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Diagnostic Capabilities of Ultra-low-dose Computed Tomography with a Dose Equivalent to Chest X-ray Radiography

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ABSTRACT

Background: Digital chest X-ray radiography (CXR) is the imaging modality of first choice for detecting chest pathology. The average effective dose for CXR (posteroanterior and lateral projection) is 0.10 mSv (range: 0.01 to 0.26 mSv). CT examinations using ultra–low–dose CT (ULDCT) with doses equivalent to CXR examinations allow for detecting chest pathologies and pulmonary nodules with comparable sensitivity to previous standard or low-dose CT techniques. The ULDCT may improve the detection of pulmonary nodules and diagnose a broader range of pathologies.
Objectives: This study aims to show the possibility of recognizing and defining a variety of chest pathology using ultralow-dose CT of the chest below 1mSv.
Methods: For all patients, after initial CXR, chest ultra-low (ULDCT) and standard-dose CT were performed. The ultra-low dose was achieved by fixing the tube voltage, lowering the tube current, or reducing the scan length. The field size was adapted individually for each patient. In order to reduce radiation exposure, sonograms were not obtained throughout this study. Instead, a conventional laser beam was used to manually set up the start of the scan range (from the lung apex to the whole diaphragm) at the gantry. The CT scan was taken while holding a breath during inspiration with the following parameters: helical scan, 80 kV, 30 mA, 80 0.5 mm collimation, and 0.3 seconds rotation time. No iodinated contrast material was used.
Results: We compare the imaging properties of low voltage (80 kV - dosages equal to CXR) CT to a standard voltage (120 kV) CT and CXR in different chest pathologies and lung nodules with diameters from 4 to 30 mm. The sensitivity of ULDCT was 100% compared to CXR. CXR was considered diagnostic in 98% and ULDCT in 100%. The mean perceived confidence for diagnosis was 88±12% with CXR and 98±2% with ULDCT. Ultra-low-dose CT offered higher sensitivity for lesions like consolidation (97%), pleural effusion (95%), fibrosis (92%), and solid pulmonary nodules (91%).
Conclusions: ULDCT is a safe and effective method for evaluating lung nodules of different sizes or densities.
Keywords: Chest X-ray radiography (CXR); low-dose computer tomography (LDCT); scanogram; ultra-low-dose computer tomography (ULDCT).

INTRODUCTION

Digital chest X-ray radiography (CXR) is the imaging modality for identifying chest pathology. However, as CXR is a two-dimensional (2D) projection technique, the superposition of structures could lead to misunderstanding, resulting in false-positive and false-negative results. Phantom and clinical studies have demonstrated that 3-dimensional (3D) volume computed tomography (CT) can improve confidence and accuracy of diagnosis compared to CXR.[1]

The higher radiation dose is a crucial drawback of CT compared to CXR. According to a European survey, the average effective dose for CXR (posteroanterior and lateral projection) is 0.10 mSv (range: 0.01 to 0.26 mSv). The effective dose for standard chest CT is about 50-fold higher, with a typical value of 5.5 mSv (range: 2.0 to 20.4 mSv).[2]

According to the existing evidence, ultralow-dose (<1 mSv) CT of the chest is feasible for detecting and characterizing various pulmonary and chest diseases.1,2 Several studies have also shown that chest CT examinations using ultra–low–dose CT (ULDCT) with doses equivalent to CXR examinations allow for detecting pulmonary nodules with comparable sensitivity to standard or low-dose CT modalities.[3-6]

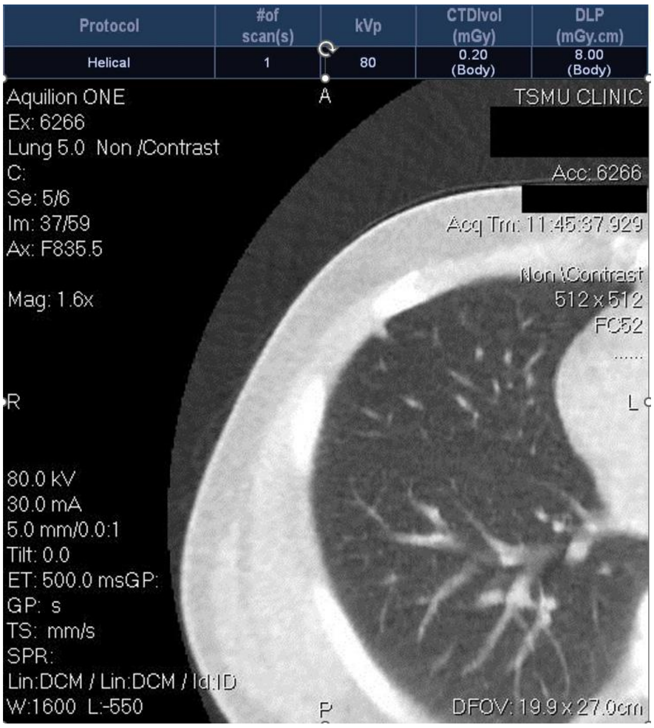
In the present study, we aimed to evaluate the diagnostic capabilities of ULDCT for detecting pulmonary nodules and diagnosing a broader range of pathologies.

