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ORIGINAL RESEARCH ARTICLE

Appropriateness and outcomes of complementary radiological studies for pulmonary embolism diagnosis in routine clinical practice

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Abstract

Background: The use of complementary radiological studies for suspected pulmonary embolism (PE) during the same clinical episode is uncommon and is usually due to a suboptimal or indeterminate initial study. However, the prevalence and decision-making in this clinical scenario are uncertain. **Aim:** The objective of this study was to determine the appropriateness of complementary studies (computed tomography angiography [CTA] and perfusion single-photon emission computed tomography/low-dose computed tomography [SPECT/ldCT]) in patients with suspected acute PE in real-world clinical practice. **Methods:** We analyzed all patients who underwent both tests for suspected PE during the same clinical process over a 10-year period. **Results:** Pulmonary CTA and perfusion SPECT/ldCT were performed as complementary studies in 4.42% of patients with suspected PE. In 69.7% of these patients, CTA was the initial diagnostic test and was subsequently followed by perfusion SPECT/ldCT, of which 64.6% were considered to have been inappropriately indicated. In 30.3% of patients, an initial lung perfusion SPECT/ldCT was followed by CTA; of these, 26.4% of CTA and 33.9% of perfusion studies were considered inappropriate. The overall agreement between the results of both tests was 49.3%. **Conclusion:** At least one imaging test was considered inappropriately indicated in 67.6% of patients who underwent both tests. This may result in unjustified risk associated with these procedures, unnecessary increase in costs, and additional difficulty in interpreting the high proportion of studies with discrepant results. Diagnostic and treatment protocols should be implemented in patients with suspected PE to reduce differences in clinical outcomes and optimize resource use. **Relevance for patients:** Inappropriate indications for radiological studies may cause unnecessary harm to certain patients, especially with regard to contrast-induced nephropathy.

Keywords: Pulmonary embolism; Diagnosis; Chest computed tomography angiography; Single-photon emission computed tomography/low-dose computed tomography

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1. Introduction

Venous thromboembolism (VTE) is the third leading cause of cardiovascular disease worldwide, after ischemic heart disease and cerebrovascular disease.[1] The incidence of pulmonary embolism (PE) is estimated in epidemiological studies to be around 39–115 per 100,000 inhabitants, and appears to be increasing in recent years, associated with population aging, a higher prevalence of VTE risk factors, and an increasing number of incidental PE diagnoses on imaging tests performed for other clinical reasons.[2] Although recent epidemiological studies suggest a downward trend in the case fatality rate for PE[3], PE-related mortality remains estimated at around 370,000 deaths/year in Europe[2,4]; in many cases, death occurs within the first few hours after presentation, or PE is identified only at post-mortem examination, thus requiring a high degree of suspicion and early diagnosis and treatment. Both PE and its main long-term sequela, chronic thromboembolic pulmonary hypertension, have a significant negative impact on patients' quality of life and result in a high consumption of economic and social resources.[5]

The diagnosis of suspected PE is based on the combination of clinical probability scales (the most commonly used being the Wells scale)[6,7] and D-dimer determination. Diagnostic imaging tests are indicated in patients in whom PE cannot be ruled out/confirmed based on decision algorithms.[8] While multidetector computed tomography angiography (CTA) is the imaging method of choice for diagnosing PE, pulmonary perfusion studies are particularly useful in patients with renal failure, allergy to iodinated contrast, or pregnancy.[7] Furthermore, in 5–10% of patients, CTA is indeterminate (non-diagnostic) or shows suboptimal visualization of the pulmonary arterial tree[9], which reduces diagnostic accuracy.

The use of multiple complementary radiological tests to confirm or rule out PE in the same patient is often prompted by an inconclusive (non-diagnostic) result from an initial study. However, this diagnostic process may be inappropriate for some patients, leading to excessive risk and economic costs, and generating heterogeneous and controversial clinical situations in cases of discrepancies between the tests. There is limited evidence regarding the prevalence, causes, and management of this clinical scenario[10-12]; the study of these patients may shed light on these issues and suggest possibilities for improved care.

