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Impact of Emergency Department CTPA Imaging on Overdiagnosis: An Incidence Analysis of Subsegmental Pulmonary Embolism

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Abstract
Objective: The aim of this study was to investigate how overuse of computed tomographic pulmonary angiography (CTPA) in the emergency department (ED) contributes to overdiagnosis by (1) examining subsegmental pulmonary embolism (SSPE) and (2) informing the development of more accurate and efficient diagnostic strategies.

Methods: To assess the impact of CTPA on SSPE incidence, a secondary data analysis was first performed. Age-adjusted incidence was calculated, and a longitudinal extrapolation of data compared emergency and primary sources of care. ED overuse compromises quality-of-care and was studied as a point of reference. Applying retrospective cohort analytics, samples included patients who had undergone CTPA for suspected SSPE. Data was aggregated from administrative databases, and the diagnostic accuracy of CTPA was compared with ventilation-perfusion (V/Q) scintigraphy.

Results: Compared to Non-Hispanic Whites, 73% more non-Hispanic Blacks and 217% more Hispanics did not have a usual source of care (USC). For individuals with a USC, unnecessary ED utilization was 60% greater if care was inaccessible. Succeeding multirow CTPA introduction (1998), incidence of SSPE increased by 81%, with a consistent 7% annual percent change (APC), case fatality remained largely unchanged, and mortality decreased. Overall, SSPE overdiagnosis by CTPA was associated with unnecessary anticoagulant therapy, radiologic harm, and drug-induced complications (i.e., hemorrhage of the brain and gastrointestinal tract).

Conclusion: CTPA-diagnosed SSPE may represent a milder disease spectrum, expose patients to high-level radiation, and increase complications from unnecessary treatment. Therefore, it is important to develop accurate and efficient hospital-centric delivery-of-care strategies to avoid SSPE and all overdiagnoses in clinically emergent settings.

Keywords: *computed tomographic pulmonary angiography (CTPA), emergency department (ED), subsegmental pulmonary embolism (SSPE), usual source of care (USC), ventilation-perfusion scintigraphy (V/Q)*

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I. Introduction

Background: The introduction of computed tomography (CT) in the early 1970s has been among the most important tools in medical imaging, facilitating qualitative diagnoses of soft tissue structures. While CT constitutes a vital supplement to traditional radiographic techniques (i.e., x-ray imaging), studies in recent decades suggest overdiagnosis of subsegmental pulmonary embolism (SSPE) by computed tomographic pulmonary angiography (CTPA) is of particular concern for both physicians and patients. Untreated SSPE can result in irreparable harm to the pulmonary parenchyma or even death (National Heart, Lung, and Blood Institute, 2022). Upward longitudinal trends in SSPE incidence suggest the overuse of CTPA in patients with suspected SSPE, and in patients who had not been evaluated for clinical pretest prediction.

High-resolution diagnostic imaging technology has played a significant role in the advancement of medical science. When regulated and ordered appropriately, it has the potential to contribute to improvement in healthcare delivery, allowing for more accurate and efficient diagnoses and treatment of diseases. However, overuse of

computed tomographic pulmonary angiography (CTPA) and proclivity for overdiagnosis of subsegmental pulmonary embolism (SSPE) can result in unnecessary and potentially harmful treatments and adverse patient outcomes. SSPE is an acute medical condition characterized by the occlusion of 4th division subsegmental branches in the pulmonary arteries. In the event of deep vein thrombosis (DVT), a thrombus or blood clot may detach from the intima of vessels, migrate from the deep venous system of lower extremities, and traverse to the abdominal viscera and heart. Thrombosis in the pulmonary arteries or its subsegmental branches obstructs blood flow to the lungs and restricts oxygen circulation throughout the body. Additionally, reliance on these technologies may lead to a decrease in the clinical acumen and diagnostic judgment of healthcare providers, further exacerbating the issue of overdiagnosis.

When an individual is diagnosed with a disease that was never going to cause harm, when a clinically insignificant condition is medicalized and subsequently treated, overdiagnosis has occurred. Thus, overdiagnosis in this study was indicative of excess screening performed for suspected SSPE, excess investigation of mild symptoms, and excess diagnostic reliance on biological and molecular markers, giving rise to too much diagnosis and too much treatment (Brodersen et al., 2018). Contemporary causes for concern, chiefly among patients, included cost-ineffective care, adverse reactions, surprise billing[1], and financial burdens. Resources, time availability, and diagnostic efficacy, too, dwindled in the face of inappropriate CTPA diagnostic imaging.

