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Image Quality Evaluation of Photon Counting CT for Pulmonary Monitoring in Bronchiectasis

[1]Mukholiq Fathunnisa*, [1]Eko Hidayanto, [1]Catur Edi Widodo

[1]Department of Physics, Faculty of Science and Mathematics, Diponegoro University, Jl Prof Jacob Rais, Tembalang, Semarang, 50275, Indonesia

*Corresponding Author: Mukholiq Fathunnisa, fathunnisam@gmail.com

Abstract—This study evaluates the image quality of Photon-Counting Computed Tomography (PCCT) for pulmonary imaging in bronchiectasis patients using quantitative metrics. A retrospective observational study was conducted using thoracic CT datasets from 20 patients. Image quality was assessed based on mean attenuation, standard deviation (SD), Signal-to-Noise Ratio (SNR), and Contrast-to-Noise Ratio (CNR) measured in regions of interest (ROI) of the lung, mediastinum, and background. Lung attenuation ranged from −814 to −922 HU, mediastinum from 20 to 57 HU, and background values approached −1000 HU, consistent with expected tissue characteristics. SNR was calculated using an air-referenced formulation to ensure physically meaningful interpretation, while CNR ranged from 29.76 to 319.09, indicating strong contrast performance. Despite variability in image noise, PCCT demonstrated consistent quantitative image quality across patients. These findings suggest that PCCT is capable of providing reliable image quality for pulmonary imaging. Further studies including radiation dose evaluation and comparative analysis with conventional CT systems are required to establish its clinical advantage.

Keywords: Bronchiectasis; Photon-Counting CT; Image Quality; Signal-to-Noise Ratio; Contrast-to-Noise Ratio.

1. Introduction

The increasing prevalence of pulmonary diseases, particularly following the COVID-19 pandemic, has led to a significant rise in the use of thoracic imaging, especially computed tomography (CT). CT provides high spatial resolution and detailed visualization of bronchial structures, making it an essential modality for diagnosing and monitoring lung diseases. However, the relatively high radiation dose associated with CT remains a major concern, particularly for patients requiring long-term follow-up, such as those with bronchiectasis [1].

To minimize radiation exposure, the principle of *As Low As Reasonably Achievable* (ALARA) has driven the development of low-dose CT (LDCT) protocols. Previous studies have demonstrated that LDCT can significantly reduce radiation dose—up to 91%—while maintaining acceptable diagnostic image quality [2]. Despite these advantages, the application of LDCT in non-neoplastic chronic lung diseases remains challenging. In bronchiectasis, accurate assessment requires high spatial resolution to evaluate bronchial dilation, wall thickening, and structural abnormalities, which may be compromised at lower dose settings [3].

Recent advancements in reconstruction algorithms, such as iterative reconstruction (IR) and deep learning reconstruction (DLR), have shown improvements in image quality by reducing noise and enhancing signal detectability [4]. However, limitations still exist, particularly in maintaining optimal contrast and spatial resolution under low-dose conditions.

Photon-Counting Computed Tomography (PCCT) has emerged as a next-generation CT technology that enables direct photon detection and energy discrimination, resulting in improved spatial resolution and reduced electronic noise. Studies have shown that PCCT can enhance Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR), even at reduced radiation doses, compared to conventional energy-integrating detector CT (EID-CT) [5]. This capability makes PCCT particularly promising for applications requiring repeated imaging, such as long-term monitoring of bronchiectasis patients.

Despite its potential, studies evaluating the performance of PCCT in bronchiectasis, especially within the context of LDCT protocols, remain limited. Furthermore, quantitative assessments of image quality using parameters such as mean attenuation, SNR, and CNR in clinical datasets are still scarce, particularly in Indonesia.

Therefore, this study aims to evaluate the image quality of PCCT in pulmonary imaging using quantitative parameters, including mean attenuation, standard deviation, SNR, and CNR. Additionally, this study seeks to assess the capability of PCCT to differentiate lung and mediastinal structures under low-dose conditions and to explore its potential as a reliable modality for long-term monitoring of bronchiectasis patients. However, this study focuses on quantitative image quality characterization and does not include direct comparison with conventional CT systems.

2. EXPERIMENTAL PROCEDURE

2.1 Study Design and Data Collection

This study employed a retrospective observational design using secondary thoracic CT image datasets obtained from 20 patients diagnosed with bronchiectasis. The data were collected from the Radiology Department of Pantai Indah Kapuk Hospital, Jakarta, Indonesia.