The objectives of this study were to: (i) describe the population in which CTA and pulmonary perfusion single-photon emission computed tomography/low-dose computed tomography (SPECT/ldCT) are performed for clinical suspicion of symptomatic acute PE in real-world clinical practice, and their prevalence; (ii) analyze the reasons why both tests are performed in a complementary manner in these patients; (iii) determine the appropriateness of this indication, with respect to the recommendations of clinical practice guidelines and the PE management protocol of our hospital; and (iv) analyze the degree of concordance between the results of both diagnostic tests, and the mortality and incidence of VTE in this group of patients.

2. Methods

We selected all patients who had undergone any diagnostic imaging procedure (CTA or SPECT/ldCT) for suspected acute PE at the Hospital Universitario de La Princesa over a 10-year period, starting from January 1, 2010. We then selected those undergoing CTA and pulmonary perfusion SPECT/ldCT consecutively during the same clinical course (defined as a single visit to the Emergency Department or a single episode of clinical suspicion during hospital admission), excluding patients who underwent only CTA or only pulmonary perfusion SPECT/ldCT, and those undergoing both procedures in different clinical episodes. The Hospital Universitario de La Princesa is a tertiary university hospital without Gynecology–Obstetrics or Pediatrics departments. We did not include patients from 2020 onward to avoid the confounding factor associated with SARS-CoV-2 infection, which could have resulted in different use of diagnostic studies.[13]

Variables of interest were obtained by retrospective review of data in the patients' electronic medical records; all collected data were reviewed by another physician to minimize selection or information bias. We recorded age and sex, baseline characteristics, dates and results of CTA, SPECT/ldCT, and lower limb compression ultrasound, reason for performing SPECT/ldCT, presence of an alternative diagnosis on CTA, clinical and laboratory variables at diagnosis, including the Wells probability scale, and incidence of VTE and mortality from VTE and all causes at 1, 3, and 12 months.

The appropriateness of the indication for CTA and perfusion SPECT/ldCT was assessed by two physicians specializing in VTE, according to the recommendations of our hospital's PE management protocol (Figure 1) and clinical practice guidelines[8], after analysis of patients' baseline characteristics, pre-test probability of PE, D-dimer values, results of imaging procedures, and one-year outcomes; the inter-rater agreement was 95%. CTA is the imaging test of first choice for the confirmatory diagnosis of PE in most patients, while SPECT/ldCT is the technique of choice in patients with contraindications to the administration of iodinated contrast, and lower limb

