ORIGINAL RESEARCH

The Value of Low-dose Multi-slice Computed Tomography protocol of the Chest at Mzuzu Central Hospital, Malawi

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Abstract

Objective:

To evaluate low-dose Computed Tomography (LDCT) chest vs. routine CT chest for image quality and diagnosis in suspected lung lesions, aiming to optimize LDCT protocol.

Methods

We retrospectively analyzed 85 patients with suspected lung lesions who underwent non-contrast enhanced (NCE) CT chest at Mzuzu Central Hospital from July 2023 to April 2024. The study divided patients into routine dose (43 patients, 120 kV, 300 mAs) and low-dose groups (42 patients, 120 kV with automatic tube current modulation) based on a transition point on February 16th, 2024. Both groups used filtered back projection (FBP) reconstruction with a 1mm layer thickness. Data were analyzed for signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR), and radiation dose parameters on AVW post-processing workstation, and for background noise and image quality on PACS.

Results

(1) Objective evaluation revealed significantly higher SNR and CNR (6.58 ± 1.70, 175.96 ± 26.06) in the routine dose group compared to the low-dose group (4.17 ± 1.02, 141.23 ± 19.04) ($P < 0.001$). Additionally, the routine dose group had significantly higher CTDIvol, DLP, and ED [(9.95 ± 0) mGy, (372.84 ± 25.52) mGy·cm, (5.22 ± 0.37) mSv] compared to the low-dose group [(5.76 ± 1.12) mGy, (211.48 ± 50.64) mGy·cm, (2.96 ± 0.71) mSv] ($P < 0.001$). (2) Subjective evaluation showed no significant difference in scoring for background noise and overall image quality between the routine dose group [(1.95 ± 0.21) points, (4.09 ± 0.42) points] and the low-dose group [(1.93 ± 0.26) points, (3.98 ± 0.34) points] ($P > 0.05$).

Conclusion

The image quality of LDCT protocol is comparable to that of routine dose, while radiation dose is significantly reduced. The image quality meets the requirements for imaging diagnosis of lung lesions, and this protocol can be widely promoted in clinical practice.

Keywords: Multi-slice spiral CT; Chest CT scan; Low-dose; Image quality; Radiation dose

Introduction

Mzuzu Central Hospital (MCH) is a tertiary referral hospital located in Mzuzu City, Malawi. It provides medical services to nearly 3 million people from several hospitals in the northern region of Malawi as well as other parts of the country[1]. The hospital also receives patients from neighboring countries of Zambia, Mozambique and Tanzania. In late 2021, the hospital installed the first 16-slice spiral CT scanner. With the improvement of the hospital's diagnostic capabilities and the increasing awareness of patients seeking medical attention, the application of CT technology in clinical practice has become increasingly common, and the number of CT scans has been rising year by year. However, CT is a radiological examination with relatively high radiation doses, which significantly increases potential cancer risks due to ionizing radiation to patients and the public[2-4]. Balancing the radiation dose and image quality of CT scans is an important subject among scholars both domestically and internationally[5-7].

In recent years, low-dose multi-slice spiral computed tomography (MSCT) examination techniques have gradually been applied in the diagnosis of chest diseases[8-10]. This technology optimizes scanning parameters and image reconstruction algorithms to achieve high image quality and diagnostic accuracy while reducing radiation doses[8,11]. Studies have shown that low-dose Computed Tomography (LDCT) examination exhibits good performance in the diagnosis of various chest diseases[12-14]. Nevertheless, much research has not been done on the application of LDCT examination in resource-limited areas like Malawi. This study takes Mzuzu Central Hospital as an example to retrospectively analyze the differences in image quality between routine-dose and low-dose chest CT scans, evaluating the practical effects of LDCT examination in the diagnosis of chest diseases. Therefore, this study aims to investigate the value of LDCT chest protocol over routine CT chest on image quality among patients with suspected lung lesions at MCH in Malawi, aiming to optimize LDCT protocol and apply it in similar medical environments.

Materials and Methods

General Information

This retrospective study analyzed 85 patients who underwent chest CT scans in our hospital due to symptoms such as cough, sputum production, and dyspnea, suspected chest lesions, from July 2023 to April 2024. Among them, there were 48 males and 37 females, with an average age of (54 ± 11) years. February 16, 2024, was set as the scheme switching point, with the period before this date designated as the conventional dose group, consisting of 43 cases, and the period after this date designated as the low-dose group, with 42 cases. Exclusion criteria included patients with artifacts in the chest, such as respiratory motion artifacts and foreign body artifacts, as well as those with defective localization images that precluded the use of automatic tube current modulation technology. 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.