Inclusion criteria included patients with a confirmed diagnosis of bronchiectasis and availability of complete CT image datasets. Exclusion criteria included datasets with severe motion artefacts or incomplete imaging data that could affect quantitative analysis. Patient-related factors such as age, sex, and body weight may influence CT image quality and quantitative measurements. However, these variables were not available in this retrospective dataset and were therefore not included in the analysis.

2.2 Imaging System and Software

All CT images were acquired using a Photon-Counting Computed Tomography (PCCT) system available at the radiology facility. Images were reconstructed using a standard reconstruction kernel for thoracic imaging, with a slice thickness of 1 mm and a reconstruction increment of 1 mm. Quantum iterative reconstruction (QIR) was applied to improve image quality and reduce image noise.

The images used for analysis were reconstructed as polyenergetic images. Quantitative image analysis and ROI measurements were performed using 3D Slicer software (version 5.2.1), which provides reliable tools for medical image visualization and quantitative assessment.

2.3 Region of Interest (ROI) Selection

Quantitative image analysis was performed by placing regions of interest (ROI) in three predefined anatomical regions: lung parenchyma, mediastinum, and background air outside the patient. Circular ROIs with an approximate area of 50–100 mm² were used to ensure consistency across measurements. Three ROIs were placed in each region per patient, and the mean value was calculated.

ROI placement was carefully performed in homogeneous areas while avoiding visible vessels, airways, and abnormal structures such as bronchiectatic lesions to minimize variability. All measurements were performed by a single observer. To ensure measurement consistency, repeated measurements were conducted in a subset of cases. The placement of regions of interest in the lung parenchyma, mediastinum, and background is illustrated in Figure 1.

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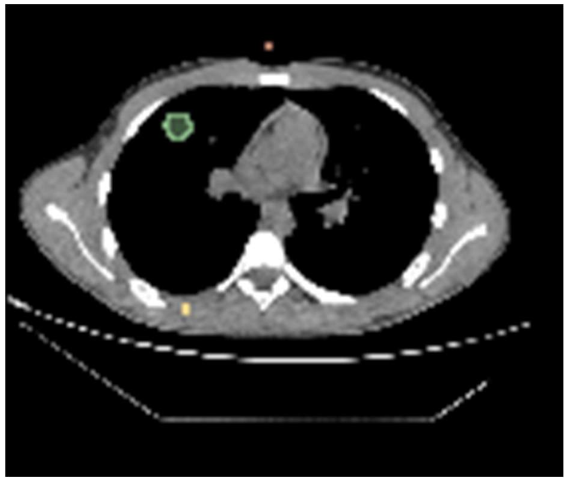

Fig. 1. Placement of regions of interest (ROI) in lung parenchyma, mediastinum, and background using 3D Slicer.

2.4 Image Quality Parameters

Image quality assessment was performed using quantitative parameters, including mean attenuation (in Hounsfield Units), standard deviation (SD), Signal-to-Noise Ratio (SNR), and Contrast-to-Noise Ratio (CNR). The mean value represents the average attenuation within the ROI, while SD reflects the level of image noise.

The Signal-to-Noise Ratio (SNR) was calculated differently for lung and mediastinum regions due to differences in attenuation characteristics. For lung parenchyma, SNR was calculated relative to air to avoid negative values:

$$SNR_{lung} = \frac{\mu lung - \mu air}{\sigma lung} \quad (1)$$

For mediastinum, SNR was calculated using the conventional formulation:

$$SNR_{mediastinum} = \frac{\mu mediastinum}{\sigma mediastinum} \quad (2)$$

The Contrast-to-Noise Ratio (CNR) was calculated using:

$$SNR_{lung} = \frac{|\mu lun \quad \mu mediastinum|}{\sigma backgorund} \quad (3)$$

The use of background noise in the denominator reflects system noise under minimal attenuation conditions and is commonly applied in CT image quality assessment.

2.5 Data Analysis

Quantitative values obtained from ROI measurements were analyzed descriptively and presented as mean, standard deviation, and range. The analysis focused on evaluating overall image quality characteristics and consistency across patient datasets.

3. RESULTS AND DISCUSSION

The quantitative evaluation of CT image quality was conducted based on measurements of mean attenuation, standard deviation (SD), and Contrast-to-Noise Ratio (CNR) obtained from 20 patient datasets. The results are summarized in Table 1.