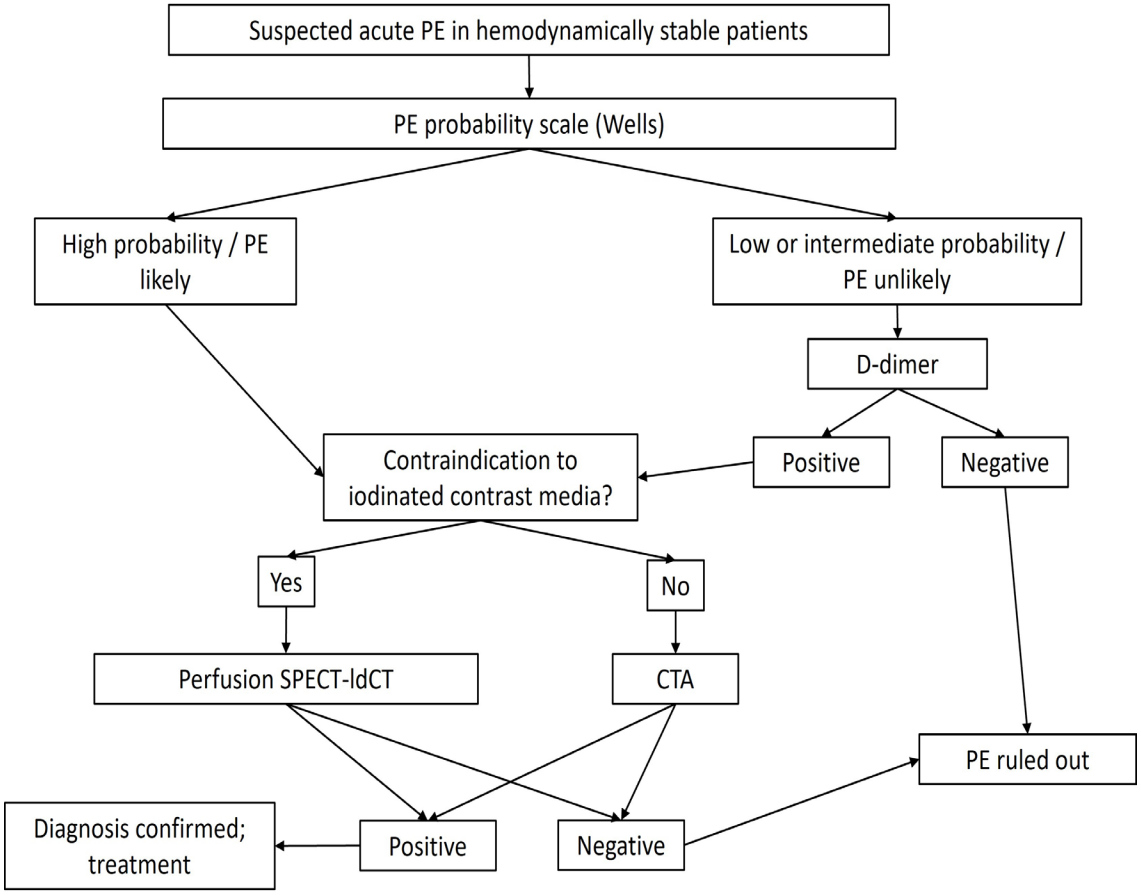

Figure 1. Diagnostic algorithm for PE in hemodynamically stable patients based on the PE management protocol of La Princesa University Hospital. Abbreviations: CTA: Computed tomography angiography; PE: Pulmonary embolism; SPECT/ldCT: Single-photon emission computed tomography/low-dose computed tomography.

Doppler ultrasound would be recommended in those patients with an intermediate-to-high probability of PE when the aforementioned tests cannot be performed immediately, or there are inconclusive results. CTA and lower limb Doppler ultrasound are available immediately and continuously, while SPECT/ldCT is available only Monday to Friday from 8 a.m. to 3 p.m. The technical specifications of CTA and SPECT/ldCT are shown in Figures A1 and A2, respectively.

For the descriptive analysis, quantitative variables were expressed using measures of central tendency (mean for symmetric, continuous data, and median for skewed data and outliers) and dispersion (standard deviation and range), while qualitative variables were expressed as frequencies and percentages. Analyses were performed using SPSS version 29.0 (IBM Corp, United States of America).

The study was approved by the Ethics Committee of La Princesa Hospital, exempting patients from providing informed consent as it was a retrospective review of medical records.

3. Results

During the study period, 3,595 diagnostic imaging tests (CTA or pulmonary perfusion SPECT/ldCT) were performed at our hospital in 3,211 patients with suspected acute symptomatic PE. At least two tests were performed in 182 patients during this period, and of these, 142 underwent CTA and SPECT/ldCT consecutively during the same clinical course (4.42% of patients). The patients' baseline characteristics are shown in Table 1. All patients underwent chest X-ray prior to CTA and perfusion SPECT/ldCT. Lower extremity Doppler ultrasound was performed in 32.4% of patients; among these patients, 21.7% had findings positive for deep vein thrombosis (DVT); no patient was diagnosed with venous thrombosis in a location other than the lower extremities. No pulmonary

perfusion SPECT/ldCT was reported as indeterminate (non-diagnostic).

In 99 of the 142 patients (69.7%), CTA was indicated as the initial diagnostic test, followed by an additional perfusion SPECT/ldCT scan, while in 43 (30.3%), the reverse sequence was performed. The main indications for performing an initial pulmonary perfusion SPECT/ldCT were renal failure, suspected allergy to iodinated contrast, and pregnancy, although in 41% of the patients, none of these were present, as shown in Figure 2.

An analysis was performed to determine the appropriateness of the indication for CTA and perfusion SPECT/ldCT, according to the recommendations of our hospital's PE management protocol and clinical practice guidelines[8], based on the time sequence between the two tests.

