

Success of a Safe and Simple Algorithm to Reduce Use of CT Pulmonary Angiography in the Emergency Department

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OBJECTIVE. The purpose of our study was to determine whether the radiation exposure to patients with suspected pulmonary embolism (PE) could be decreased by safely increasing the use of ventilation–perfusion (V/Q) scanning and decreasing the use of CT pulmonary angiography (CTPA) through an educational intervention.

MATERIALS AND METHODS. Collaborative educational seminars were held among the radiology, nuclear medicine, and emergency medicine departments in December 2006 and January 2007 regarding the radiation dose and accuracies of V/Q scanning and CTPA for diagnosing PE. To reduce radiation exposure, an imaging algorithm was introduced in which emergency department patients with a clinical suspicion of PE underwent chest radiography. If the chest radiograph was normal, V/Q scanning was recommended, otherwise CTPA was recommended. We retrospectively tallied the number and results of CTPA and V/Q scanning and calculated mean radiation effective dose before and after the intervention. False-negative findings were defined as subsequent thromboembolism within 90 days.

RESULTS. The number of CTPA examinations performed decreased from 1,234 in 2006 to 920 in 2007, and the number of V/Q scans increased from 745 in 2006 to 1,216 in 2007. The mean effective dose was reduced by 20%, from 8.0 mSv in 2006 to 6.4 mSv in 2007 ($p < 0.0001$). The patients who underwent CTPA and V/Q scanning in 2006 were of similar age. In 2007, the patients who underwent V/Q scanning were significantly younger. There was no significant difference in the false-negative rate (range, 0.8–1.2%) between CTPA and V/Q scanning in 2006 and 2007.

CONCLUSION. The practice patterns of physicians changed in response to an educational intervention, resulting in a reduction in radiation exposure to emergency department patients with suspected PE without compromising patient safety.

Keywords: CT, lung scan, practice pattern, pulmonary angiography, pulmonary embolism, radiation exposure, ventilation–perfusion scanning

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Recently, there has been a rise in physician and public awareness of radiation exposure in diagnostic radiology. Much of this attention has been due to the increased use of CT [1] and the resulting increase in radiation exposure. In 2007, the National Council on Radiation Protection and Measurements announced that the per capita effective dose due to medical radiation in the United States rose from 0.54 mSv in 1980 to 3.2 mSv in 2006—a 600% increase [2].

In the 1980s and early 1990s, ventilation–perfusion (V/Q) scanning was the main imaging technique for the detection of pulmonary embolism (PE). However, with the increasing availability of CT pulmonary angiography (CTPA), there has been a rapid increase in the use of this technique for imaging patients with suspected PE [3] and a concomitant decrease in the use of V/Q scanning [1].

The total effective radiation dose from CTPA is approximately five times greater than that from V/Q scanning, and the dose is 20–40 times greater to the female breast [4, 5]. Many physicians are not aware of these differences [6, 7].

The Prospective Investigation of Pulmonary Embolism Diagnosis (PIOPED) II trial [8] described a similar positive predictive value (PPV) for CTPA compared with V/Q scanning in patients with suspected PE, with a PPV for CTPA of 86% and a negative predictive value (NPV) of 95%. The original PIOPED study [9] found a greater than 85% PPV for high-probability V/Q scans and a less than 20% PPV for low-probability scans, which fell to less than 10% PPV with later modifications to the assessment criteria [10].

The purpose of the current study was to decrease radiation exposure to emergency department patients with suspected PE, for

CT Pulmonary Angiography in the Emergency Department

whom imaging was clinically warranted, by safely increasing the use of V/Q scanning and decreasing the use of CTPA through an educational intervention.

Materials and Methods

The study was approved by our institutional review board and informed consent was not required. After interdisciplinary discussion, an intervention in the form of educational seminars was conducted to reduce patient radiation dose for emergency department patients with suspected PE. Two hour-long seminars were held in December 2006 and January 2007 with the available emergency department staff, including residents and attending physicians, of a large urban academic medical center and were led by the director of nuclear medicine in collaboration with the chief of radiology and the section chief of cardiothoracic radiology. Information from the literature about the radiation dose and accuracy of V/Q scanning and CTPA was discussed at these sessions. It was recommended to the emergency department clinicians that stable patients with a clinical suspicion of PE should initially be imaged with chest radiography. If the chest radiography findings were normal and further imaging for suspected PE was deemed appropriate by clinical assessment, the emergency department staff was advised to request a V/Q scan. If the chest radiograph showed a pleural or parenchymal abnormality, CTPA was recommended. If either examination was equivocal or the imaging results were discordant with the clinical impression, the emergency department staff was advised to request the alternative test in addition. The algorithm was provided to the emergency department staff as a handout, which resulted in a collaborative, consultative approach between the imaging services and the emergency department staff.