Equipment and Methods

Scanning was performed using the NeuViz 16 Essence CT scanner, independently developed and produced by Neusoft Medical. Patients underwent respiratory training before scanning to ensure a breath-hold state after deep inspiration. All examinations were performed with patients in supine position and radiation-sensitive organs were shielded with a lead apron. The scanning range encompassed from the inlet of the thoracic cage to the lower boundary of the bilateral costophrenic angles. Scanning conditions were set as follows: for the conventional dose group, the tube voltage was 120 kV, and the reference tube current was 300mAs; for the low-dose group, the tube voltage was 120 kV, and tube current modulation based on Signal to Noise Ratio (SNR) at 0.5 mode (O-Dose automatic tube current modulation technology). Both groups had a detector collimation width of 16 × 1.25 mm, a matrix of 512 × 512, a rotation time of 0.5 s/r, a pitch of 1.5, and a scan thickness of 5mm.

Image Reconstruction

Both the conventional dose group and the low-dose group underwent 1mm thin-layer reconstruction using the filtered back projection (FBP) algorithm. All data were transferred to the AVW post-processing workstation for measurement and simultaneously to PACS for subjective analysis.

Analysis of Image Quality

Subjective Evaluation Images were subjectively evaluated by two radiologists with over 10 years of experience. A tie breaker was involved where the two did not agree. The evaluation included background noise and overall image quality. Background noise was assessed using a 3 - point scale: 1 point for low noise, 2 points for moderate noise, and 3 points for severe noise[15]. Noise scores of 1 or 2 indicated that the noise did not affect the diagnosis of the disease or the identification of normal structures, while a noise level of 3 indicated that the noise did affect diagnosis or identification of normal structures. The overall image quality was evaluated based on the display of normal and diseased tissue structures, including interlobar fissures, proximal bronchi and adjacent pulmonary vessels, peripheral bronchi and adjacent pulmonary vessels, and subpleural vessels. The overall image quality was analyzed using a 5 - point scale for normal and abnormal lung tissue, with 5 points indicating excellent image quality and very clear tissue structure display, 4 points indicating good image quality and relatively clear tissue structure display, 3 points indicating slightly blurred tissue structure display with no limitation to image diagnosis, 2 points indicating moderately blurred tissue structure display with mild limitations to image diagnosis, and 1 point indicating severely blurred tissue structure display with severe limitations to image diagnosis.

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)

Objective Evaluation The Viewer software of the AVW post-processing workstation was used to measure data from images in both the conventional dose group and the low-dose group. The size and location of the Region of Interest (ROI) measured in the images were consistent. The ROI was placed in the middle of the aortic arch's largest slice and in the air directly above the same level of the sternum, avoiding aortic arch calcification and anterior sternum foreign bodies.

The average CT value and noise value standard deviation (SD) were measured, and the image signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated. The calculation formulas were: SNR = CT value of the aortic arch / SD of the lung background; CNR = (CT value of the aortic arch - CT of the lung background) / SD of the lung background.

Radiation Dose Analysis

The volumetric CT dose index (CTDIvol), dose-length product (DLP), and effective dose (ED) were recorded for all patients. The ED was calculated using the formula ED = k × DLP, where the k value was set at 0.014 $mSv \cdot mGy^{1} \cdot cm^{-1}$.

Statistical Analysis

Statistical analysis was conducted using the SPSS 22.0 software (IBM, Chicago, USA). For continuous variables, they were expressed as mean ± SD $(\bar{x} \pm s)$

The Kolmogorov-Smirnov test was used to assess the normality of the data distribution. Independent samples t-test was employed to compare the SNR (signal-to-noise ratio) and CNR (contrast-to-noise ratio) between groups for those variables that followed a normal distribution. For categorical variables, they were represented as frequencies or percentages, and the $\chi 2$ test was used for inter-group comparisons. Subjective evaluations were assessed using Cohen's Kappa test to evaluate the consistency of the scores between the two doctors. If the Kappa value indicated good agreement, the average image scores of the two doctors were further analyzed using the Mann-Whitney U test. A P - value of less than 0.05 was considered statistically significant.