(i) Patients who initially underwent CTA followed by pulmonary perfusion SPECT/ldCT (99):
   (a) In 53 of these patients (53.5%), the reason for performing a perfusion SPECT/ldCT scan as an adjunct to the CTA was a persistent high clinical suspicion of PE despite a negative CTA result, even though the latter was performed using optimal technique. However, 49.1% of the patients had a low pre-test probability of PE according to the Wells probability score, 47.2% an intermediate probability, and 3.7% a high probability. Doppler ultrasound was performed in 37.7% of the patients, revealing DVT in two patients. The agreement between the CTA and pulmonary perfusion SPECT/ldCT results was 43.4%, since 56.6% of the pulmonary perfusion studies were reported as having a high probability of PE, resulting in the initiation of anticoagulation in all of these patients for acute PE.

   (b) In the remaining 46 patients, the indication for performing a complementary perfusion SPECT/ldCT scan was a suboptimal result on the initial CTA, due to motion artifacts or suboptimal opacification of the distal pulmonary arteries. However, in 4 patients (8.7%), the CTA result had been positive, and 9 (19.6%) were on chronic anticoagulant therapy for atrial fibrillation or previous VTE. In this group, 16 perfusion studies (34.8%) were reported as showing a high probability of PE, including all four patients with positive CTA findings, but none of the patients were receiving chronic anticoagulant therapy. Doppler ultrasound was performed in 39.1% of these patients, two of whom were positive for DVT, both in patients with positive CTA. According to the Wells probability score, 26.1% of these patients had a low pre-test probability of PE, and 73.9% had an intermediate probability. An alternative cardiorespiratory diagnosis to VTE was present in 52.2% of the patients. At hospital discharge, anticoagulation for acute PE was prescribed in 19.6% of the patients in this group, in addition to the 9 patients who already had a prior indication for anticoagulation.

(ii) Patients in whom pulmonary perfusion SPECT/ldCT was initially performed and subsequently CTA (43):
   (a) In 21 of these patients, SPECT/ldCT was performed as the initial diagnostic imaging study, despite the absence of a contraindication for CTA, at the discretion of the attending physician. CTA was subsequently performed as a complementary procedure because of a discrepancy between the clinical findings and the SPECT/ldCT results, with a mean time between the two tests of 9 (range: 1–17) days. Overall, 38.1% of the patients had a low pre-test probability of PE according to the Wells probability score, 52.4% an intermediate probability, and 9.5% a high probability. Abnormalities were present on chest X-ray performed in the Emergency Department in 76.2% of the patients. The concordance between the radiological study results was 23.8%, with 85.7% of perfusion studies reported as showing a high probability of PE, compared to 28.6% of CTA studies positive for PE. At discharge, 76.2% of these patients received anticoagulant treatment for PE. Lower limb Doppler ultrasound was indicated in four patients (19.1%), of whom two were positive for DVT.

   (b) In 16 patients, pulmonary perfusion SPECT/ldCT was initially performed due to renal failure that contraindicated CTA; 75% of these studies were reported as indicating a high probability of PE, and anticoagulant therapy was initiated in all cases. CTA was performed after a mean period of 7 days (range: 1–13) from the initial SPECT/ldCT scan (once deemed safe based on improved renal function), yielding a positive result in 18.8% of patients, all of whom had an initial perfusion study indicating a high probability of PE. Lower extremity Doppler ultrasound was performed in 12.5% of these patients, all with negative results. In this subgroup, 10 of 16 patients (62.5%) remained on anticoagulation at discharge due to a diagnosis of acute PE.