Although CTPA is a faster and more convenient examination than V/Q scanning, the emergency department agreed that reducing patient radiation exposure would improve the care of appropriate stable patients despite the inconvenience of a slight delay in patient disposition. The algorithm was reinforced by a telephone call consultation and reminder initiated by a radiologist every time CTPA was requested in an emergency department patient with a normal chest radiograph. If the differential diagnosis included aortic dissection, a CT was performed. In accordance with our usual clinical care, V/Q scanning was recommended for patients with contraindications to CTPA regardless of the findings on chest radiography. The algorithm was well accepted, but if it was not used for an individual patient, an e-mail dialogue with the emergency department was initiated by

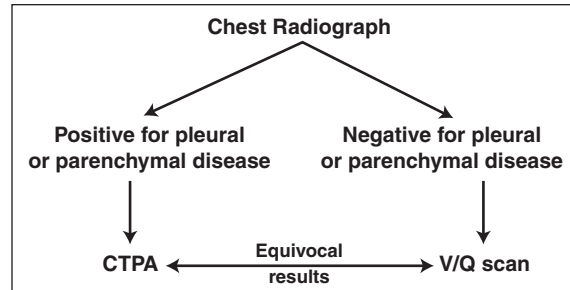


Fig. 1—Flowchart shows algorithm for suspected pulmonary embolism. CTPA = CT pulmonary angiography, V/Q scan = ventilation-perfusion scanning.

the imaging services to discuss the specific details. In each case, the final decision on the appropriate imaging technique for an individual patient was left to the clinician caring for the patient in the emergency department (Fig. 1).

Pregnant patients composed only a very small minority of our emergency department patients with suspected PE because there is no labor and delivery service at our institution and they were not specifically tracked for this study.

To determine the efficacy and safety of the intervention, we retrospectively tallied the number and results of CTPA and V/Q scanning performed quarterly for 2006, the year before the intervention and for 2007, the year after the intervention. We calculated the mean effective dose for imaging performed to evaluate for suspected PE for each year, for each patient in the study population, and for the subsets of all patients younger than 40 years and women younger than 40 years. Because measuring individual patient radiation exposure is not practical, estimations by Mettler et al. [5] were used to assign a dose of 2.2 mSv to each V/Q scan. Each CTPA was assigned an estimated dose of 10 mSv. This dose was selected on the basis of the most recent literature available for nonoptimized CTPA protocols [11] and a survey of recent CTPA examinations performed at our institution before the introduction of new radiation reduction protocols. The radiation doses estimated by the CT scanner for each CTPA in 2006 and 2007 were not available.

CTPA was performed on a 64-MDCT LightSpeed VCT scanner (GE Healthcare) or a Brilliance 16 scanner (Philips Healthcare) using the manufacturers' suggested protocols (LightSpeed scanner: pitch, 0.98; 12 kVp; mAs determined using automatic exposure control [SmartmA, GE Healthcare] and Brilliance scanner: pitch, 0.9; 120 kVp; 250 mAs). Images were reconstructed to 1.25 mm in the axial plane and 2 mm in the coronal and sagittal planes. Scanning was performed with the administration of 80–125 mL of IV nonionic contrast material. Either bolus tracking or a timing injection was performed to optimize enhancement of the pulmonary arteries. The CTPA examinations were reviewed on a

Centricity PACS workstation (GE Healthcare) by a board-certified radiologist. Off-hours studies were reviewed by an in-house radiology resident (postgraduate year [PGY] 3–5).

V/Q scanning is available 24 hours a day, 7 days a week at our institution. The ventilation portion of the scan was performed routinely using 40 mCi (1,480 MBq) of aerosolized ^{99m}Tc-labeled DTPA (Aerovent, MediNuclear) followed by the IV administration 4–5 mCi (148–185 MBq) of ^{99m}Tc-labeled macroaggregated albumin for the perfusion study. Ventilation and perfusion images were both acquired in eight standard projections for 100 seconds using a photopeak of 140 keV (20% window) on a SkyLight or Forte ADAC gamma camera (Philips Healthcare) to obtain approximately 100,000 and 500,000 counts, respectively. The scintigrams were reviewed on printed films by attending physicians in the nuclear medicine department with 10–42 years of experience interpreting V/Q scans. Overnight and weekend studies were reviewed by an in-house radiology resident (PGY 3–5). All of our radiology residents receive extensive training in the interpretation of V/Q scans. There is a technologist present in the hospital from 8:00 am until midnight. Overnight, the technologist is on call to the hospital and usually arrives within 30 minutes to perform a study.

