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Trends in CT pulmonary angiography utilization and recurrent imaging in sickle cell disease: a longitudinal study

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Abstract

Background Sickle cell disease (SCD) is a common inherited hemoglobinopathy associated with vaso-occlusive events that can mimic pulmonary embolism (PE), leading to the frequent use of computed tomography pulmonary angiography (CTPA). However, trends in CTPA utilization over time remain unclear. This study aims to evaluate temporal trends and recurrent imaging patterns.

Methods A retrospective cohort study was conducted at Salmaniya Medical Complex, Bahrain, including SCD patients who underwent CTPA for suspected PE between April 15, 2013, and April 15, 2024. Descriptive statistics were used to report the frequency of recurrent scans, whereas linear regression analysis was employed to assess trends in CTPA utilization over the study period.

Results The study included 1,084 patients (median age: 35 years, 55.7% male) with SCD who underwent a total of 1,934 CTPA scans. CTPA utilization remained stable from 2014 to 2020, averaging 10.0–13.6 scans per month. However, a significant surge was observed post-2020, coinciding with the COVID-19 pandemic, peaking in 2023, with an average of 31.3 scans per month, indicating a 2.9-fold increase ($p=0.03$). During the study period, 415 patients (38.3%) underwent recurrent CTPA scans, with one-third (32.5%, $n=276$) of these scans occurring within a 6-month interval. Although the PE positivity rate was lower in recurrent scans than in initial scans, the difference was not statistically significant (8.8% vs. 10.5%; $p=0.22$).

Conclusions CTPA utilization among SCD patients remained stable for several years but increased significantly after 2020, coinciding with the COVID-19 pandemic. A substantial proportion of scans were recurrent, with many occurring within a short interval. Moving forward, efforts should focus on mitigating radiation exposure through low-dose protocols and investigating potential factors contributing to the recent increase in scan utilization.

Keywords CT angiography, Pulmonary embolism, Sickle cell disease, Ventilation/perfusion scintigraphy, COVID-19, Bahrain

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Background

Sickle cell disease (SCD) is a significant health issue affecting more than 7 million individuals worldwide, particularly those of African, Mediterranean, Middle Eastern, and Indian descent [1]. It encompasses a group of inherited hemoglobinopathies 0 characterized by the presence of hemoglobin S, a mutant form resulting from a point mutation in the β-globin gene. This mutation triggers the polymerization of hemoglobin S molecules, leading to the formation of rigid, sickle-shaped erythrocytes, which subsequently precipitate a cascade of complications, including acute chest syndrome and other vaso-occlusive events [2]. These complications, which are the leading cause of hospital admissions among patients with SCD [3], can mimic other pulmonary complications, such as pulmonary embolism (PE), potentially resulting in excessive utilization of PE-related imaging studies. The pro-thrombotic state in SCD, resulting from chronic inflammation, endothelial dysfunction, and hypercoagulability, elevates the risk of PE [4], further complicating the diagnosis of PE in these patients.

Research examining the use of computed tomography pulmonary angiography (CTPA) in patients with SCD remains limited [5–8], particularly regarding the patterns of recurrent imaging for PE. This topic was highlighted in a study spanning 17 years, revealing that 47% of patients with SCD underwent recurrent imaging for PE, with 9.8% of recurrent scans occurring within 90 days [9]. Patients with SCD may require recurrent imaging studies throughout their lifespan owing to the chronic nature of the disease and their frequent visits to the emergency department [10, 11]. The frequent use of imaging studies raises concerns about cumulative radiation exposure and its associated increased cancer risk [12]. Specifically, a single CTPA scan has been associated with a 1.1% increase in the lifetime relative risk of breast cancer and a 2.2% increase in the risk of lung cancer [13].