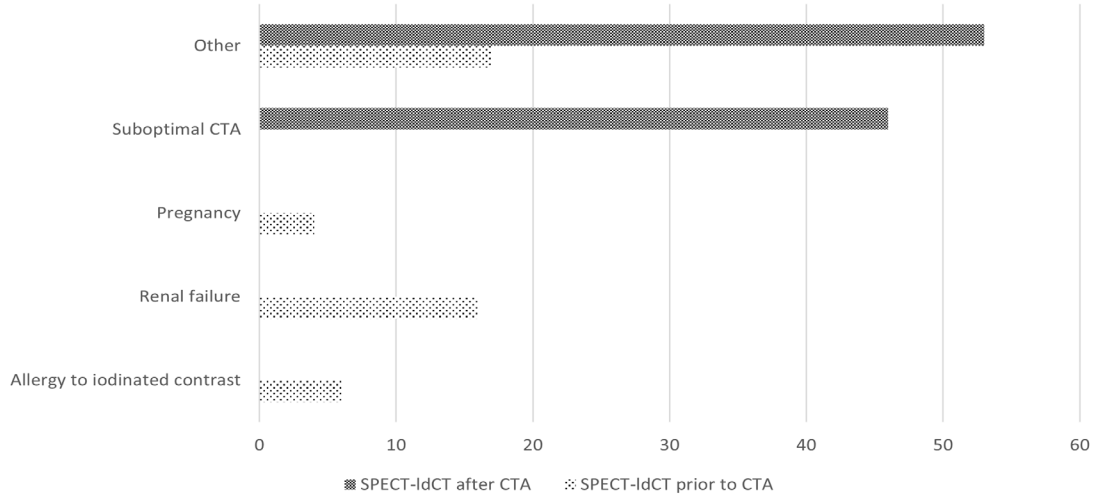

Figure 2. Number of patients by indication for pulmonary perfusion SPECT/ldCT, stratified by whether SPECT/ldCT was performed before or after CTA. Abbreviations: CTA: Computed tomography angiography; SPECT/ldCT: Single-photon emission computed tomography/low-dose computed tomography.

(c) In the remaining six patients, there was a suspected allergy to iodinated contrast upon arrival at the Emergency Department. Therefore, a pulmonary perfusion SPECT/ldCT scan was initially performed; this was reported as indicating a high probability of PE in all patients. After evaluation by the Allergy Department, CTA with premedication or Xenetix® contrast medium was deemed safe. This CTA was performed within 48 h of the initial perfusion SPECT/ldCT scan in all patients and was positive in 33.3% of patients. Both of these patients had a high pre-test probability of PE according to the Wells score, while the four patients with negative CTA had a low probability of PE and a clinical diagnosis other than PE. Doppler ultrasound was performed on the two patients diagnosed with PE on CTA, both of whom were diagnosed with DVT. Only the two patients with positive CTA were maintained on anticoagulation at discharge.

No PE-related deaths or new DVT or PE diagnoses occurred during one year of follow-up in the study group. Overall, anticoagulation was prescribed at discharge in 60.6% of patients, while only one patient required inferior vena cava filter placement due to a contraindication to anticoagulation, and no patient received any treatment other than anticoagulation or inferior vena cava filter placement for PE.

4. Discussion

In our population, 4.42% of patients with suspected acute PE underwent complementary CTA and SPECT/ldCT during the same clinical course. Although the literature indicates that this indication is motivated by an indeterminate (non-diagnostic) result from an initial study[14], this was the case in only 28.17% of our patients.

Among patients who initially underwent CTA, subsequent perfusion SPECT/ldCT was deemed inappropriate in 64.6% of cases (those with suboptimal but positive CTA for PE, or with negative CTA and a low or intermediate pre-test probability of PE). CTA currently has a sensitivity and specificity of 90% and 95%, respectively, for the diagnosis of PE, allowing it to be ruled out even in patients with a high clinical probability or probable PE, although its negative predictive value is reduced in the latter.[8,15–17] Suboptimal visualization of the pulmonary arterial tree occurs in 5–10% of CTA studies[9], which reduces diagnostic accuracy. Although the rate of PE in these patients appears to be very low[18,19], there is recent evidence suggesting that pre-test probability could help determine which of these patients require further study.[20]

Among patients in whom initial pulmonary perfusion SPECT/ldCT was followed by CTA, 26.4% of the latter were considered inappropriate (patients with positive perfusion SPECT/ldCT scan, high pre-test probability and presence of concomitant DVT, patients with negative perfusion SPECT/ldCT scan, and patients with positive perfusion SPECT/ldCT scan and negative CTA in whom anticoagulation was maintained at discharge assuming recanalization associated with anticoagulant treatment), along with 33.9% of the SPECT/ldCT scans (patients without contraindication for CTA who presented baseline alterations on chest X-ray).

