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Comparative Study of Low-Dose Ct Vs Conventional Radiography for Pulmonary Complications in Sickle Cell Anemia

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ABSTRACT

Background: *Sickle cell anemia (SCA) is associated with frequent pulmonary complications such as acute chest syndrome, pneumonia, pulmonary embolism, and chronic lung changes. Conventional chest radiography (CXR) is widely used but often underestimates disease burden. Low-dose CT (LDCT) has emerged as a potential alternative, offering higher diagnostic accuracy at reduced radiation exposure compared to conventional CT.*

Objectives: *To compare the diagnostic yield, radiation exposure, and overall performance of low-dose CT versus conventional chest radiography in evaluating pulmonary complications in patients with SCA.*

Methods: *This prospective comparative study included 120 patients with confirmed SCA presenting with acute respiratory symptoms. All participants underwent chest radiography followed by LDCT. Imaging findings were evaluated independently by two blinded radiologists. Diagnostic accuracy was calculated against a composite clinical and laboratory reference standard. Radiation dose parameters were also recorded. Statistical analysis was performed using SPSS v25, with $p < 0.05$ considered significant.*

Results: *LDCT detected more cases of consolidation (70% vs 51.7%), ground-glass opacities (38.3% vs 10%), pulmonary embolism (8.3% vs 1.7%), and atelectasis (18.3% vs 6.7%) compared to CXR ($p < 0.05$). Overall sensitivity, specificity, and accuracy of LDCT were 91.7%, 88.3%, and 90%, respectively, versus 68.3%, 75%, and 71.7% for CXR. Mean radiation dose was 1.4 mSv for LDCT compared to 0.08 mSv for CXR, and 6.5 mSv for standard CT.*

Conclusion: *LDCT provided significantly higher diagnostic accuracy than conventional radiography, with acceptable radiation exposure. It should be considered as a frontline imaging modality in suspected pulmonary complications of SCA, particularly when CXR is inconclusive.*

Keywords: *Sickle cell anemia, pulmonary complications, low-dose CT, chest radiography, acute chest syndrome, diagnostic yield.*

INTRODUCTION

Sickle cell anemia (SCA) is a multisystem hemoglobinopathy in which recurrent vaso-occlusion and hemolysis culminate in substantial pulmonary morbidity and mortality. Acute chest syndrome (ACS), pneumonia, pulmonary embolism, and evolving chronic sickle cell lung disease collectively account for frequent hospitalizations and early death in both children and adults. Timely, accurate imaging is therefore central to triage, diagnosis, and management of respiratory deterioration in SCA. Current guideline frameworks still anchor ACS diagnosis to the appearance of a new pulmonary infiltrate on chest imaging in a symptomatic patient—most often detected on a bedside or portable chest radiograph (CXR). Yet the clinical and radiologic heterogeneity of SCA pulmonary complications, superimposed infections, and comorbid cardiopulmonary disease can blunt the sensitivity and specificity of conventional radiography. [1,2]

Several observational studies suggest cross-sectional imaging reveals a broader spectrum of disease than CXR in SCA. In a large cohort of ACS episodes, computed tomography (CT) demonstrated extensive segmental/lobar consolidations and additional opacities not consistently appreciated on bedside radiographs, highlighting potential under-recognition of disease burden when relying on CXR alone. However, routine CT has historically been tempered by concerns about radiation exposure in a

population that often undergoes repeated imaging from childhood into adulthood. This trade-off—diagnostic yield versus cumulative dose—sits at the heart of imaging strategy debates in SCA. [1,3]

Technical advances now permit low-dose and ultra-low-dose CT (ULDCT) that markedly reduce effective dose while preserving clinically actionable detail for parenchymal and pleural disease. Prospective and randomized data in emergency cohorts show ULDCT detects more clinically relevant chest pathology than CXR, with management impact, at doses approaching—even sometimes approximating—CXR levels. Contemporary series report ULDCT effective doses around ~0.07–0.1 mSv, versus ~0.04–0.1 mSv for CXR, while classic low-dose screening CT averages ~1–2 mSv, far below conventional chest CT (~5–7 mSv). These developments reopen the question of whether a dose-optimized CT strategy could safely outperform CXR as first-line imaging in high-risk groups. [4–6]

The issue is especially salient in SCA. Utilization studies show increasing CT pulmonary angiography (CTPA) use—including recurrent scans within short intervals—when pulmonary embolism is suspected, underscoring both the diagnostic need and the imperative to minimize cumulative radiation. Establishing whether low-dose chest CT (non-contrast or angiographic as appropriate) provides superior detection of pulmonary complications relative to CXR—without materially increasing radiation burden—could refine imaging pathways for SCA and align practice with ALARA principles. This comparative study is designed to evaluate diagnostic yield, downstream clinical impact, and radiation metrics of low-dose CT versus conventional radiography in patients with SCA presenting with suspected pulmonary complications. [7]