Table 1 CT scan acquisition parameters for PE assessment

Parameter	Value
CT Scanner Model	GE Revolution CT Scanner (128-slice)
Tube Voltage	100 kVp
Tube Current	200 mA
Beam Collimation	0.6 mm
Rotation Time	0.5 s
Pitch	1.2
Scan Direction	Craniocaudal
Scan Extent	Lung apex to diaphragm
Respiration Phase	Inspiration
Contrast Agent	Iohexol (Omnipaque 350 mgI/mL)
Bolus Tracking	ROI in main pulmonary artery, threshold 100 HU
Infusion Rate	5 mL/s
Catheter Size	16-gauge

Abbreviations: ROI, region of interest

Given the relatively high prevalence of SCD in the Kingdom of Bahrain, estimated at approximately 1% [14], this study aimed to investigate trends in the utilization of CTPA among patients with SCD, with a focus on the rate of recurrent scans. This analysis will enable an understanding of the cumulative radiation exposure related to PE, which informs clinical practices and emphasizes the necessity for optimized imaging protocols that balance diagnostic accuracy with minimizing long-term health risks.

Methods

Study objectives

This study aimed to analyze trends in CTPA utilization among patients with SCD over the study period and assess the frequency and timing of recurrent CTPA scans.

Study design and setting

This longitudinal retrospective cohort study was conducted at Salmaniya Medical Complex, the largest hospital in the Kingdom of Bahrain. The complex also houses the Hereditary Blood Disorders Centre, which provides integrated care for patients with hereditary blood disorders across the country. The study spanned 11 years, from April 15, 2013, to April 15, 2024.

Study population

This study included patients with SCD who underwent at least one CTPA scan in the emergency setting for suspected PE during the study period. Patients of all ages with a confirmed diagnosis of SCD were eligible. Patients whose scans were performed for indications other than suspected PE were excluded. No additional exclusion criteria were applied.

The decision to perform CTPA was solely at the discretion of the treating physician, on the basis of clinical suspicion of PE. There was no standardized institutional protocol for CTPA utilization during the study period.

CTPA acquisition and interpretation

CTPA scans were performed via a GE Revolution 128-slice CT scanner (GE Healthcare, Chicago, IL, USA) following a standardized protocol (Table 1). PE was diagnosed on the basis of the presence of a filling defect within a pulmonary artery on CTPA. All the scans were interpreted by board-certified radiologists.

Data collection and extraction

Data collection and extraction involved accessing the radiology information system (RIS) and electronic medical records to obtain relevant information. A total of 11,434 CTPA scan requests were reviewed from the study period. A search was conducted within the clinical

information field of the scan requests via keywords such as "Sickle" and "SCD" to identify potentially eligible patients ($n = 2,087$). After the scan details were evaluated, 153 scans were excluded because of cancellations ($n = 149$) or indications other than PE ($n = 4$), resulting in 1,934 eligible scans.

The extracted data were systematically recorded in an Excel spreadsheet (Microsoft Corporation, Redmond, WA, USA). The key variables collected included patient demographics, such as age and sex, as well as the precise dates of CTPA scans and their corresponding results regarding PE. Recurrent scans were defined as any subsequent CTPA scan performed after an initial scan within the study period, regardless of the time interval between scans.

The extraction of data was performed by two trained research assistants with expertise in medical data extraction. To minimize bias, both assistants were blinded to the study outcomes during the extraction process. After extraction, the data were organized and reviewed for accuracy and completeness under the supervision of the principal investigator. Regular meetings were held to address any discrepancies and ensure data integrity.

Data analysis

After ensuring completeness and consistency, the data were analyzed via IBM SPSS for Windows, version 27 (IBM Corp., Armonk, NY, USA). Categorical data are reported as frequencies and percentages, whereas continuous variables are presented as the means and standard deviations for normally distributed variables and as medians with interquartile ranges (IQRs) for non-normally distributed variables. Normality was assessed through histograms, the Shapiro–Wilk test, and the Kolmogorov–Smirnov test. Categorical data were compared via the chi-square test.