Overall, of the 142 patients who underwent CTA

Table 1. Baseline characteristics of patients (*n* = 142)

Characteristic	Value
Demographic variables	
Females, *n* (%)	74 (52.1)
Age, years, mean ± SD	66.18 ± 16.03
Chronic comorbidities[a]	
Barthel Scale, mean ± SD	85.32 ± 8.72
Heart failure, *n* (%)	34 (23.9)
Pulmonary disease, *n* (%)	32 (22.5)
COPD, *n* (%)	20 (14.1)
Pulmonary hypertension, *n* (%)	32 (22.5)
Cardiopulmonary disease, *n* (%)	76 (53.5)
Cognitive impairment, *n* (%)	20 (14.1)
Active smoking, *n* (%)	39 (27,5)
VTE risk factors	
Cancer, *n* (%)	20 (14.1)
Surgery in the previous month, *n* (%)	14 (9.9)
Hormonal treatment, *n* (%)	2 (1.4)
Pregnancy, *n* (%)	4 (2.8)
Previous VTE, *n* (%)	21 (14.8)
Thrombophilia, *n* (%)	4 (2.8)
Anthropometric variables	
Weight, kg, mean ± SD	78.1 ± 20.5
BMI, kg/m^2, mean ± SD	28.6 ± 6.4
Clinical variables on admission	
SBP, mmHg, mean ± SD	133.6 ± 21.8
Heart rate, beats/min, mean ± SD	95.3 ± 19.8
SpO_2, %, mean ± SD	93.2 ± 5.6
Laboratory variables on admission	
Hemoglobin, g/dL, mean ± SD	13.1 ± 2.4
Platelets, ×10^9/L, mean ± SD	239.8 ± 102.1
eGFR, mL/min/1.73 m^2, mean ± SD	70.8 ± 27.1
D-dimer, μg/mL, mean ± SD	4.5 ± 7.4

Note: [a]Chronic comorbidities were recorded as pre-existing conditions and not as secondary conditions attributable to acute PE.
Abbreviations: BMI: Body mass index; COPD: Chronic obstructive pulmonary disease; eGFR: Estimated Glomerular filtration rate; PE: Pulmonary embolism; SBP: Systolic blood pressure; SD: Standard deviation; SpO_2: Peripheral oxygen saturation; VTE: Venous thromboembolism.

and pulmonary perfusion SPECT/ldCT, 67.6% had an inappropriate indication for one of these tests (57.7% of SPECT/ldCT scans and 9.9% of CTA scans). This inappropriate use of complementary radiological diagnostic tests could result in increased associated risks (especially regarding contrast-induced nephropathy associated with CTA) and in an unnecessary increase in costs. The degree of agreement between the results of both tests was only 49.3%; although this discrepancy may be partly due to recanalization associated with anticoagulant treatment (in those patients with a positive first test and a negative second test for PE), since 42.3% of patients received anticoagulation between the two diagnostic tests, this clinical scenario presents a complex challenge in terms of clinical decision-making. SPECT/ldCT has been shown to reduce the percentage of non-diagnostic planar scintigraphy studies to 0–5%[21–25], which is confirmed in our population, in which there were no inconclusive results. Although its sensitivity for diagnosing PE is high, and a normal result allows for ruling out PE[26], its specificity is uncertain, especially in patients with pre-existing lung disease or low clinical probability[8,27–29]; thus, it is recommended to perform it preferably on outpatients with a low clinical probability and a normal chest X-ray.[8,27,29,30] However, evidence regarding the usefulness, diagnostic accuracy, and optimal technique of SPECT/ldCT for the diagnosis of PE is scarce.[8,22,23,31-35] Despite the proportion of patients with discrepant results between diagnostic imaging tests, we consider underdiagnosis of PE unlikely, since no patient was diagnosed with VTE or died during the year of follow-up, and the estimated mortality of untreated PE is 5–30%.[36–39] However, the uncertain specificity of SPECT/ldCT could result in overdiagnosis of PE in our population, resulting in an unjustified hemorrhagic risk associated with anticoagulant treatment; further studies should establish the diagnostic accuracy of perfusion SPECT/ldCT in patients with suspected PE, to adapt its indication in clinical practice, and allow a correct interpretation of its findings. Finally, we found an underutilization of lower limb Doppler ultrasound, performed in only 32.4% of patients, despite being a non-invasive, harmless, low-cost diagnostic method with immediate availability in our hospital, and considering that the finding of proximal DVT has a specificity of 96% and sensitivity of 41% to establish the diagnosis of PE when there is clinical suspicion of it.[40,41]