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Table 1. Quantitative Image Quality Parameters

Patient	Lung Mean (HU)	Lung SD	Mediastinum Mean (HU)	Mediastinum SD	Background Mean (HU)	Background SD	SNR Lung	SNR Mediastinum	CNR
1	-904.459	34.509	56.6206	14.5798	-1007.69	16.7205	2.99	3.88	57.47
2	-899.172	29.394	38.5613	16.417	-985.369	31.4985	2.93	2.35	29.76
3	-891.867	22.120	20.0158	46.8769	-996.769	5.71766	4.74	0.43	159.4
4	-856.199	40.995	39.4203	21.5102	-950.153	12.4756	2.29	1.83	71.97
5	-866.726	42.801	47.0237	20.3357	-1000.72	5.17473	3.13	2.31	176.6
6	-897.594	18.112	45.5072	18.2327	-991.704	5.31573	5.20	2.49	177.1
7	-894.204	95.349	56.5072	46.0995	-999.319	26.0528	1.10	1.23	36.49
8	-857.929	29.385	40.2174	18.2119	-997.609	8.94463	4.75	2.21	100.4
9	-875.792	64.483	51.3333	19.9467	-993.812	9.24388	1.83	2.57	100.3
10	-814.763	63.006	21.913	26.3923	-991.826	8.26217	2.81	0.83	101.2
11	-875.395	25.291	32.1739	19.8964	-992.198	3.73748	4.62	1.62	242.8
12	-922.557	22.157	43.000	21.4373	-993.377	3.36986	3.20	2.01	286.6
13	-906.103	20.025	56.3043	20.1424	-1005.35	8.39787	4.96	2.79	114.6
14	-855.826	16.989	54.000	7.71934	-992.725	3.18491	8.06	6.99	285.3
15	-900.580	16.752	53.7826	21.1722	-987.304	10.4689	5.18	2.54	91.07
16	-859.783	24.775	31.971	8.89476	-992.449	2.79462	5.35	3.59	319.09
17	-909.536	29.518	37.6087	34.0874	-995.203	7.94388	2.90	1.10	119.3
18	-880.130	23.747	39.1594	20.6409	-1001.12	14.0582	5.09	1.90	65.39
19	-904.000	29.908	45.0145	15.6727	-984.667	9.35205	2.70	2.87	101.0
20	-851.043	21.251	57.6812	27.3885	-998.203	7.88629	6.92	2.10	115.2

The mean attenuation values of the lung region ranged from −814 to −922 HU, while mediastinum values ranged from 20 to 57 HU, and background values approached −1000 HU. These findings are consistent with the known attenuation characteristics of lung tissue, soft tissue, and air. The negative attenuation values observed in the lung region reflect the low density of aerated lung parenchyma, whereas the mediastinum exhibits higher attenuation due to its soft tissue composition. Background values close to −1000 HU confirm accurate ROI placement in air regions, which is essential for reliable noise estimation.

The standard deviation (SD) values demonstrated variability in image noise across patients, which may be influenced by differences in acquisition conditions or patient-related factors such as motion during scanning. One notable observation was Patient 7, which exhibited substantially higher noise (SD = 95.35 HU) compared to other patients. This elevated noise level is likely attributable to motion artefacts or suboptimal breath-holding during image acquisition. This finding highlights the sensitivity of quantitative image quality metrics to variability in clinical conditions.

The Signal-to-Noise Ratio (SNR) values in the lung region, calculated using an air-referenced formulation, ranged from 1.10 to 8.06, providing a physically meaningful representation of signal relative to background air. In contrast, SNR values in the mediastinum followed the conventional formulation and remained positive due to the higher attenuation of soft tissue.

The Contrast-to-Noise Ratio (CNR) values ranged from 29.76 to 319.09, indicating strong contrast between lung and mediastinum regions. High CNR values suggest that the imaging system is capable of effectively differentiating anatomical structures despite variations in image noise, which is essential for pulmonary imaging.

Overall, these results demonstrate that Photon-Counting Computed Tomography (PCCT) provides consistent and quantifiable image quality metrics under clinical conditions. However, this study does not include a direct comparison with conventional CT systems or diagnostic image quality assessment by radiologists. Therefore, while the findings indicate that PCCT provides reliable quantitative image quality characteristics, further studies incorporating comparative evaluation, radiation dose analysis, and diagnostic performance assessment are required to establish its full clinical value.

4. CONCLUSIONS

This study provides a quantitative characterization of image quality in photon-counting CT (PCCT) for pulmonary imaging in bronchiectasis patients.

The results demonstrate that attenuation values in lung, mediastinum, and background regions are consistent with expected tissue characteristics, confirming the reliability of ROI-based measurements. The relatively high CNR values indicate strong contrast performance between anatomical structures, while noise levels show variability across patients.

These findings suggest that PCCT provides consistent and reliable quantitative image quality under clinical conditions. However, this study does not include radiation dose analysis, comparative evaluation with conventional CT systems, or subjective diagnostic assessment.

Therefore, further studies incorporating these aspects are required to fully establish the clinical value of PCCT for pulmonary imaging and long-term monitoring applications.

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