Primary difficulties encountered by physicians when diagnosing SSPE are outlined below:

1. Subtle radiologic presentation of significant occluded blood in subsegmental arteries makes discernment processes particularly nebulous.
2. Lack of consensus on optimal diagnostic approaches and appropriate courses of treatment leads to unnecessary diagnostic testing.

II. Methods

This study assesses how CTPA diagnostic imaging in emergency medical settings, when overused, increases SSPE overdiagnoses and poor delivery of vital healthcare services.

The following questions are regarded in detail:
1. What demographic factors determine one's usual source of care (primary vs. emergency department)?
2. How does poorly regulated CTPA imaging in emergency medicine (EM) contribute to the overdiagnosis of subsegmental pulmonary embolism?
3. How can the efficacy of clinical triage, diagnostic ruling, and EM training be optimized to increase the significance of SSPE diagnoses?

To inform public discourse on these issues, a retrospective meta-analytic design was employed. Various samples included patients who had undergone CTPA for both suspected SSPE and other conditions. After aggregating data from publicly accessible administrative databases, the diagnostic accuracy of CTPA was compared with ventilation-perfusion (V/Q) scintigraphy, an ancillary diagnostic tool. A final review of the literature queried how the implementation of training protocols serves to ameliorate high rates of SSPE morbidity and case fatality.

To identify relevant literature, including published and ready-to-publish articles, a manual web and database search was performed. This research was conducted using the following bibliographic databases: PubMed, Science Direct, Scopus, Annals and Archives of Internal Medicine, and Google Scholar. The search was guided by the following set of keywords: subsegmental pulmonary embolism; computed tomographic pulmonary angiography; overdiagnosis; overcrowding; overtreatment; emergency department; demographic disparities; access to care; and value at risk. Demographic analysis of primary care accessibility was performed using the National Healthcare Quality and Disparities Reports' (NHQDR) Healthcare Cost and Utilization Project[2] (HCUPnet), and a follow-up study of non-urgent emergency department care was conducted using retrospective cohort analytics from the 1996 Medical Expenditure Panel Survey[3] (MEPS).

Secondary research was carried out to ascertain important quality improvement (QI) methods to monitor and evaluate performance of triage and EM systems. QI methods allow healthcare providers to identify areas where

[1] Occurs when unexpected medical treatment by out-of-network providers leads to exorbitant out-of-pocket bills for patients. While sanctions do exist to protect individuals from surprise billing, such as the No Surprises Act (NSA), effective January 1, 2022, such practices are poorly regulated and often deemed ineffective (Innes et al., 2016).

[2] http://datatools.ahrq.gov//hcupnet?type=subtab&tab=hcned&count=12

[3] https://www.meps.ahrq.gov/mepsweb/

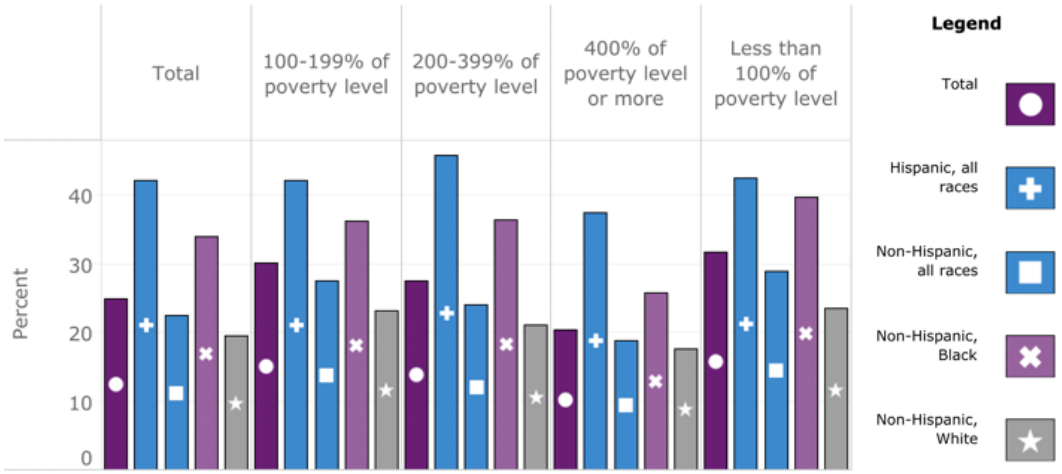
EM systems are not performing optimally, such as long wait times, overcrowding, high rates of adverse events, or low patient satisfaction. This data was used to analyze current SSPE diagnostic practices and evaluate areas of improvement in emergency department clinical performance.

