ORIGINAL RESEARCH

Impact of reconstruction techniques on low dose chest CT image quality: comparison of FBP, Clear View at Mzuzu Central Hospital, Malawi

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Abstract

Objective

To investigate the impact of two reconstruction techniques, Filtered Back Projection (FBP) and Clear View (CV) iterative algorithm, on the image quality of low-dose thin-slice chest CT.

Methods

A retrospective study of 42 patients undergoing low-dose chest CT at Mzuzu Central Hospital from Feb-Apr 2024 used automatic tube current modulation at 120 kV. Raw data were reconstructed with FBP, 20% CV, 40% CV, 60% CV, and 80% CV, with 1 mm slice thickness and 0.625 mm spacing. Image noise, Signal-to-Noise Ratio (SNR), and Contrast-to-Noise Ratio (CNR) were measured, and image quality was rated on a 5-point scale for lung and mediastinal windows. Qualitative and quantitative parameters of the two different reconstruction algorithms in the five groups were comparatively analyzed.

Results

(1) Objective evaluation showed noise decreased in lung parenchyma, aorta, and erector spinae muscle with increasing CV weight. Mean noise reductions in lung parenchyma were 23.34% and 27.69% in 60% CV and 80% CV ($P < 0.05$). Aorta noise decreased by 23.43%, 37.16%, and 46.18% in 40% CV, 60% CV, and 80% CV ($P < 0.05$, $P < 0.001$, $P < 0.001$). Erector spinae muscle noise decreased by 35.91% and 44.78% in 60% CV and 80% CV ($P < 0.05$, $P < 0.001$). SNR and CNR were higher in CV groups than FBP. Among them, the differences in SNR between the 60% CV and 80% CV groups and the FBP group were statistically significant ($P < 0.05$). (2) Subjective scores for all groups were > 3, meeting diagnostic standards, with 60% CV yielding the highest lung and mediastinal window image quality ($P < 0.05$).

Conclusion

Compared to FBP, CV iterative reconstruction reduces noise and improves chest CT image quality under low-dose conditions as the weight increases, with 60% CV showing optimal performance.

Keywords: Iterative reconstruction algorithm; Low-dose; Chest diseases; Computed Tomography; Radiation dose

Introduction

In recent years, the widespread availability of CT equipment, coupled with the high resolution and sensitivity of Multi-Slice Spiral Computed Tomography (MSCT) to detect subtle lesions, has significantly expanded its use in the diagnosis of chest diseases[1-3]. However, there is growing public concern about the radiation exposure and associated carcinogenic risks posed by CT scans, as CT contributes significantly to patient radiation exposure in diagnostic radiology[4]. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), in countries with Healthcare Level I, CT accounts for only 6% of all diagnostic medical X-ray examinations but contributes to 41% of the total population's radiation dose[4].

Optimizing CT scanning protocols to minimize radiation dose without compromising diagnostic accuracy has become a focal point of research. While adjusting scanning parameters like reducing tube voltage, tube current, and increasing pitch can lower radiation exposure, these measures often come at the cost of image quality due to limitations inherent in traditional Filtered Back Projection (FBP) reconstruction techniques[9-11]. In contrast, the emerging iterative reconstruction techniques for CT images have demonstrated significant reductions in image noise, enhancements in Contrast to Noise Ratio (CNR), and overall image quality compared to conventional FBP algorithms[12-14]. This study aims to compare the objective metrics (image noise, Signal-to-Noise Ratio [SNR], and CNR) and subjective assessments (image quality scores for mediastinal and lung windows) of low-dose thin-slice (1 mm) chest CT images reconstructed using FBP and Clear View algorithms. We seek to explore the impact of these two reconstruction techniques on the quality of chest CT images.

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Methods

General Information

This retrospective study included 42 patients (23 males and 19 females) who underwent low-dose chest CT scans at Mzuzu Central Hospital radiology department from February to April 2024. The patients' ages ranged from 18 to 66 years with an average age of (42.44 ± 5.79) years. Inclusion criteria were age ≥ 18 years, Body Mass Index (BMI) between 18 and 25 kg/m2, including patients undergoing follow-up after breast cancer surgery, those with suspicious lesions detected on chest radiographs, and those with symptoms such as cough or chest pain requiring chest CT scans. Exclusion criteria included unclear images due to improper scanning techniques and images with artefacts. This study was approved by Mzuzu University Research Ethics Committee (MZUNIREC) (Approval Number: MZUNIREC/DOR/24/153). Patient informed consent was waived due to retrospective nature of the study.