Final reports of all V/Q and CTPA examinations were reviewed. Agreement between the residents' preliminary reports and the final report is consistently very high in our institution, with amended reports issued in approximately 1% of cases for both CTPA and V/Q scanning. The V/Q scans were deemed positive if they were reported as high probability for PE and negative if they were interpreted as normal, very low probability, or low probability. Intermediate and indeterminate scans were categorized as indeterminate. CTPA was deemed positive if the reviewing radiologist identified a PE and negative if no PE was identified. CTPA was considered indeterminate if the main or lobar pulmonary arteries were not visualized or if the examination was interpreted as equivocal or nondiagnostic. The number and results of alternative imaging within 7 days after nonpositive

(negative or indeterminate) V/Q scanning or CTPA were reviewed for the diagnosis of PE.

The electronic medical records of all patients with negative examinations were reviewed using Clinical Looking Glass (CLG) (Montefiore Medical Center), a user-friendly, interactive data mining software application developed at our institution to evaluate health care quality, effectiveness, and efficiency. Using CLG, records were reviewed to determine if each patient with a negative examination returned to our medical center and was given a new diagnosis of deep vein thrombosis or PE within 90 days. These cases were defined as false-negative. Additionally, the electronic medical record and the Social Security Death Index were reviewed to identify patients with a negative imaging study who died of any cause within 90 days. This included at least the 98% of our patient population who had Social Security numbers.

For statistical analysis, continuous variables were compared using the Student's *t* test and dichotomous variables were compared using chi-square tests.

Results

During 2006, the year before the educational intervention, 1,979 imaging examinations (1,234 CTPA and 745 V/Q scanning) were performed from the emergency department in 1,753 patients with suspected PE. In 2007, after the intervention and initiation of the new imaging algorithm, 2,136 imaging examinations (920 CTPA and 1,216 V/Q scanning) were performed in 1,843 patients with suspected PE from the emergency department ($p < 0.0001$, chi-square) (Table 1).

In 2006, CTPA was the dominant imaging technique for emergency department patients with suspected PE in each quarter, performed in 60.3–64.6% of examinations (Fig. 2). The first quarter of 2007 showed an immediate decline in CTPA to 49.8% of examinations, declining further to 39.4% in the final quarter.

In 2006, there was no significant difference in the ages of patients evaluated with CTPA compared with V/Q scanning (mean, 55.0 vs 54.7 years). Women were more frequently imaged than men, with a higher proportion of women imaged by V/Q scanning (71%) than CTPA (66%) ($p = 0.03$). In contrast, in 2007, patients imaged with V/Q scanning were significantly younger than those imaged with CTPA (mean, 50.8 vs 56.7 years) ($p < 0.0001$). V/Q scanning (74.0%) again showed a significantly greater proportion of women than CTPA (65.9%) ($p < 0.0001$).

The mean effective dose to patients being evaluated for PE fell 20% from 8.0 mSv in

2006 to 6.4 mSv in 2007 ($p < 0.0001$). The reduction in mean effective dose to patients younger than 40 years was 34%, from 7.7 to 5.1 mSv, ($p < 0.0001$). Women younger than 40 years had a 32% reduction in mean effective dose from 7.2 mSv in 2006 to 4.9 mSv in 2007, ($p < 0.0001$).

V/Q scans were significantly more often negative than CTPA in both 2006 (89.4%

vs 84.8%) and 2007 (89.4% vs 81.8%) ($p < 0.0001$ each year). The proportion of CTPA and V/Q scans interpreted as negative or positive and the proportion of indeterminate V/Q scans did not significantly change between 2006 and 2007 (Table 2). However, the proportion of CTPA examinations interpreted as indeterminate increased from 2.1% in 2006 to 4.7% in 2007 ($p = 0.001$).