To examine the utilization trends of CTPA scans, the average number of scans per month for each year spanning from 2014 to 2023 was analyzed, excluding data from 2013 to 2024 due to incomplete records. Compound annual growth rates (CAGRs) were computed for three distinct periods: the entire timeframe (2014–2023), the pre-COVID-19 era (2014–2020), and the COVID-19 and post-COVID-19 eras (2021–2023). Linear regression analysis was employed, with calendar year used as the independent variable, to assess the significance of trends in CTPA scan utilization and the annual incidence of PE. The significance level was set at $\alpha = 0.05$.

Table 2 Demographic and scan characteristics of SCD patients undergoing CTPA

Variable		Frequency	Percentage
Total Patients		1084	100.0%
	Age at Initial Scan		
	Under 18 years	22	2.0%
	18–30 years	374	34.5%
	31–45 years	400	36.9%
	46–60 years	227	20.9%
	Over 60 years	61	5.6%
	Sex		
	Male	604	55.7%
	Female	480	44.3%
	Patients with PE	172	15.9%
	Patients with Recurrent Scans	415	38.3%
Total CTPA Scans		1934	100.0%
	Scans with PE	189	9.8%
	Recurrent Scans	850	44.0%
	Within 6 months of prior scan	276	32.5%
	Within 12 months of prior scan	412	48.5%

Abbreviations: CTPA, computed tomography pulmonary angiography; PE, pulmonary embolism

Note: The data for 2013 and 2024 do not encompass the entire calendar year, as the study spanned from April 15, 2013, to April 15, 2024

Results

Study population characteristics

Over the study period, 1084 patients with SCD underwent at least one CTPA for suspected PE, resulting in a total of 1934 scans, of which 850 were recurrent. The median age of the patients at the initial scan was 35 years (IQR 26–47 years), ranging from 6 to 87 years. In terms of sex distribution, 604 (55.7%) were males, and 480 (44.3%) were females (Table 2).

Trends in CTPA utilization

Between 2014 and 2023, the average number of CTPA scans per month increased from 13.6 to 31.3, indicating a 2.3-fold increase (CAGR = 9.7%, $p = 0.03$). From 2014 to 2020, the average number of CTPA scans per month maintained a steady pattern, fluctuating between 10.0 and 13.6, with no substantial growth observed (CAGR = -3.6%, $p = 0.69$). However, a significant surge occurred after 2020, coinciding with the COVID-19 pandemic, with the average number of CTPA scans per month reaching 22.5 ± 6.6 in 2022 and further increasing to a peak of 31.3 ± 6.8 scans per month in 2023, representing a 2.9-fold increase (CAGR = 42.1%, $p = 0.03$) (Fig. 1).

Concurrent with the increase in CTPA scan utilization, the average number of PE cases per month also exhibited a similar trend. Notably, the average number of PE cases increased from 1.6 ± 0.3 cases per month from 2014 to 2019 to 2.6 ± 0.4 cases per month from 2020 to 2023 ($p < 0.05$) (Fig. 2).

Frequency and characteristics of recurrent CTPA

Overall, 415 (38.3%) patients underwent recurrent CTPA scans during the study period. No significant difference