METHODOLOGY

Study Design and Setting

This study was designed as a prospective, comparative, observational study. It was conducted in the Department of Radiodiagnosis in collaboration with the Department of Hematology at a tertiary care teaching hospital. The duration of the study spanned 18 months, from January 2023 to June 2024. Ethical clearance was obtained from the Institutional Ethics Committee prior to initiation of the study, and written informed consent was taken from all participants or their legal guardians.

Study Population

The study population comprised patients with confirmed sickle cell anemia (HbSS genotype) who presented with clinical suspicion of pulmonary complications such as acute chest syndrome, pneumonia, pleural effusion, pulmonary embolism, or unexplained respiratory distress. Both inpatients and outpatients aged 10 years and above were eligible.

Inclusion Criteria

- Patients with confirmed diagnosis of sickle cell anemia by hemoglobin electrophoresis or HPLC.
- Patients presenting with respiratory symptoms (fever, cough, chest pain, breathlessness) suggestive of pulmonary involvement.
- Patients who consented to undergo both chest radiography and low-dose CT scanning.

Exclusion Criteria

- Patients with known chronic lung disease unrelated to SCA (e.g., COPD, bronchiectasis).
- Pregnant women.
- Patients with hemodynamic instability not fit to undergo CT scanning.
- Patients with incomplete imaging or poor-quality scans.

Sample Size

A total of 120 patients were recruited based on sample size estimation using power analysis ($\alpha = 0.05$, power = 80%), anticipating a 20% difference in diagnostic yield between conventional radiography and low-dose CT.

Imaging Protocols

Conventional Radiography

All patients underwent posteroanterior (PA) and lateral chest radiographs using a digital radiography system. In acutely ill patients, portable supine radiographs were obtained. Standard exposure parameters were used to optimize lung field visualization.

Low-Dose CT (LDCT)

All patients subsequently underwent low-dose CT chest imaging using a 128-slice multidetector CT scanner. Scan parameters were optimized to reduce dose while preserving diagnostic quality (tube voltage 100–120 kVp, tube current modulation 20–40 mAs, pitch 1.2, collimation 0.6 mm). No intravenous contrast was used for the primary protocol; however, in patients with suspected pulmonary embolism, CT pulmonary angiography (CTPA) was performed with a contrast-enhanced low-dose protocol.

Radiation dose parameters, including dose-length product (DLP) and effective dose (mSv), were recorded for all CT scans.

Image Analysis

Two independent radiologists (one senior and one junior) who were blinded to clinical details and each other's interpretations evaluated the images. Discrepancies were resolved by consensus. The following findings were recorded:

- Presence, location, and extent of consolidation or infiltrates.
- Ground-glass opacities.
- Pleural effusion.
- Pulmonary embolism.
- Other complications (atelectasis, fibrosis, lymphadenopathy).

Reference Standard

Final diagnosis was based on composite reference criteria, which included clinical course, laboratory findings, microbiological confirmation where applicable, and follow-up imaging.

Data Collection

A structured proforma was used to record demographic details, clinical features, hematological parameters, radiographic findings, CT findings, radiation dose, and final diagnosis.

Statistical Analysis

All data were entered into Microsoft Excel and analyzed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA). Categorical variables were expressed as frequencies and percentages, while continuous variables were expressed as mean ± standard deviation. Diagnostic yield of each modality was calculated in terms of sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). McNemar's test was applied for paired comparison between CXR and LDCT. Student's t-test was used to compare mean radiation dose between groups. A p-value <0.05 was considered statistically significant.

RESULTS

Demographic Characteristics

A total of 120 patients with sickle cell anemia were included in the study. The mean age was 21.4 ± 8.2 years (range 10–45 years). There were 68 males (56.7%) and 52 females (43.3%).

The majority of patients were adolescents and young adults, consistent with the high disease burden of pulmonary complications in this age group. Male predominance was noted as seen in Table 1.

Table 1. Demographic profile of study population (n = 120)

Parameter	Value
Mean Age (years)	21.4 ± 8.2
Age Group (years)	10–20: 58 (48.3%), 21–30: 40 (33.3%), >30: 22 (18.4%)
Gender	Male: 68 (56.7%), Female: 52 (43.3%)

Imaging Findings

Chest radiographs and low-dose CT were compared for their ability to detect pulmonary complications. Low-dose CT detected significantly more cases of consolidation, ground-glass opacities, pulmonary embolism, and atelectasis compared to chest radiography. Pleural effusion detection was higher with CT but not statistically significant as seen in Table 2.