Examination Method

All patients underwent full-lung CT scans using a NeuViz 16 Essence CT scanner while holding their breath. The patients were positioned supine with arms raised and head first. The scanning range extended from the thoracic inlet to the level of the diaphragm. The low-dose scanning protocol employed automatic tube current modulation (ATCM) with a tube voltage of 120 kV. Other parameters included a detector collimation width of 16 × 1.25 mm, a matrix size of 512 × 512, a rotation time of 0.5 s/r, a pitch of 1.5, and a scan slice thickness and interval of 5mm. Raw data were reconstructed using FBP and Clear View algorithms at 20%, 40%, 60%, and 80% strengths, resulting into five sets of thin-slice images with a slice thickness of 1mm and an interval of 0.625 mm. These image sets were labeled as FBP, 20% CV, 40% CV, 60% CV, and 80% CV groups, respectively. Lung window settings were WW 1200 HU and WL -600 HU, while mediastinal window settings were WW 350 HU and WL 45 HU.

Image Analysis

All images were imported into the post-processing workstation AVW for objective and subjective evaluation, and radiation doses were recorded.

Subjective Evaluation: Two experienced CT diagnosticians performed blind subjective scoring of image quality using a 5 - point scale. Consensus opinions were used for comparison. The 5 - point scale for evaluating image quality in lung and mediastinal windows was as follows[15]: 5 - Excellent anatomic structure and detail clarity, negligible noise, sharp edges, no waxy appearance; 4 - Good anatomic structure and detail clarity, slight noise, slightly reduced edge sharpness; 3 - Most anatomic structures are clear, some waxy appearance, locally noticeable but acceptable noise, lower edge sharpness; 2 - Blurred anatomic structure and details, noticeable noise, low edge sharpness, strong waxy appearance; 1 - Unrecognizable anatomic structure, extremely noticeable noise, poor edge sharpness, severe waxy appearance. Images scoring ≥ 3 were considered clinically diagnostic.

Objective Evaluation: The objective evaluation was conducted by an experienced chest radiologist. During the reconstruction of the lung window, the region of interest (ROI) was placed in the avascular portion of the upper lobe of the left lung. For the mediastinal window reconstruction, the ROI was placed within the aorta at the level of the aortic arch and within the right paravertebral muscle at the same level. The corresponding CT values and standard deviations (SD) were obtained. The ROI area ranged from 30 to 100 mm^2 and was placed in a region of uniform density. A copy-and-paste method was used during measurement to maintain consistent ROI sizes across different reconstructed images. Measurements were repeated three times, and the average values were taken. Using the SD as the noise value, the SNR and CNR were calculated for each ROI in the five image groups: SNR = CT value / SD, CNR = (CT value of vessel - CT value of muscle) / SD of muscle.

Radiation Dose

The volumetric CT dose index (CTDIvol) and dose length product (DLP) were automatically generated by the machine after completion of the scan. The effective dose (ED) was calculated using the formula: ED = DLP × k (0.014 $mSv \cdot mGy^{-1} \cdot cm^{-1}$).

Statistical Analysis

Statistical analysis was performed using SPSS 22.0 software. Continuous variables with normal distribution were expressed as mean ± standard deviation ($\bar{x} \pm s$)

Single-factor analysis of variance was used to compare the SNR and CNR of the five image groups, and pairwise comparisons were conducted using the LSD-t test. Subjective scores among groups were compared using the Kruskal-Wallis H test and pairwise comparisons. The Kappa test was used to analyze the consistency of subjective scores between the two radiologists: a Kappa value of 0 to 0.4 indicated poor consistency, 0.4 to 0.6 indicated moderate consistency, and 0.6 to 1.0 indicated good consistency. A P-value of less than 0.05 was considered statistically significant.

Results

Subjective Evaluation

The two radiologists demonstrated good consistency in evaluating the images, with Kappa values of 0.816 and 0.827 for the lung window and mediastinal window image quality scores, respectively. The subjective scores for all five image groups using the FBP and Clear View reconstruction algorithms were above 3, meeting the diagnostic requirements. The lung window image quality score for the 60% CV group was higher than the other four groups, with statistically significant differences compared to the FBP and 20% CV groups (both $P < 0.01$), but no significant differences compared to the 40% CV and 80% CV groups. The mediastinal window image quality of the 60% CV group was the highest, with statistically significant differences compared to the FBP, 20% CV, and 80% CV groups (all $P < 0.05$), but no significant difference compared to the 40% CV group ($P > 0.05$). The subjective image quality scores for both the lung window and mediastinal window of the four Clear View iterative reconstruction groups were higher than those of the FBP group, with only the 20% CV group showing no statistically significant difference from the FBP group ($P > 0.05$). The subjective image quality scores for the five groups are presented in Table 1.