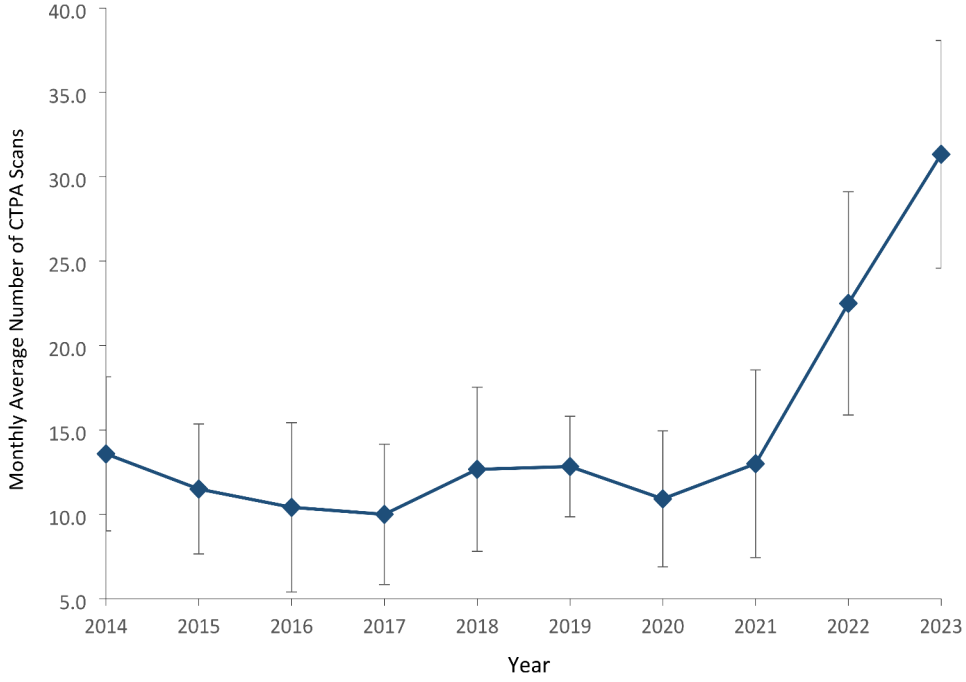

Fig. 1 Trends in CTPA scan utilization in patients with SCD (2014–2023). Abbreviations: CTPA, computed tomography pulmonary angiography. The error bars in the chart represent ± 1 standard deviation around the mean. Data for the years 2013 and 2024 are not included, as the study did not span the full calendar years of those years

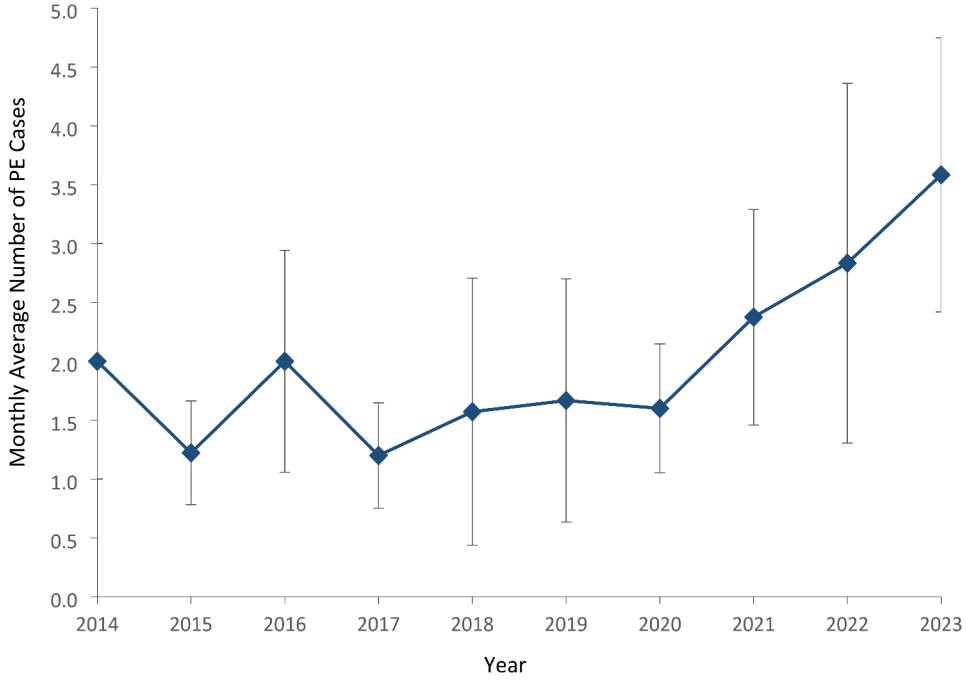

Fig. 2 Trends in diagnosed PE cases in patients with SCD (2014–2023). Abbreviations: PE, pulmonary embolism. The error bars in the chart represent ± 1 standard deviation around the mean. Data for the years 2013 and 2024 are not included, as the study did not span the full calendar years of those years

was observed in the rate of recurrent scans between sexes (χ^2 = 0.22, p = 0.64); specifically, 180 (37.5%) female patients and 235 (38.9%) male patients underwent recurrent scans.

