1527 patient encounters were included in the study—(median age, 63.11 years; interquartile range [IQR], 51.00-78.00; range, 19.00-103.00 years; 57.17% female) (Table 1). Patients had a median Charlson Comorbidity Index of 5.00 (IQR, 2.00-8.00). This value corresponds to approximately 21% 10-year survival.[20] Patients were seen by a total of 83 providers (median age, 38.63 years; IQR, 32.50-42.00; range, 27.00-70.00 years; 39.76% female). Providers included attending physicians (79.52%), nurse practitioners (2.41%), and physician assistants (18.07%).

PE risk prediction tool display, finalization, and adoption

A total of 1527 patient encounters in which a CTPA order was initiated were included in the analysis (Table 2). The tool was displayed to providers in 20.50% of these encounters. Once displayed, the tool was finalized in almost all encounters. Overall tool adoption was 31.67%. In unadjusted analyses, tool adoption was significantly higher at the ED that received the tool with incorporated behavioral nudges (39.11% vs 20.66%; $P < .001$).

CTPA hit rate and tool adoption

Of 1527 observations in the study, 1347 had a CTPA order completed. Among 1347 observations with a CTPA order completed, 256 (19.01%) had a PE detected. The PE detection rate was significantly higher at the intervention ED

Table 1. Characteristics of patients and providers.

Patient characteristics	Overall (N = 1527)	Control (N = 734)	Intervention (N = 793)	*P*
Age				.066
Median (IQR)	65 (51, 78)	64 (49, 77)	65 (53, 79)	
Mean (SD)	63.11 (18.48)	62.08 (19.13)	64.06 (17.82)	
Female, No. (%)	873 (57.17%)	432 (58.86%)	441 (55.61%)	.201
Race/Ethnicity, No. (%)				<.001
Asian	44 (2.88%)	30 (4.09%)	14 (1.77%)	
Black	475 (31.11%)	435 (59.26%)	40 (5.04%)	
Hispanic or Latino	101 (6.61%)	32 (4.36%)	69 (8.70%)	
Other	92 (6.02%)	76 (10.35%)	16 (2.02%)	
Unknown	77 (5.04%)	21 (2.86%)	56 (7.06%)	
White	738 (48.33%)	140 (19.07%)	598 (75.41%)	
Charlson Comorbidity Index				<.001
Median (IQR)	5.00 (2.00, 8.00)	5.00 (2.00, 7.00)	5.00 (2.00, 9.00)	
Mean (SD)	5.44 (4.24)	4.98 (4.01)	5.87 (4.41)	
Provider characteristics	**Overall (N = 83)**	**Control (N = 34)**	**Intervention (N = 49)**	***P***
Age				.188
Median (IQR)	37 (32.50, 42)	35.00 (32.50, 38)	38 (33, 44)	
Mean (SD)	38.63 (8.80)	36.97 (7.58)	39.78 (9.46)	
Female, No. (%)	33 (39.76%)	15 (44.12%)	18 (36.73%)	.499
Provider type				>.999
Attending	66 (79.52%)	27 (79.41%)	39 (79.59%)	
Nurse practitioner	2 (2.41%)	1 (2.94%)	1 (2.04%)	
Physician assistant	15 (18.07%)	6 (17.65%)	9 (18.37%)	
Employment type				
Full-time (%)	52 (62.65%)	21 (61.76%)	31 (63.27%)	.889
Part-time (%)	31 (37.35%)	13 (38.24%)	18 (36.73%)	

Table 2. PE risk prediction tool display, finalization, and adoption.

Characteristic, No. (%)	Overall (N = 1527)	Control (N = 734)	Intervention (N = 793)	*P*
CDS displayed	313 (20.50%)	129 (17.57%)	184 (23.20%)	.006
Finalization	300 (95.85%)	121 (93.80%)	179 (97.28%)	.128
Adoption (acceptance)	95 (31.67%)	25 (20.66%)	70 (39.11%)	<.001

as compared to the control (26.45% vs 10.76%; $P < .001$). This is in comparison to baseline, 3-month average (May 1, 2021-July 31, 2021), pre-intervention hit rates for the intervention and control EDs that were 9% and 10%, respectively. Overall, for both EDs combined, the CTPA hit rate was higher when the tool was adopted compared to when it was not adopted (30.88% vs 15.93%, $P = .009$).

There were no missed PEs at either ED during the study dates.

Discussion

We designed, developed, and pilot tested a CDS tool for PE risk prediction that incorporated behavioral nudges to reduce the rate of unnecessary CTPA testing in the ED. The tool was developed on an EHR-agnostic web-based platform. Our study demonstrated feasibility of this technical and design approach. Additionally, we demonstrated preliminary efficacy of the incorporated behavioral nudge with noted higher provider CDS tool adoption rates and therefore more appropriate ordering behavior by providers. Differences between baseline and study hit rates were also higher for the ED receiving the behavioral nudge. Differences in hit rates with tool adoption support previous work showing a 25% reduction in CTPA with tool use. These pilot study results are well positioned to support a well-powered randomized controlled clinical trial.

Our findings are consistent with the growing literature supporting the use of behavioral design techniques for impacting provider behavior. Several studies and systematic reviews have shown that peer comparison, default, and salient messaging nudge types are acceptable, feasible, and impactful.[26–31] The growing literature has also detailed key design aspects that are important for high-quality, impactful nudges.[32] Small design choices can significantly impact nudge effect. For example, for peer-comparison nudges, simple feedback on one metric designed to minimize cognitive load, delivered frequently, with a comparison group similar to the target group is more likely to be impactful. We incorporated these and many other key design considerations. Notably, this is the first study to incorporate a peer-comparison nudge within the user interface of a CDS tool, providing peer-comparison feedback synchronously with the target behavior.

CDS tool adoption rates at both sites were high in comparison to meta-analyses of CDS, with typical adoption rates as low as 10%.[33–37] The user-centered approach for designing the tools likely contributed to this. The tool with and without nudges included an EHR automated PE risk assessment, minimizing provider clicks to complete the tool and allowing for a significant reduction in tool triggering. The tool displayed

only about 20% of the time providers placed an order for CTPA, reducing alert fatigue, which is a significant contributor to low tool adoption. The tool's technological development on a web-based platform additionally allowed for a simple intuitive user interface that is often not possible when constrained by EHR functionality.

Our study has limitations. First, this was a nonrandomized pilot study where differences between the 2 EDs may have contributed to differences in observed provider CDS tool adoption. For example, there were significant differences in the diversity of the patient populations at the 2 EDs. Second, findings might not generalize to EDs dissimilar to those enrolled. Third, results are dependent on EHR data collected during routine clinical practice, which can be imperfect; however, validity was demonstrated for key metrics.[24] Lastly, our safety analyses were limited to return visits to the study site health system, so if a patient presented to a site outside of the study site health system, it would not have been captured.

Conclusion

We applied insights from behavioral science to design, develop, and pilot test a CDS tool for PE risk prediction that incorporated behavioral nudges to reduce the rate of unnecessary CTPA testing in the ED. The tool was developed on an EHR-agnostic web-based platform, designed for dissemination. We demonstrated feasibility and preliminary efficacy of this approach. The tool is well-positioned to be tested in a randomized clinical trial.

Author contributions

All authors contributed to the conception of the work, the acquisition or analysis of data, and the drafting of intellectual content. All authors are accountable for all aspects of the work and provided final approval of the work.

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Conflicts of interest

None declared.

Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

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