Objective Evaluation

Comparison of CT Values Among Groups

At low dose levels, with the increase in the weight of CV iterative reconstruction, there were no statistically significant

Table 1: Comparison of SNR, CNR, CTDIvol, DLP, and ED between Conventional Dose Group and Low Dose Group($\bar{x} \pm s$)

Group	n	SNR	CNR	CTDIvol	DLP	ED
Conventional Dose Group	43	6.58 ± 1.70	175.96 ± 26.06	9.95 ± 0	372.84 ± 25.52	5.22 ± 0.37
Low Dose Group	42	4.17 ± 1.02	141.23 ± 19.04	5.76 ± 1.12	211.48 ± 50.64	2.96 ± 0.71
P		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Table 2: Comparison of Subjective Image Scoring between Conventional Dose Group and Low Dose Group [n (%)]

Evaluation Content	Conventional Dose Group (n = 43)	Low Dose Group (n = 42)
Subjective Background Noise		
Mild Noise	2 (4.7)	3 (7.1)
Moderate Noise	41 (95.3)	39 (92.9)
Severe Noise	0 (0.0)	0 (0.0)
Overall Image Quality		
Very Good Image Quality, Structures Very Clear (5 points)	6 (14.0)	2 (4.8)
Good Image Quality, Structures Clear (4 points)	35 (81.4)	37 (88.1)
Mild Blurring of Structures, No Limitation in Diagnosis (3 points)	2 (4.7)	3 (7.1)
Moderate Blurring of Structures, Mild Limitation in Diagnosis (2 points)	0 (0.0)	0 (0.0)
Severe Blurring of Structures, Cannot Diagnose (1 point)	0 (0.0)	0 (0.0)

differences in CT values among the lung parenchyma, aorta, and paraspinal muscles ($P > 0.05$), as shown in Table 2.

Noise Comparison

Compared with FBP, the noise in the lung parenchyma, aorta, and paraspinal muscles gradually decreased with the increase in the weight coefficient of Clear View iterative reconstruction. Specifically, the average noise in the lung parenchyma decreased by 23.34% and 27.69% in the 60% CV and 80% CV groups, respectively (both $P < 0.05$). The average noise in the aorta decreased by 23.43%, 37.16%, and 46.18% in the 40% CV, 60% CV, and 80% CV groups; ($P < 0.05$, $P < 0.001$, $P < 0.001$) respectively. The average noise in the paraspinal muscles decreased by 35.91% and 44.78% in the 60% CV and 80% CV groups; ($P < 0.05$, $P < 0.001$) respectively.

The SNR and CNR values of the 20% CV, 40% CV, 60% CV, and 80% CV groups were all higher than those of the FBP group. In particular, the differences in SNR between the 60% CV and 80% CV groups and the FBP group in the lung parenchyma, aorta, and paraspinal muscles were statistically significant (all $P < 0.05$). The results of the objective image evaluation are presented in Table 3.

Radiation Dose

The average ED in this study was (2.96 ± 0.71) mSv with a CTDIvol of 5.76 ± 1.12 mGy and a DLP of (211.48 ± 50.64) mGy·cm.

Five sets of reconstructed images were obtained from 42 patients using two different reconstruction algorithms. Subjective image quality assessment was conducted by comparing images on the same axial plane, with consistent window width and window level settings. Among them, the 60% CV group exhibited the highest image quality in both lung and mediastinal windows (Figure 1D; I), with excellent display of anatomical and lesion structures (Figure 1D; 2D). Figure 1 presents a case of a patient with a nodule in the upper lobe of the right lung. Thin-slice axial images with a slice thickness of 1 mm and an interslice gap of 0.625 mm were obtained from the original data using two reconstruction algorithms. When observing small nodules in the lung fields, the 60% CV algorithm demonstrated clearer nodule morphology and edge contours compared to FBP, particularly in terms of shallow lobulation features. Regarding the noise values in the aortic arch in Figure 1, the ranking is as follows: Figure 1J < 1I < 1H < 1G < 1F. The CV 80% reconstruction algorithm yielded the lowest image noise. Clear view thin-slice images provided superior lesion detail compared to FBP images, significantly enhancing image quality (Figure 2).

Discussion

With the continuous development of medical technology, CT has played a significant role in clinical practice particularly in the differential diagnosis of pathological changes in the lungs. However, an increase in radiation intensity comes with radiation-related carcinogenicity to patients. A key topic of interest in radiology is finding the optimal balance between radiation dose and diagnostic image quality, aiming to obtain diagnostically satisfactory images with the lowest possible radiation dose[16,17]. The use and research of low-dose CT technology should always adhere to As Low As Reasonably Achievable (ALARA) principle, which aims to minimize the examination dose for patients while ensuring good CT image quality that meets the needs of clinical diagnosis[18]. Current methods to reduce radiation dose include decreasing tube current, reducing tube voltage, increasing pitch, reducing scan time, and increasing image noise.