TABLE 1: Distribution and Ratios of Imaging for Suspected Pulmonary Embolism (PE) in 2006 and 2007 Before and After Educational Intervention in December 2006

Imaging	Year		<i>p</i>
	2006	2007	
All PE imaging	1,979	2,136	
CTPA	1,234 (62.4)	920 (43.1)	
V/Q scanning	745 (37.6)	1,216 (56.9)	
Ratio of CTPA:V/Q scanning	1.7	0.8	< 0.0001

Note—Data in parentheses are percentages. CTPA = CT pulmonary angiography, V/Q = ventilation–perfusion.

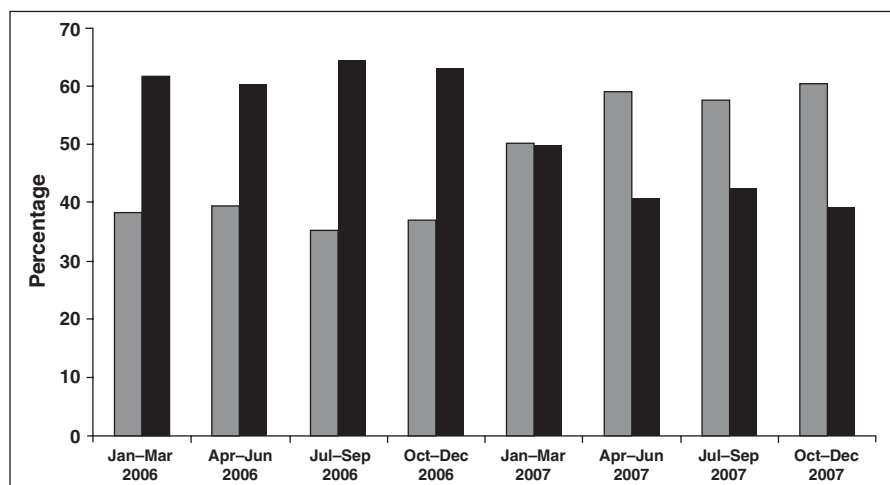


Fig. 2—Bar chart shows percentage of ventilation–perfusion scanning (gray) and CT pulmonary angiography (black) performed for workup of suspected pulmonary embolism for each quarter in 2006 and 2007.

TABLE 2: Results of Imaging for Suspected Pulmonary Embolism in 2006 and 2007

Imaging Examinations	2006		2007		<i>p</i> ^a
	V/Q scanning	CTPA	V/Q scanning	CTPA	
Total	745	1,234	1,216	920	
Negative	666 (89.4)	1,046 (84.8)	1,087 (89.4)	753 (81.8)	0.003 negative CTPA vs V/Q in 2006; < 0.0001 negative CTPA vs V/Q in 2007
Indeterminate	49 (6.6)	26 (2.1)	86 (7.1)	43 (4.7)	0.001 indeterminate CTPA in 2006 vs 2007; < 0.0001 indeterminate CTPA vs V/Q in 2006
Positive	30 (4.0)	162 (13.1)	43 (3.5)	124 (13.5)	< 0.0001 positive CTPA vs V/Q 2006 and 2007

Note—Data in parentheses are percentages. CTPA = CT pulmonary angiography, V/Q = ventilation–perfusion. ^aChi-square test; all other comparisons were not statistically significant.

CT Pulmonary Angiography in the Emergency Department

In 2006, 6.0% (45/745) of V/Q scans were followed by a CTPA within 7 days compared with 6.1% (74/1,216) in 2007 ($p = 1.000$). Among patients with nonpositive V/Q scans, 5.6% (40/715) underwent CTPA within 7 days in 2006 compared with 5.3% (62/1,173) in 2007 ($p = 0.754$). In 2006, 25% (10/40) of patients with nonpositive V/Q scans who underwent CTPA were diagnosed with PE compared with 10% (6/62) in 2007 ($p = 0.038$).

In 2006, 2.4% (30/1,234) of CTPA examinations were followed by V/Q scanning within 7 days compared with 3.2% (29/920) in 2007 ($p = 0.31$). Among patients with nonpositive CTPA, 1.9% (20/1,072) underwent V/Q scanning within 7 days in 2006 compared with 2.8% (22/796) in 2007 ($p = 0.20$). In 2006, no patients with a nonpositive CTPA were diagnosed with PE on V/Q scanning compared with 14% (3/22) in 2007 ($p = 0.087$).