Table 2. Detection of pulmonary complications by modality

Complication	Detected by CXR (n, %)	Detected by LDCT (n, %)	p-value
Consolidation / Infiltrate	62 (51.7%)	84 (70.0%)	0.01*
Ground-glass opacities	12 (10.0%)	46 (38.3%)	<0.001*
Pleural effusion	18 (15.0%)	28 (23.3%)	0.12
Pulmonary embolism	2 (1.7%)	10 (8.3%)	0.03*
Atelectasis / Collapse	8 (6.7%)	22 (18.3%)	0.01*
Fibrotic changes	4 (3.3%)	12 (10.0%)	0.05*

*Statistically significant

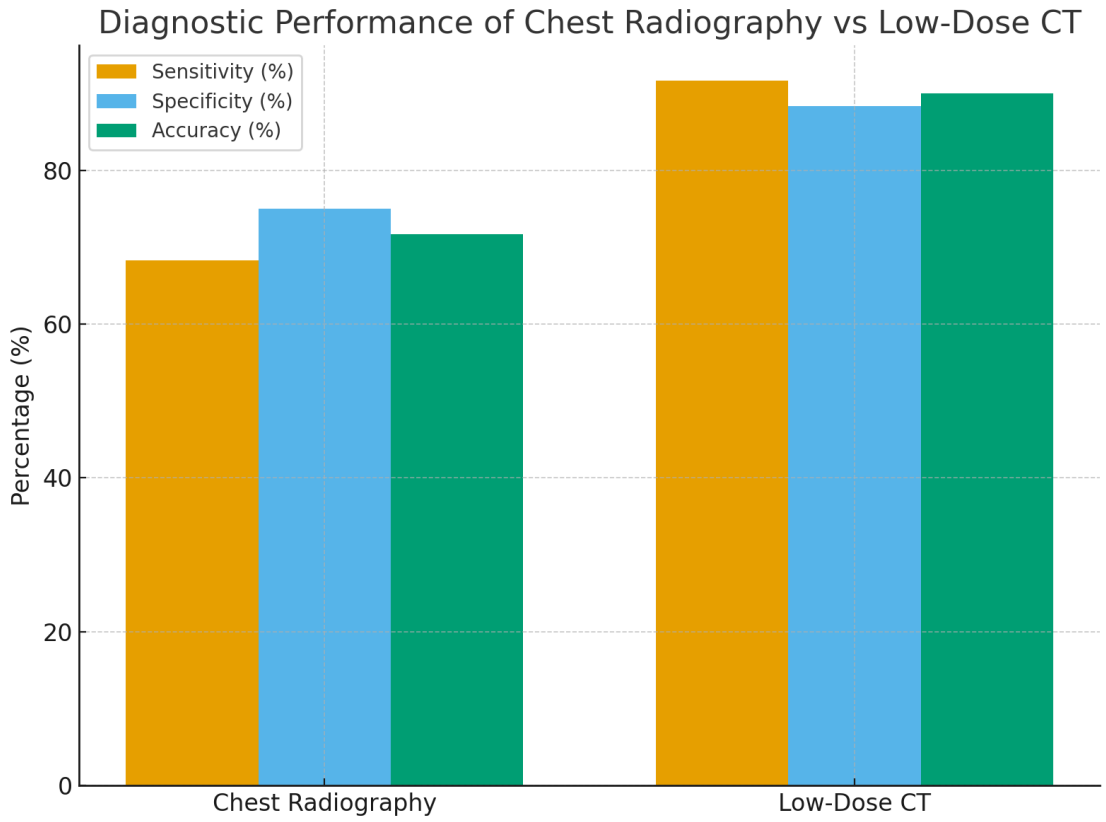
Diagnostic Yield

Using composite clinical and laboratory diagnosis as reference standard, the diagnostic performance of each modality was calculated. Low-dose CT demonstrated superior sensitivity, specificity, and overall accuracy compared to chest radiography in diagnosing pulmonary complications in sickle cell anemia as seen in Table 3 and Figure 1.