Results

Objective Image Quality

Objective evaluation of the images from 85 patients revealed that the SNR and CNR were 36.63% and 19.74% higher in the conventional dose group compared to the low-dose group, respectively, with a statistically significant difference ($P < 0.001$). Similarly, the CTDIvol, DLP, and ED were 42.11%, 43.28%, and 43.30% in the conventional dose group compared to the low-dose group, respectively, with a statistically significant difference ($P < 0.001$). These results are summarized in Table 1.

Subjective Evaluation of Image Quality

The Kappa values for the evaluation of image quality by two senior radiologists were 0.81 and 0.86, respectively, indicating good agreement between their scores. Regarding background noise, there was no statistically significant difference between the conventional dose group [(1.95 ± 0.21) points] and the low-dose group [(1.93 ± 0.26) points] ($P = 0.496$). Similarly, there was no statistically significant difference in the overall image quality between the conventional dose group [(4.09 ± 0.42) points] and the low-dose group [(3.98 ± 0.34) points] ($P = 0.125$). These results are presented in Table 2.

Discussion

Since the introduction of CT in 1973, it has played an increasingly important role in disease diagnosis, physical examination screening, surgical planning, and therapeutic evaluation[16,17]. Due to its higher density resolution compared to ordinary X-ray examinations, CT is significantly more accurate in the screening and assessment of many lung diseases, making multi-slice spiral chest CT a widely used clinical tool[18].

With the increasing application of multi-slice spiral CT in chest imaging, particularly in children, reducing the radiation dose of this technology has become a focal point for scholars worldwide[19,20]. In 1990, Naidich et al. first proposed the concept of LDCT, which is typically considered to deliver 10% - 30% of the radiation dose of standard-dose CT in chest imaging[21]. To effectively reduce radiation exposure from chest CT, exploring methods to manage CT radiation dose is crucial. Among them, ATCM is one of the most effective methods, as it can lower CT radiation dose while ensuring acceptable image diagnostic quality[22].

Optimization of Tube Current

There is a positive correlation between tube current and radiation dose, with a direct proportionality to mAs[23]. Reducing tube current while keeping other parameters unchanged can lead to a decrease in radiation exposure. Although reducing tube current leads to fewer radiation photons and subsequently lower image resolution, the lungs are primarily air-filled tissues with minimal X-ray attenuation, making this reduction less impactful on their naturally good contrast. Therefore, in chest disease diagnosis, treatment, and follow-up, reducing tube current is currently considered a highly effective approach, leading to the emergence of ATCM. ATCM automatically adjusts tube current based on the patient's body size and organ thickness, achieving a reduction in radiation dose while maintaining consistent image quality, thus fulfilling the goal of individualized and optimized scanning. Taking Neusoft CT's Odose ACTM technology as an example, the output radiation is corrected by empirically assessing the body's X-ray attenuation characteristic and accordingly adjusting the mA value, to achieve a desired image quality or noise level. Compared with scanning with fixed output radiation dose, using Odose may achieve the desired image quality at a lower dose level. When the size, shape or density of the body part to be scanned is not uniformly distributed, Odose can dynamically adjust the scanner's output radiation dose and the mA value in the Z direction (along the body length) as well as XY direction (around the body) in real time according to attenuation characteristics of respectively. If the attenuation level remains unchanged, Odose will set the mA at a constant level based on the body's overall thickness and desired image noise or quality level. ATCM has gradually become the mainstream of low-dose scanning in routine practice[22]. In this study, the CTDIvol, DLP, and ED values in the low-dose group were (5.76 ± 1.12) mGy, (211.48 ± 50.64) mGy·cm, and (2.96 ± 0.71) mSv, respectively, while those in the conventional-dose group were (9.95 ± 0) mGy, (372.84 ± 25.52) mGy·cm, and (5.22 ± 0.37) mSv, respectively. The differences between the two groups were statistically significant ($p < 0.001$). By adopting ATCM in the low-dose group, CTDIvol, DLP, and ED were reduced by 42.11%, 43.28%, and 43.30% respectively compared with the conventional-dose group. The effective radiation dose of the subjects was significantly reduced, only 56.70% of that in the conventional-dose group.