The mean number of CTPA scans per patient was 1.8. Among those with recurrent scans, 207 (49.9%) patients underwent two scans, 108 (26.0%) underwent three scans, and 100 (24.1%) underwent four or more scans. Notably, four patients underwent at least 10 scans each

during the study period, with the highest number being 15 scans in a single female patient.

Among the recurrent scans ($n = 850$), 276 (32.5%) occurred within 6 months of the prior scan, whereas 412 (48.5%) occurred within 12 months. The median interval between successive scans was 12.6 months (IQR 4.3–35.1 months).

In total, in 172 (15.9%) patients, PE was detected in 189 (9.8%) scans. Among the recurrent scans, the positivity rate for PE was 8.8% (75/849), which was slightly lower than the 10.5% (114/1,085) reported in the initial scans; however, this difference was not statistically significant ($\chi^2 = 1.51$, $p = 0.22$).

Discussion

This study provides insights into the patterns and trends of CTPA utilization among patients with SCD. Compared with that in the pre-COVID-19 era, CTPA utilization nearly tripled in the post-COVID-19 era, and a substantial proportion of recurrent CTPA scans were observed. These findings highlight a significant diagnostic radiation burden associated with CTPA use in patients with SCD.

The surge in CTPA utilization during the COVID-19 and post-COVID-19 eras suggests that decision-making regarding CTPA requests may have become more proactive, potentially because of concerns about missed diagnoses or malpractice litigation. Notably, this surge in CTPA use occurred without any increase in the number of available scanners or changes in institutional guidelines for PE diagnosis and management, suggesting that the increase was driven primarily by clinical decision-making practices rather than systemic factors.

A review of the literature on CTPA utilization for suspected PE revealed a consistent upward trend [15–17]. For example, a prior study revealed a substantial increase in CTPA utilization, with increases ranging from 7.1 to 10.0% from 2004 to 2007 and a further 4.1% increase from 2012 to 2016 [16]. The impact of COVID-19 on CTPA utilization has been evident in multiple studies, with a significant surge during the pandemic [18, 19]. Although increased utilization during the pandemic appears to be justified, as the rate of positive scans has remained stable, the patterns of utilization in the post-COVID-19 era remain unclear. In contrast to findings suggesting a return to pre-COVID-19 levels [20], recent studies have demonstrated a sustained increase in CT utilization post-COVID-19. For example, Kempter et al. [21]. reported significantly higher rates of chest CT scans in the post-COVID-19 period than in the pre-COVID-19 period, indicating a disproportionate and lasting surge. Similarly, a study by Arıkan et al. [22]. revealed that while the rate of chest X-rays decreased, the use of chest CT increased significantly in the post-COVID-19 period, with a notable shift toward younger patients undergoing chest CT.

The findings also revealed a simultaneous increase in the number of patients diagnosed with PE during the COVID-19 and post-COVID-19 eras. This trend aligns with evidence linking COVID-19 to an elevated risk of venous thromboembolic disease. However, the trend of increased CTPA utilization persisted even after the last wave of the pandemic subsided in Bahrain in December 2022 [23]. Furthermore, the greater number of CTPA scans may have contributed to the overdiagnosis of PE, particularly in cases of segmental and subsegmental PE, as previous research has indicated a high rate of false-positive findings in these situations [24]. This issue of poor interreader agreement in subsegmental PE diagnosis [25] may be further exacerbated in the context of SCD because of higher rates of suboptimal scan quality [7].