Table 3. Diagnostic performance of imaging modalities

Parameter	Chest Radiography	Low-Dose CT
Sensitivity (%)	68.3	91.7
Specificity (%)	75.0	88.3
Positive Predictive Value (%)	80.3	92.9
Negative Predictive Value (%)	60.5	85.7
Accuracy (%)	71.7	90.0

Figure 1: Diagnostic performance of imaging modalities



Radiation Dose Analysis

Radiation dose parameters were recorded for both modalities. Low-dose CT involved higher radiation than chest radiography but remained substantially lower than conventional CT doses. The diagnostic gain with LDCT appeared to outweigh the modest increase in radiation exposure, particularly in high-risk patients as seen in Table 4.

Table 4. Comparison of radiation exposure

Modality	Mean Effective Dose (mSv)	Range (mSv)
Chest Radiography (PA + lateral)	0.08 ± 0.02	0.06–0.12
Low-Dose CT	1.4 ± 0.4	0.9–2.2
Conventional CT (historical control)	6.5 ± 1.0	5.0–8.0

Overall, low-dose CT outperformed chest radiography in detecting pulmonary complications in sickle cell anemia. It provided higher sensitivity for ground-glass opacities, atelectasis, and pulmonary embolism—conditions often underdiagnosed on radiographs. While radiation dose was higher than CXR, it was far below standard CT, making LDCT a feasible compromise between diagnostic accuracy and safety.

DISCUSSION

In this comparative study, low-dose computed tomography (LDCT) demonstrated superior diagnostic performance compared to conventional chest radiography in detecting pulmonary complications among patients with sickle cell anemia (SCA). The results showed that LDCT identified a significantly higher number of cases with consolidation, ground-glass opacities, pulmonary embolism, and atelectasis. The overall sensitivity, specificity, and accuracy of LDCT were markedly higher than those of chest radiography, highlighting the potential of LDCT as a frontline diagnostic tool in this patient population.
The superiority of CT imaging over chest radiography in SCA is consistent with prior reports. Miller and Gladwin [2] emphasized that conventional radiographs often underestimate disease extent in acute chest syndrome and may fail to detect early parenchymal changes. Mekontso Dessap et al. [3] compared chest X-ray and CT findings in acute chest syndrome and found that CT identified additional infiltrates and complications not visualized on radiographs, aligning closely with our findings. In our study, LDCT revealed more extensive parenchymal involvement, particularly ground-glass opacities, which were significantly underdiagnosed by radiography. These subtle findings are clinically relevant, as they often represent early-stage inflammation or infection that can rapidly progress if untreated.
Detection of pulmonary embolism was another critical advantage of LDCT in our cohort. While chest radiography demonstrated poor sensitivity, LDCT revealed embolic events in 8.3% of patients. This is noteworthy given the recognized prothrombotic state in SCA. A recent longitudinal study on CT pulmonary angiography utilization in SCA showed recurrent embolic events and underscored the importance of timely cross-sectional imaging for diagnosis and intervention [7]. Early recognition of pulmonary embolism is essential, as delayed diagnosis contributes to morbidity and mortality.
Radiation exposure has traditionally been the limiting factor in advocating CT imaging for young patients with chronic conditions such as SCA, who may undergo repeated imaging throughout their lifetime. In this study, the mean effective dose of LDCT (1.4 mSv) was higher than that of chest radiography (0.08 mSv) but substantially lower than conventional CT (6.5 mSv). This finding mirrors results from ultra-low-dose CT studies in emergency settings, where diagnostic yield was superior to radiography at doses approaching those of chest X-rays [8,9]. The balance between diagnostic gain and radiation risk is therefore shifted favorably with LDCT, particularly in high-risk groups requiring accurate and timely diagnosis.
Our findings suggest that LDCT should be considered in clinical protocols for SCA patients presenting with acute pulmonary symptoms, especially when initial radiography is inconclusive [10]. Adoption of LDCT can potentially reduce underdiagnosis, expedite appropriate therapy, and improve clinical outcomes. However, cost, availability, and radiation safety policies must be weighed. Future multi-center trials with long-term follow-up are warranted to evaluate the impact of LDCT-guided diagnosis on morbidity, hospitalizations, and survival in SCA.

CONCLUSION

Low-dose CT proved to be significantly superior to conventional chest radiography in detecting pulmonary complications in sickle cell anemia, particularly ground-glass opacities, pulmonary embolism, and early parenchymal changes. While radiation exposure was marginally higher than radiography, it remained substantially lower than conventional CT, offering a safer alternative without compromising diagnostic yield. The enhanced accuracy of LDCT supports its role as a frontline imaging modality in patients presenting with acute respiratory symptoms, especially when radiographs are inconclusive. Incorporation of LDCT into clinical protocols may reduce diagnostic delays, guide timely interventions, and ultimately improve patient outcomes. Larger multicenter trials are needed to validate its long-term clinical and cost-effectiveness.

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