Reducing the CT scan dose inevitably leads to increased image noise, which is a major factor in evaluating image quality[19]. Previous studies have shown that image reconstruction techniques can effectively reduce image noise and improve image contrast[20]. Currently, there are two main types of CT image reconstruction algorithms used in clinical practice: analytic reconstruction (AR) and iterative reconstruction (IR)[9,11]. Among AR, FBP is the most representative and widely used commercially, offering high resolution and fast imaging speed[21]. Therefore, FBP reconstructed images are often used as a standard to measure the performance of other reconstruction techniques. However, due to the idealized assumptions of various parameters, FBP has limitations in its development. If the reconstruction process requires a realistic CT data acquisition process, the actual imaging space must be taken into account. IR idealizes the system's optical characteristics and weightedly merges the data according to proportions, compensating for the decrease in image quality caused by the increase in noise and artifacts in images reconstructed using FBP as the tube voltage decreases[22-25]. Studies have shown that Clear View iterative reconstruction technology can reduce radiation dose by approximately 70%, significantly reducing the radiation hazard associated with CT use and enabling widespread application in clinical diagnosis[26]. This iterative technique also significantly reduces image noise, increases SNR and CNR, and relies on powerful hardware to increase the speed of image reconstruction, ensuring rapid image display and improved image quality. This study also confirmed that as the weight of Clear View iterative reconstruction increases, image noise decreases significantly and SNR and CNR gradually increase. Compared to FBP reconstruction, the average noise in lung parenchyma decreased by 11.62%, 12.30%, 23.34%, and 27.69% under 20% CV, 40% CV, 60% CV, and 80% CV algorithms respectively, while the SNR increased by 13.85%, 15.63%, 26.89%, and 34.57%. Similarly, the average noise in the aorta decreased by 15.80%, 23.43%, 37.16%, and 46.18%, with corresponding increases in SNR of 18.05%, 29.27%, 57.07%, and 83.41%. The average noise in the erector spinae muscle decreased by 16.61%, 23.13%, 35.91%, and 44.78%, with corresponding increases in SNR of 20.09%, 30.77%, 55.98%, and 79.49% and CNR increased by 32%, 44%, 84%, and 116%, respectively.

In this study, traditional FBP reconstruction and CV iterative reconstruction were applied to adult chest low-dose non-contrast enhanced CT scan images. Objective metrics were used to compare the ability of different reconstruction algorithms to improve image quality. The results showed that the Clear View iterative algorithm significantly reduced image noise, increased image SNR and CNR, and preserved anatomical and textural information compared to the traditional FBP algorithm. Particularly at low dose levels, 60% CV and 80% CV reconstructions are recommended.

According to literature reports, within a certain range, as the IR weight increases, both image noise and artifacts decrease successively and image resolution improves. However, with the continuous increase of the weight, wax-like artifacts or speckled artifacts appear in the image, weakening the contrast of the chest tissue structure interface, making the vascular wall and bronchial wall unclear, resulting in a blurring effect and excessive smoothing of the image, and the subjective quality score curve exhibits a parabolic shape[27]. In this study, the subjective scores of the five groups of images under the two reconstruction algorithms of FBP and Clear View were all>3, which meet the needs of image diagnosis. In the subjective evaluation based on lung window images, the image quality score of the 60% CV group (4.81 ± 0.39) was the highest, significantly higher than that of the FBP group and the 20% CV group. The image quality scores of the 40% CV group and the 80% CV group were slightly lower, but there was no statistically significant difference compared with the 60% CV group. In the subjective evaluation of mediastinal window images, the image quality score of the 60% CV group was still the highest, significantly higher than that of the FBP group, the 20% CV group, and the 80% CV group, but there was no statistically significant difference compared with the 40% CV group. By comparing the ability of different reconstruction algorithms to improve image quality through subjective indicators, the results showed that the subjective image quality trends of the four groups of lung window and mediastinal window images reconstructed by CV iterative reconstruction exhibited a parabolic shape change, but the scores were all higher than those of the FBP group. Among them, 60% CV reconstruction was the best, while 80% CV reconstruction had a slightly lower subjective score due to poor image hierarchy and the appearance of wax-like artifacts.

Conclusion

In summary, this study compared FBP and Clear View reconstruction algorithms under low-dose scanning conditions through subjective and objective indicators. The results showed that CV iterative reconstruction techniques with different weights can reduce noise and improve image quality to varying degrees. In particular, 60% CV reconstruction achieves the best balance in reducing noise, improving SNR, CNR, and subjective image quality in chest CT images, and can be recommended as the optimal reconstruction parameter choice for low-dose chest CT. Overall, the combination of CV iterative reconstruction technique and low-dose chest CT has important clinical value, as it can further ensure CT image quality while reducing the radiation dose of CT scanning.

Declarations

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Conflicts of interest/ Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and material

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethical approval

This study was approved by Mzuzu University Research Ethics Committee (MZUNIREC) (Approval Number: MZUNIREC/DOR/24/153).

Consent for Publication

The manuscript is approved by all authors for publication.

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