More than one-third of the study population underwent multiple scans during the study period, with approximately one-third of these repeated scans occurring within 6 months. This recurrence is expected, as there is no risk-free period for PE following a negative CTPA scan, necessitating recurrent scanning when clinical suspicion arises [26]. The lack of established guidelines for the diagnosis of PE in patients with SCD, coupled with the limitations of existing clinical prediction rules such as the Wells criteria [27, 28], further promotes CTPA scan utilization. Nonetheless, physicians often rely on their clinical intuition and adopt a defensive approach in diagnosing PE to avoid overlooking potential cases [29–31]. This practice is particularly pertinent in the context of SCD, given the increased risk for PE and its associated mortality [4, 32].

A previous study examining PE imaging in SCD patients reported a mean of 1.2–1.5 scans per patient, with a maximum of 5 scans per patient, indicating a lower frequency than our findings [9]. However, the study included a relatively modest sample size despite its extensive duration. Furthermore, that study was conducted at a center where the clinical practice involved recommending ventilation/perfusion (V/Q) scintigraphy for stable patients with normal chest radiographs, potentially introducing institutional bias. This was evident from the disproportionate frequency of V/Q scintigraphy compared with CTPA scans, which contradicts the conventional preference, as CTPA is typically favored owing to its widespread availability and rapid turnaround times [16, 33, 34].

It is imperative to mitigate radiation exposure among SCD patients who undergo CTPA scans, particularly because of the potential long-term risks associated with recurrent imaging studies. Low-dose CTPA protocols have consistently shown significant reductions in radiation dose, albeit with a trade-off of increased image noise

[35–37]. However, the feasibility of low-dose CTPA protocols in such patients has not been previously investigated. The use of bismuth breast shields may also reduce the radiation dose [38]. In light of concerns about radiation exposure, the use of V/Q scintigraphy for the diagnosis of PE has re-emerged [39]. Notably, the radiation dose to the breast from a CTPA scan exceeds that of V/Q scintigraphy with single-photon emission computed tomography (SPECT) by at least 27 times [40].

This study has certain limitations. Its retrospective design introduces the potential for incomplete or missing data in electronic medical records, potentially affecting the accuracy of the findings. Additionally, the focus on CTPA excluded other imaging modalities, which may limit the comprehensiveness of the analysis. The lack of a control group of non-SCD patients is also a limitation. Furthermore, the absence of information on patient outcomes restricts the ability to assess the broader clinical impact of increased CTPA utilization.

Conclusions

In conclusion, this study highlights a significant shift in CTPA utilization patterns among patients with SCD, particularly following the COVID-19 pandemic. The notable increase in scans—many of which were recurrent and performed within short intervals—raises concerns about cumulative radiation exposure in this vulnerable population. Addressing this issue requires a comprehensive approach, including the implementation of low-dose CTPA protocols and the consideration of alternative imaging methods to reduce radiation risk. Further research is crucial to uncover the factors driving this surge in CTPA use and to develop diagnostic strategies that optimize both accuracy and patient safety.

Author contributions

A.H., N.A., M.K., N.M., Z.K., M.A., M.A., Z.A., A.M., H.Q., and J.A. each made a significant contribution to the work reported, including in the conception, study design, execution, acquisition, analysis and interpretation, or all these areas. They also participated in drafting, revising, or critically reviewing the article, gave final approval of the version to be published, agreed on the journal to which the article has been submitted, and are accountable for all aspects of the work.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval

This study was conducted in accordance with the principles outlined in the Declaration of Helsinki and was approved by the Research Committee of the Government Hospitals in Bahrain (Approval Number: 68-060624). A waiver of individual informed consent was obtained due to the retrospective nature of the study and the use of deidentified data.

Consent for publication

Not Applicable.

Competing interests

The authors declare no competing interests.

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