Concomitant Findings

Usual Source of Care: Assessing Demographic Disproportionalities in the Emergency department. The utilization of primary care as the initial point of contact between patients and physicians is crucial for the implementation of preventative measures and pre-diagnostic evaluations. However, due to various inaccessibility factors[4], a significant number of individuals resort to emergency medicine as a primary source of care. In accordance with the Emergency Medical Treatment and Labor Act (EMTALA), all patients presenting to the emergency room must be treated and stabilized, regardless of insurance status or ability to pay (Centers for Medicare & Medicaid Services, 2022).

A synthesis of administrative data extrapolated from the National Healthcare Quality and Disparities Reports (NHQDR) was conducted to discern the demographic breakdown of adults (>18) in the United States who had attempted to schedule appointments with specialists and had been unsuccessful in obtaining care when needed. These data were carefully consolidated and categorized by household income to account for monetary factors limiting access to care. When these data were collected in 2019, 45.8% (SE: ± 2.9; 95% CI) of Hispanic, 36.5% (SE: ± 3.4; 95% CI) of non-Hispanic Black, and 21.1% (SE: ± 1.3; 95% CI) of non-Hispanic White persons between 200-399% of the federal poverty line[5] (FPL) did not have a usual source of care (USC) for both emergent and non-emergent conditions. At or below 100% of the FPL, these results were exasperated for all but Hispanics, with 42.6% (SE: ± 3.6; 95% CI) of Hispanic, 39.8% (SE: ± 3.5; 95% CI) of non-Hispanic Black, and 23.5% (SE: ± 2.6; 95% CI) of non-Hispanic White persons without a USC. Similar trends were observed for groups between 100-199% and at or above 400% of the FPL (Figure 1).

Figure 1. A demographic breakdown of adults who had attempted to schedule one or more appointments for routine healthcare and were either partially or entirely unsuccessful in obtaining care in a timely manner, data derived from 2019 NHQDR query.



Impact: an examination of emergency department USC and quality of care. While analysis of this data does not allow for definitive conclusions regarding correlation or causality, it may provide quantifiable insight into accessibility trends and patterns. In this study, overuse of the emergency department was seen when the demand for services exceeded the capacity of an institution to provide those services in a timely and efficient manner. This led to extended waiting periods, and among others, delays in the provision of care. Potential drivers included an aging population, an increase in the prevalence of chronic health conditions (Sarver et al., 2002), and a lack of access to primary care services, as observed in the above extrapolation of 2019 NHQDR data sets (Figure 1).

[4] One of the main causes of ED strain is an increase in the volume of patients presenting to the ED. This can be due to a variety of factors, such as age, sex, economic factors, and racial disparities that preclude prevention, and a lack of access to primary care services.

[5] The federal poverty line in 2019 was $12,490 for one person, $16,910 for two, $21,330 for three, and $25,750 for four dependent persons in each family/household (Office of the Assistant Secretary for Planning and Evaluation, 2019).

The preponderance of patients presenting to EDs with non-emergent conditions. Approximately one-third of the United States population abstains from (primary) necessary medical treatment due to financial burdens (Taber et al., 2015). This contributes to a burgeoning number of patients who, without preventative healthcare, turn to the emergency department for problems of low acuity. Even if an individual's conditions could be addressed in alternative settings such as urgent care centers and primary care clinics, similar trends have been observed (Grumbach et al., 1993). Patients who use the ED as their USC may be more susceptible to overdiagnosis, overtesting, and overtreatment. Similarly, overdiagnosis may give rise to ED overcrowding as excessive testing and treatment increase patient volume and strain available resources (Brodersen et al., 2018).

To quantify these associations, a follow-up study of non-urgent emergency department (ED) care was examined using retrospective cohort analytics from the 1996 Medical Expenditure Panel Survey (MEPS). With a population size of 9,146 individuals, this study used bivariate and multivariate logistic regression models to evaluate one's access to primary care[6] and non-urgent ED utilization (Sarver, 2002). Among participants with a usual source of care (USC) who reported access to medical services, 5.3% ($p < 0.01$) had at least one annual non-urgent ED visit. Of participants with a USC who expressed difficulty in obtaining care, 8.3% ($p < 0.01$) reported at least one annual non-urgent ED visit (Sarver, 2002). In a final comparison of ED crowding between participants with and without access to care (of whom had a USC), ED utilization was 60% (CI 95%; $p < 0.01$) greater among individuals who were unable to access care.