Image Quality of Low-Dose Scanning

In evaluating image quality between the two groups, objective assessments revealed that the conventional-dose scan had higher SNR and CNR but also a higher radiation dose. In contrast, low-dose scanning significantly reduced radiation exposure to patients while maintaining diagnostic image quality. Subjective image quality assessments were challenging

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due to the lungs' natural contrast and increased background noise in the low-dose group. There was no significant difference in image quality between the two groups. Over 95% of images in both groups were rated as good or better in quality, with 95% (41/43) in the conventional-dose group and 93% (39/42) in the low-dose group. Subjective image quality scores did not show a statistically significant difference between the two groups ($P > 0.05$). The low-dose scan images clearly displayed lung texture, intrapulmonary vessels, and mediastinal structures, including the bronchi and their surrounding structures down to the segmental level. Therefore, LDCT combined with ATCM can produce satisfactory images that meet the diagnostic requirements for chest diseases.

Techniques to Reduce Radiation Dose

Tube voltage, tube current, scan time, pitch, slice thickness, and scan volume are the main factors influencing radiation dose. Radiation dose is linearly related to tube current, scan time, and scan volume. In clinical practice, reducing tube current and increasing pitch are the primary methods to decrease CT radiation exposure[24-26]. To further reduce radiation dose in low-dose chest multi-slice spiral CT scanning, some researchers have proposed decreasing tube current while keeping other parameters constant. Since there is a linear relationship between radiation dose and tube current, reducing tube current also leads to a decrease in radiation dose. Setting the tube current within a reasonable range can still meet the diagnostic requirements for CT images, with the tube current set to the minimum value required for the desired CT image. For chest multi-slice spiral CT, the pitch also plays an important role in radiation dose. When the pitch is less than 1, it indicates that the voxel exposure exceeds 360°, leading to increased radiation dose. Conversely, a pitch greater than 1 suggests voxel exposure of less than 360°, which can increase the risk of missed lesions due to excessive bed speed. Some researchers have experimented with increasing the pitch value from 1 to 1.5, resulting in a significant reduction in radiation dose without significant loss of diagnostic information[27]. In recent years, scholars have also attempted to adjust the scanning parameters of multi-slice spiral CT for the chest based on the patient's body weight[28]. Smaller doses are used for lighter patients, while larger doses are administered to heavier patients, satisfying the requirements for obtaining CT images. Theoretically, adjusting the scanning parameters based on the ratio of height to weight may be more appropriate, but further research is needed to confirm this.

Clinical Value of Low-dose Chest Scans

Tuberculosis (TB), a chronic respiratory infectious disease, remains prevalent globally. In densely populated urban areas and medically underserved regions of Malawi, the incidence of TB is still high[29]. Its contagious nature has a severe negative impact on the health and social development of the Malawian people. While conventional X-ray radiography has been widely used for tuberculosis screening due to its low cost and relatively lower radiation dose compared to conventional CT, its detection rate is often unsatisfactory, especially for early or atypical cases of TB. LDCT chest, compared to traditional CT chest, can reduce radiation damage to human tissues, shorten the scanning time by limiting the number of scanned body parts, and provide images with high resolution and less overlap enabling better visualization of lung lesions[30]. Therefore, LDCT chest is particularly suitable for screening and post-treatment follow-up of TB patients at MCH.

The CT tube, the core component of the CT scanner, generates high-energy electron beams and X-rays to produce images of internal tissues and organs. The quality and lifespan of the CT scanner are directly influenced by the performance of the CT tube. Therefore, proper use and maintenance of the CT tube are crucial for ensuring the smooth operation and extending the lifespan of the CT scanner which has significant implications for the normal medical work and social benefits of hospitals[31]. LDCT not only significantly reduces the radiation dose received by the patient but also decreases the wear and tear on the CT tube, thereby extending the lifespan of the machine and reducing medical costs. While LDCT chest has numerous advantages, it still poses radiation hazards, especially for patients who require multiple scans. Therefore, when assessing whether a patient needs a LDCT chest or not, it is essential to strictly adhere to the indications, minimize radiation dose, and reduce iatrogenic harm.

Conclusion

In summary, LDCT chest protocol can significantly reduce radiation dose without compromising image quality, meeting diagnostic requirements. It is recommended for use in the diagnosis and treatment of chest diseases at MCH and other hospitals to minimize unnecessary ionizing radiation exposure. Additionally, radiologic technologists should be trained and master various techniques to reduce radiation dose and optimize radiation exposure. With increasing awareness of radiation dose, the application of LDCT chest protocol will become increasingly widespread.

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/DOR/24/153).

Consent for publication

The manuscript is approved by all authors for publication.

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