Our findings, which suggest a low adherence of clinical physicians to guideline recommendations for the diagnosis of PE, are similar to those found in the only previous study that analyzed this issue.[11]

Our study has several limitations. First, its retrospective and single-center nature impacts the external validity and generalizability of the results, as the specific characteristics and diagnostic protocols of each center must be taken into account. Second, the small number of patients analyzed is limited by the infrequent use of two complementary

radiological diagnostic tests in patients with suspected PE. Finally, we did not analyze the possible emergence of new clinical data during hospitalization that might have led to a change in the initial clinical suspicion of PE. However, the critical analysis of real-world clinical practice in a tertiary hospital over a very long period should be noted as a strength.

5. Conclusion

The proportion of patients undergoing multiple complementary diagnostic imaging tests for suspected symptomatic acute PE during the same clinical course occurred in a measurable proportion of patients in real-world practice.

We found inappropriate indications for certain radiological studies (SPECT/ldCT or CTA) in a high proportion of these patients, which could result in unnecessary risks associated with these studies (especially regarding contrast-induced nephropathy associated with CTA), an unnecessary increase in cost, and additional difficulty in interpreting the high proportion of studies with discrepant results between the two tests, found in almost half of the patients.

The ordering of diagnostic imaging studies in patients with suspected PE should follow the recommendations of clinical practice guidelines, taking into account their diagnostic accuracy in different clinical scenarios. Although perfusion SPECT/ldCT appears to offer certain advantages over planar scintigraphic studies, it is necessary to establish its predictive value in patients with suspected PE to ensure its appropriate use in clinical practice and allow for the correct interpretation of its findings. Systematic lower extremity Doppler ultrasound could help reduce uncertainty and the need for additional studies in a large number of patients with an initial suspicion of PE.

The availability of various diagnostic and therapeutic procedures, along with the constant updating of scientific evidence on the management of PE, requires that healthcare professionals have a precise understanding of them. However, significant variability may exist in clinical practice, possibly leading to differences in various areas of care. In this regard, in addition to clinical practice guidelines, the development and dissemination of diagnostic and treatment protocols for patients with suspected PE, adapted to the specific characteristics of each hospital, may standardize clinical practice, reduce differences in clinical outcomes, and optimize resource utilization. As has already been demonstrated in several other clinical scenarios, optimizing diagnostic protocols may reduce the unnecessary use of investigations and improve health outcomes.[42-44]

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Conflict of interest

The authors declare that they have no conflict of interest relevant to the content of this article.

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All authors have read and approved the final version of the manuscript.

Ethics approval and consent to participate

This retrospective study was approved by the Clinical Research Ethics Committee (CEIC) of the Hospital Universitario de La Princesa (approval ID: CEIM 5940, LIB 14/2007), exempting patients from providing their consent, as it is a retrospective review of medical records.

Consent for publication

This retrospective study used anonymized/de-identified patient data and contains no identifiable individual information. The requirement for informed consent was waived by the ethics committee.

Availability of data

Data is available from the corresponding author upon reasonable request.