Augmenting access to primary care services could potentially mitigate overcrowding within public emergency departments, afford less costly options for indigent individuals seeking immediate medical attention, and foster stable sources of care for patients with ongoing medical needs (Grumbach et al., 1993).

Imaging in the ED, Overdiagnosis, Subsegmental Pulmonary Embolism (SSPE), and Iatrogenic Harms

CTPA, a high-resolution diagnostic imaging tool, exposes patients to ionized radiation and exacerbates value-at-risk (VaR) for individuals with high diagnostic threshold and radio sensitivity. Value at risk (VaR) is a risk management concept that is widely used in the financial industry. It is defined as the maximum potential loss that an investment can incur over a given time, with a given level of confidence. Diagnostic threshold, or risk threshold, refers to the probability below or above which a patient's clinical evaluation would deem further testing unnecessary. While the standardization of observed symptoms as per ICD-9 and 10 guidelines is supported by evidence-based medicine, the diagnostic threshold at which anomalous symptoms are considered significant ($p < 0.05$) varies greatly across institutions (Himmel et al., 2021). One's risk threshold may be established through regulations or standards specific to the institution; it is a level of risk that is considered acceptable or tolerable for a particular medical intervention, procedure, or treatment, and it is a decision point that helps healthcare providers balance the potential benefits and drawbacks of intervention. In general, a lower risk threshold is considered for interventions that are invasive or carry a higher risk of harm, while a higher risk threshold may be acceptable for interventions that are less invasive or carry a lower risk of harm.

A thorough evaluation of the literature was carried out and findings indicated the dangers of SSPE precautionary imaging in emergency medical settings. This occurs when healthcare providers order excessive diagnostic imaging as a precautionary measure, which can result in iatrogenesis if insignificant diseases are overtreated among patients with low SSPE pre-test probability and high-risk threshold. Pre-test probability refers to the probability of a significant disease or condition prior to conducting any diagnostic tests. It is a crucial component in Bayesian statistical analysis, for example, which allows healthcare providers to revise their initial diagnostic hypotheses based on new information obtained from the patient's symptoms and history, as well as any available test results. Pre-testing is particularly important when SSPE is suspected, as the accuracy of CTPA testing is limited, and the number of false positives is high.

Table 1. Rate of ED Visits per 100,000 Population (Combined Hospital Admission and Treat-and-Release), United States, 2016 to 2020

Diagnosis	**2016**	**2017**	**2018**	**2019**	**2020**
Pulmonary Embolism (PE)	110.1	123.6	125.6	131.9	150.0
Nonspecific Chest Pain (NCP)	2,506.2	2,577.2	2,577.7	2,653.4	2,379.3

[6] Access determined by the presence of a usual source of care (USC)

Table 2. Confidence Intervals ($p < 0.05$) for Rate of ED Visits per 100,000 Population (Combined Hospital Admission and Treat-and-Release), United States, 2016 to 2020

95% Confidence Intervals	**2016**	**2017**	**2018**	**2019**	**2020**
Pulmonary Embolism (PE)	3.8	4.2	4.4	4.4	4.9
Nonspecific Chest Pain (NCP)	82.5	84.6	81.5	73.1	65.7

Table 3. Number of ED Admissions (Combined Hospital Admission and Treat-and-Release), United States, 2016 to 2020

Diagnosis	**2016**	**2017**	**2018**	**2019**	**2020**
Pulmonary Embolism (PE)	355,915	402,736	410,800	432,900	497,040
Nonspecific Chest Pain (NCP)	8,098,248	8,394,256	8,433,403	8,709,789	7,887,451

Table 4. Confidence Intervals ($p < 0.05$) for Number of ED Admissions (Combined Hospital Admission and Treat-and-Release), United States, 2016 to 2020

95% Confidence Intervals	**2016**	**2017**	**2018**	**2019**	**2020**
Pulmonary Embolism (PE)	6,130	6,607	6,738	7,096	8,071
Nonspecific Chest Pain (NCP)	266,609	275,590	266,623	239,694	217,606