Review of the medical records for the patients imaged in 2006 revealed a false-negative rate (negative imaging examination with subsequent diagnosis of PE or deep vein thrombosis within 90 days) of 0.8% for CTPA (8/1,046) and 1.1% for V/Q scans (7/666). After the intervention, the false-negative rate for CTPA was 1.1% (8/753) and 1.2% for V/Q scans (13/1,087). The differences in the false-negative rates were not significant between 2006 and 2007 or between CTPA and V/Q scanning.

All-cause 90-day mortality among patients with negative imaging examinations was higher for patients imaged with CTPA (2006: 9.4% [92/975] and 2007: 14.1% [97/689]) than for patients imaged with V/Q scanning (2006: 5.7% [33/584] and 2007: 3.9% [38/982]) ($p < 0.0001$ for each year). Comparing 2006 with 2007, there was a significant increase in the proportion of patients with negative CTPA who died within 90 days ($p = 0.003$) accompanied by a significant decline in the proportion of patients with negative V/Q scanning who died ($p < 0.0001$).

Discussion

The current study shows that a simple algorithm, based on results of chest radiography, can successfully change the practice pattern for imaging emergency department patients with suspected PE and reduce radiation exposure without compromising patient safety. In our population, about 60% of emergency department patients with suspected PE were imaged with CTPA, the higher-radiation-dose imaging technique, in 2006. This pat-

tern reversed in 2007 after an educational intervention with about 60% of patients imaged with V/Q scanning, the lower-radiation-dose technique. The rate of false-negative examinations was low, 1.1% for CTPA and 1.2% for V/Q scanning, in 2007. These results are important because it is well documented that radiation exposure from diagnostic tests has been increasing at a rapid rate [12]. The American College of Radiology has called on physicians to become educated about radiation risks and exposure to better judge the risks and benefits of diagnostic procedures [13]. Although educational interventions often meet with limited success [14], this study shows that a simple and collaborative educational intervention can quickly change a practice pattern in a real-world setting.

Before the intervention, there was no difference in the ages of patients who underwent CTPA and V/Q scanning. After the intervention, the population of patients imaged with V/Q scanning was significantly younger than those imaged with CTPA. Additionally, a significantly higher proportion of women were imaged with V/Q scanning than with CTPA in both years, with a trend toward a more pronounced difference after the intervention. Younger patients and women are more vulnerable to the biologic effects of radiation [12], and these more vulnerable populations benefitted most from the change in practice patterns. Overall, the study population showed a 20% reduction in mean effective dose between 2006 and 2007, with a 32% reduction for women younger than 40 years.

Using the results of chest radiography as a simple triage mechanism has been previously proposed and has a number of advantages [15]. First, a chest radiographic abnormality renders V/Q scanning more difficult to interpret and often results in an indeterminate interpretation. The high indeterminate rate is one of the reasons V/Q scanning has fallen out of favor during the past decade. Performing V/Q scanning exclusively in patients with normal chest radiographs likely selected a low-risk population, which allowed the low-probability interpretation to have a very high NPV in this group. After the intervention, our number of V/Q scans increased by 63% without a significant change in the rate of indeterminate interpretations.

The proportion of positive V/Q scanning was significantly lower than the proportion of positive CTPA for both 2006 (4.0% vs 13.1%) and 2007 (3.5% vs 13.5%) and did not change significantly over the 2-year period.

However, our data suggest that triaging patients with normal chest radiographs to V/Q scanning and those with abnormal chest radiographs to CTPA resulted in increasingly separate populations. Not only did the V/Q scanning group become younger than the CTPA group, but the CTPA group became sicker and the V/Q scanning group healthier as manifested by a significant increase in the 90-day all-cause mortality of patients with negative CTPA in 2007 compared with 2006, associated with a corresponding decline in the 90-day mortality of patients with negative V/Q scanning.

A trend toward an increase in CTPA use and a decrease in V/Q scanning has been previously documented, along with an increase in overall imaging for suspected PE [3, 16]. Our institution, even before the intervention, was a bit unusual for the United States in that it continued to use V/Q scanning to image a large minority of patients with suspected PE. A number of studies suggest that the increase in CTPA has not resulted in an improvement in patient outcomes. In a recent randomized, single-blind trial that concluded that CTPA was not inferior to V/Q scanning in showing PE [17], patients who presented with a high clinical suspicion of PE were randomized to CTPA or V/Q scanning. That study found a significantly higher rate of PE diagnosis in the CTPA group compared with the V/Q scanning group but with no difference in mortality or complications due to thromboembolic events in 3 months of follow-up. In New York State, the number of patients diagnosed with PE nearly doubled between 1994 and 2004, during the period when CTPA became the dominant imaging technique for suspected PE. However, the number of deaths attributed to PE remained unchanged [18]. These findings suggest that although the diagnosis of PE increased, clinically relevant disease did not change. As has been suggested elsewhere, these findings raise the question of overdiagnosis of PE (diagnosis of clinically unimportant disease) with CTPA [19–21].