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Appendix

The CT angiograms performed between 2010 and 2020 were conducted using a 40-slice scanner (Somaton Sensation 40; Siemens) installed in the emergency department. The standard helical acquisition parameters were as follows: kV 120, effective mAs 120, rotation time 0.37 s, collimation 40 x 0.6 mm, pitch factor 1.2, reconstruction magnification 3 mm/0.75 mm, kernel B30f/B70f, CTDI volume 9.91 mGy. Image acquisition protocol: Dose modulation was applied by selecting different milliamperes (mAs) for each rotation, according to the corresponding anatomical area. This modulation had an average upper limit of 120 mAs effective (mean value across all slices). The volumetric computed tomography dose index (CTDI volume) for said 120 mAs was 9.91 mGy. This index varied proportionally. Our protocol requires a functional 20/18 gauge peripheral intravenous line, preferably in the antecubital fossa. This line is connected to an automated injector (Injektron CT2, Medtron AG, Saarbrücken, Germany). Subsequently, 80 mL of intravenous contrast medium (Omnipaque 300 mg iodine/mL, GE Healthcare Bio-Sciences, Piscataway, New Jersey, USA) is administered at a rate of 4 mL/s using a 40 mL saline injector. The saline injector prevents contrast medium residue in the line. The contrast medium volume is reduced to 60 mL in patients with a glomerular filtration rate < 45 mL/min. The helical acquisition is prepared from an initial frontal and lateral scan of the chest, followed by a localizer image acquired at the level of the tracheal carina. A region of interest (ROI) is placed in the pulmonary trunk. Upon reaching 80 Hounsfield units (HU), the table is automatically repositioned, and after a 5-second delay, the helical acquisition is performed craniocaudally during breath-hold after inspiration, from the thoracic inlet to the posterior costophrenic recesses. Multiplanar reforming (MPR) and maximum intensity projection (MIP) are essential for the detection of pulmonary embolisms. This CT angiography has a sensitivity of 83% and a specificity of 95% for the diagnosis of pulmonary embolism, which translates to a negative predictive value (NPV) of 96% in patients with low pre-test probability, 89% in those with intermediate probability, and 60% in those with high probability. and a PPV of 96% in patients with high pre-test probability, 92% in those with intermediate probability, and 58% in those with low probability.

Figure A1. Technical specifications of CTA of the pulmonary arteries at the Hospital Universitario de La Princesa, 2010–2019.
Abbreviations: CT: Computed tomography; CTA: Computed tomography angiography; PPV: Positive predictive value.

SPECT-ldCT. Isotope: 99m-Tc. Radiopharmaceutical: 99m-Tc albumin macroaggregates (99mTc-MAA). Administration technique: slow conventional intravenous injection, recommending that the patient take deep inspiration during the injection. It should be performed in the supine position to avoid apical hypoperfusion. The syringe will always be shaken before injecting. Do not puncture in the central line. Lung perfusion SPECT is a safe test that does not use iodinated contrast media, causes few allergic reactions, and generally involves less radiation than pulmonary CT angiography. It is the ideal test for outpatients with a low clinical probability of PE and a normal chest x-ray. Perfusion SPECT tomographic images have greater sensitivity and specificity for the detection of PE compared to planar images. When SPECT is combined with low-dose SPECT-ldCT, the specificity of the test can be further improved, especially in patients with other lung diseases. The main obstacles of the technique include: 1.- Irregular distribution of the radiopharmaceutical in the lung if the patient is not in a supine position during the injection or if very few particles are injected (less than 60,000); 2.- Hot spots can occur due to blood clots in the syringe or during injection through a catheter that is not well flushed, so administration is done directly i.v. and not through a peripheral route. 99mTc-MAA is injected intravenously and passes through the pulmonary arteries to the pulmonary capillaries and arterioles, where the 99mTc-MAA particles are trapped due to their relatively large size (10-100 μm). Immediately after SPECT-ldCT (General Electric, Infinia Hawkeye 4), low-dose CT is performed. This CT provides information about the lung parenchyma, which could provide alternative explanations and allow correction of attenuation. Q SPECT/CT with trinary interpretation is used. Activities for administration in adults: 140 MBq. Interpretation criteria: PE is reported if there is a V/Q mismatch of more than or equal to 1 segment or 2 subsegments that conform to the pulmonary vascular anatomy. No PE is reported if a normal perfusion pattern exists or if there are coincident or inverted V/Q mismatch defects. Other Interpretations: V/Q mismatch can be due to any cause of pulmonary arterial blood flow obstruction.

Figure A2. Technical specifications of the pulmonary perfusion SPECT/ldCT at the Hospital Universitario de La Princesa, 2010–2019.
Abbreviations: CT: Computed tomography; SPECT: Single-photon emission computed tomography; SPECT/ldCT: Single-photon emission computed tomography/low-dose computed tomography; V/Q: Ventilation/perfusion.