SSPE Incidence: A Statistical Analysis

In *Table 1* through *Table 4* above, population-level data from the Healthcare Cost and Utilization Project (HCUPnet) was categorized by age (>18) and estimates were calculated. In the five-year span between 2016 and 2020, SSPE rates per 100,000 population jumped 36.24% (SE ± 1.9; 95% CI). When adjusting for the number of SSPE emergency department admissions alone, between 2016 and 2020, there was a 39.65% (SE ± 7,101; 95% CI) increase in diagnosed SSPE. The annual percentage change (APC) for the incidence rate of SSPE per 100,000 individuals displayed an incremental 7.25% increase from 2016 to 2020, and the APC for diagnosed cases of SSPE demonstrated an incremental 7.93% increase over the same period (CI: 95%; $p < 0.05$).

Associations between overdiagnosis and SSPE have not been thoroughly explored in the medical community as much discussion is limited to cancer screening literature (Siu, 2016). Thus, to investigate the effects of CTPA use on the overdiagnosis of SSPE in the emergency department, a secondary analysis was undertaken, assimilating various results of studies on CTPA and SSPE. In *Time Trends in Pulmonary Embolism*, Wiener et al. found similar results between 1998, when the latest advancement in CTPA technology (multi-detector row CT) was first introduced, and 2006. After standardizing rates by age to account for changing demographics[7], there was a 7.1 APC ($p < 0.001$) in SSPE incidence. Wiener et al. collected previously available data from the Healthcare Cost and Utilization Project (HCUP) and was selected for analysis to control for variations in population samples. Furthermore, the incidence was calculated by dividing the number of adults diagnosed with SSPE by the adult population mid-year estimates from the US Census Survey. This value was particularly noteworthy as pre-CTPA metrics depicted a 0.5 APC ($p = 0.64$) in SSPE incidence, while post-CTPA incidence hovered around 7.1 APC. In other words, age-adjusted SSPE incidence increased by 81% (from $p = 0.64$, 0.5 APC to $p < 0.001$, 7.1 APC) within 8 years of the latest CTPA technological advancement in 1998.

Diagnostic technology and iatrogenesis: a comparative analysis.

Diagnostic imaging plays a crucial role in the identification and characterization of acute conditions. Various diagnostic tools, such as CTPA and ventilation-perfusion (V/Q) scintigraphy are frequently used to detect SSPE. Nevertheless, overdiagnoses of SSPE by CTPA are of emerging concern, and the appropriate selection and interpretation of diagnostic technology are critical to minimizing this risk.

[7] Wiener et al., 2010

CTPA is a medical imaging technique used to visualize pulmonary vasculature and identify potential instances of pulmonary embolism (PE). Compared to Ventilation/Perfusion Scintigraphy, one disadvantage of CTPA is that it exposes individuals to higher levels of radiation. It is estimated that CTPA performed with current, non-optimized techniques incurs a radiation dose nearly seven times greater than that of V/Q scintigraphy (Sheh et al., 2012). V/Q scans are similarly used to evaluate SSPE; however, they do so by assessing the balance between the ventilation (airflow) and perfusion (blood flow) of the lungs. This involves the inhalation of a radiopharmaceutical gas and injection of a radioactive tracer, both of which are subsequently imaged using a gamma camera. The resulting images can help identify areas of the lung where perfusion is disrupted, which is indicative of pulmonary embolism (PE), including SSPE. Additionally, V/Q scans provide valuable information regarding the distribution of blood flow and airflow within the lungs and can help distinguish SSPE from other respiratory disorders.

Among patients diagnosed with SSPE who underwent CTPA screening between 2000 and 2007, Sheh et al. calculated a case-fatality rate (the number of deaths divided by the total number of diagnosed cases) approximately one-half that of patients diagnosed with SSPE after a V/Q scan. While this may appear to be a positive sign (often confused with case-fatality number), inferential estimates of overdiagnosis and SSPE suggest that CTPA is not identifying substantial pulmonary emboli (Sheh et al., 2012). Regulating overdiagnosis is important as the detection of clinically unimportant SSPE results in increased exposure to high-radiation imaging and, in turn, the administration of potentially harmful anticoagulation therapies (Donato et al., 2010).