The safety of relying on a negative V/Q scan has been reaffirmed by PIOPED and PIOPED II [8, 9, 22]. Revisions in the interpretation of V/Q scans after PIOPED resulted in a change in the low-probability category. Three series have shown a less than 1% incidence of serious thromboembolic events over a 6-month or longer follow-up period after low-probability V/Q scanning [23–25]. The Christopher Group described a 1.3%

incidence of thromboembolic disease after a negative CTPA [26]. Although we broadened our definition of a negative V/Q scan to include the low-probability category, our results are similar to those in the literature, with statistically equivalent false-negative rates for CTPA and V/Q scanning ranging from 0.8% to 1.2% over the 2-year period. However, this may reflect our low-risk emergency department population and may not be generalizable to a higher-risk population.

Also of note is the importance of the clinical picture in interpreting both CTPA and V/Q scanning results [27]. Both PIOPED and PIOPED II showed a precipitous drop in accuracy when the clinical suspicion was discordant with the imaging diagnosis. The PPV of a positive CTPA has been shown to be only 58% when clinical probability is low, similar to the 56% found for V/Q scanning [8, 9]. This confirms the importance of clinical assessment in the diagnosis of PE and recognizes that when the imaging diagnosis does not match the clinical picture, alternative testing should be considered, as specified in our algorithm.

In a Canadian study, Anderson et al. [17], described a higher rate of positive V/Q scans than we found in the current study (9% vs 4%). We attribute this difference to their requirement of an objective clinical assessment as part of the trial, and only those with a high-probability Wells score qualified for imaging. Our emergency department, similar to most in the United States, used subjective assessment to decide whether imaging for PE was warranted [27, 28]. This may soon change because the pulmonary embolism rule-out criteria are under consideration by the American College of Emergency Department Physicians [29]. Although unnecessary imaging is not ideal, it is a common phenomenon in the litigious atmosphere of medical practice in the United States.

Since 2006 and 2007, the period of this study, a number of radiation reduction strategies and technologic improvements have been proposed and are being implemented that, when optimally used, will diminish the radiation exposure from CTPA to the 3–5 mSv range [30–34]. At our institution, we have begun regularly using bismuth breast shields in women and automated dose modulation when technologically feasible. Advances in CT technology, such as iterative reconstruction and automatic kVp adjustment, will continue a downward trend for CTPA dose in the future. These measures

have been estimated to lead to decreases in the dose to the lung and breast of 45% and 55%, respectively [30], and will reduce the difference in radiation exposure between CTPA and V/Q scanning.

Limitations of this study include its retrospective nature and that objective clinical assessment and D-dimer were not required before imaging. Mandating these measures before irradiating the patient with CTPA or V/Q scanning might result in further reduction in radiation dose [26, 27]. However, we chose a collaborative design using a simple educational intervention followed by collegial telephone call and e-mail reminders. This forged a strong working relationship between the imaging departments and the emergency department physicians, who developed a dedication to reducing patient radiation exposure. Even though the 24-hour coverage provided by our nuclear medicine department is not widely available in other institutions, this radiation-reducing algorithm can be used at any institution during normal working hours. Our results show the success of this approach in the real-world setting of a large urban academic medical center. In fact, our emergency department has become interested in further reducing patient radiation exposure and has recently instituted radiation reduction measures for other diagnoses, such as renal colic and hydrocephalus.

Other limitations of this study are that recurrent thromboembolic disease could only be ascertained for the group of patients who returned to our institution, so the rate of recurrent thromboembolic disease may be underestimated. However, we have no reason to believe that this biased our results in favor of the CTPA or V/Q scanning groups. Additionally, radiation exposure for both CTPA and V/Q scanning was modeled, based on the literature, rather than measured.

In conclusion, we have shown that a simple, collaborative educational intervention and routing of patients to CTPA or V/Q scanning based on the results of chest radiography can safely change the practice pattern in the emergency department for patients with suspected PE. The use of V/Q scanning in patients with normal chest radiographs results in considerably lower patient radiation exposure with a comparable NPV to CTPA.

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CT Pulmonary Angiography in the Emergency Department

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