Case fatality: a summary. Consistent among reviewed abstracts and journals, the introduction of CTPA has been associated with decreasing SSPE case-fatality rates, while diagnostic rates have increased substantially (Wiener et al., 2010). More individuals are being diagnosed with SSPE, but the rate at which it incurs death has decreased in the past two decades. Applying similar inferential evidence, it can be determined that CTPA-diagnosed SSPE (1) may represent a milder disease spectrum, (2) expose patients to high-level radiation, and (3) increase complications from SSPE anticoagulation therapy[8].

III. Discussion: Evidence of SSPE Overdiagnosis

Following the introduction of multirow CTPA, between 1998 and 2006, the incidence of SSPE diagnoses increased from 62.1 per 100,000 to 112.3 per 100,000, a rise of 81% (Wiener et al., 2010). Despite this substantial increase in SSPE diagnosis, age-adjusted mortality rates due to SSPE remained largely unchanged, with 12.3 and 11.9 deaths per 100,000 recorded in 1998 and 2006, respectively. These rises in SSPE diagnosis are unlikely to reflect a real change in the rate of SSPE in the population, as the main risk factors for SSPE have not seen a similar increase, and prophylaxis for venous thromboembolism (VE) has been promoted to patients as a quality improvement (QI) initiative during the same time. Thus, if the underlying rate of SSPE had truly risen, a corresponding increase in SSPE mortality would have been expected, but this was not observed.

Furthermore, the case fatality rate (the proportion of deaths among individuals diagnosed with SSPE) declined from 12.1% to 7.8% (Wiener et al., 2010), suggesting that the increased SSPE diagnoses are indicative of less severe cases. If the reduction in case fatality was a result of more effective treatment, a similar reduction in SSPE mortality in the general population would have been observed, however, this too was not evidenced (Dobler, 2019).

IV. Conclusions

Age-adjusted demographic trends indicated a socio-economic propensity toward the ED as a USC for individuals without access to primary care services. After assessing primary and emergency USCs among demographic groups, a substantial increase in ED use among those without easy access to care was determined. This finding was crucial in a subsequent evaluation of SSPE overdiagnosed in the ED, in which one's USC determined their subjection to longer waiting times, delays in the delivery of appropriate care, and compromised health outcomes. Perhaps the most significant determinant of SSPE overdiagnosis was found in longitudinal epidemiologic patterns. After CTPA (multirow) was introduced to the medical community, SSPE incidence increased, mortality remained stable, and case-fatality rates decreased. Increased SSPE incidence and reduced case fatality among individuals who underwent CTPA suggest that CTPA diagnostic testing is associated with an increased risk of SSPE diagnosis for patients with high pre-test threshold (low significant SSPE probability).

Mitigation: Value at Risk?

In the context of medicine, the concept of VaR can be applied to evaluate the risks associated with various medical interventions and treatments, while quantifying the potential losses that result from these risks. VaR is a powerful tool that has the potential to improve risk management for individuals with ongoing medical needs

[8] As per ICD-9 codes, complications from anticoagulation therapy include gastrointestinal tract hemorrhage, intracranial hemorrhage, secondary (e.g., drug induced) thrombocytopenia, and death, among others (Wiener et al., 2010).

(Schembri et al., 2010). By assessing risks associated with medical interventions and quantifying the potential losses that could result from these risks, VaR can help healthcare providers and patients make informed decisions about optimal prognoses and courses of action.

Future implications of emergency department overdiagnosis of SSPE

The results of this study indicate the dangers of overdiagnosis in emergency department settings by evaluating SSPE-specific patterns. This is of particular importance today as implications of unnecessary medical intervention result in potentially harmful patient outcomes due to high-dose radiologic exposure, invasive angiographic intervention, and anticoagulant therapy (blood thinners). Accordingly, the efficacy of clinical triage and EM training should be optimized to mitigate the high SSPE morbidity and case fatality rates made quantifiable in contemporary literature (Zachariasse et al., 2019). One approach could be to re-evaluate ED delivery systems. ED delivery systems, or hospital-centric systems, refer to the various methods and standards through which healthcare services are provided to individuals seeking ED care. It is important to ensure that diagnostic protocols, for example, are regularly reviewed and updated to reflect contemporary research and evidence-based (EB) practices. Additionally, ongoing training and education for healthcare providers involved in triage and ED care could reduce overdiagnoses by informing their screening and imaging decisions based on stricter criteria (Venkatesh et al., 2012). In summary, training should offer providers clear guidelines on the use of triage protocols, as well as the recognition and management of specific medical conditions and injuries.

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