METHODS

All patients enrolled in the study had a follow-up ultra-low-dose computer tomography (ULDCT) after a chest X-ray radiography (CXR). For each patient, the field size was customized. To reduce radiation exposure, scanograms were not taken during the investigation. Instead, conventional laser beams manually adjusted the start of the scan range (from the lung apex to the whole diaphragm) at the gantry. The CT acquisition was performed with breath-hold during inspiration and the following parameters: helical scan, 80×0.5 mm collimation, 80 kV, 30 mA, and a 0.3

seconds rotation time (Fig.1). The effective dose we got with these parameters was identical to an effective dose of chest X-ray. No iodinated contrast material was used. A low-frequency 3D filter is also applied to the projection data to control the noise grain size and avoid undesired over-smoothing in the reconstructed images. After reviewing the real-time reconstructions, the abort scan button terminated the scan.

FIGURE 1. Images of lung nodules. The image was acquired with an 80 kV tube voltage. Effective dose 0.112 mSv



RESULTS

Using ULDCT, we revealed several cases of false-negative, false-positive, or uncertain results on CXR (Tab.1). The pathologic findings on ULDCT were found in 23 patients, with false-negative results on previous CXR. In addition, 1 out of 23 patients had an additional asymptomatic ascending aortic aneurysm identified on ULDCT that was missed on CXR.

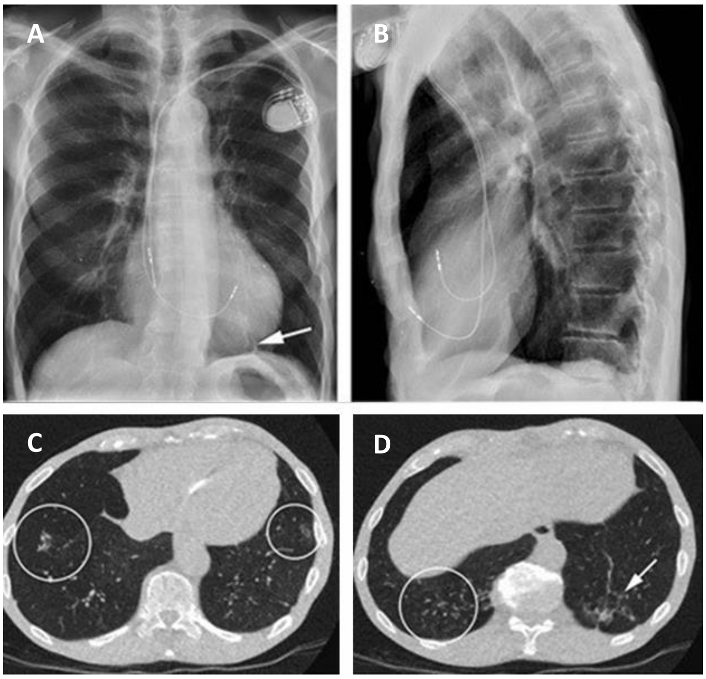
Fig.2 demonstrates the case of a 72-year-old male patient with metastasized melanoma and immunotherapy with recent pneumonia. The patient was admitted to our hospital with a recurrent fever (40^{0}C) and a preliminary diagnosis of community-acquired pneumonia. A small residual lesion in the left lower lobe (indicated by the arrow) from previous pneumonia was found on CXR with an effective dose of 0.3 mSv. (Fig.2A and Fig.2B). No radiologic signs of active pneumonia existed.

Multiple foci with a tree-in-bud aspect in the right lower lobe (encircled in Fig.2 C and Fig.2D) were found in the case of the same patient after ULDCT with an effective dose of 0.7 mSv, indicating an active respiratory infection. The left lower lobe has a band-like density after previous pneumonia (Fig.2D, indicated by the arrow).

TABLE 1. The false-negative, false-positive, or uncertain results on CXR with the actual pathological findings on ULDCT

False-negative results on CXR		False-positive/ uncertain results on CXR	
The actual ULDCT findings after negative CXR	***N***	***The suspected pathologies on CXR, excluded by ULDCT***	***N***
Infectious pulmonary consolidations	9	Pulmonary malignancy or mass	7
Nodules or possible metastasis	6	Bronchiectasis or pulmonary emphysema	3
Chronic obstructive pulmonary disease	4	Lung tumor progression	1
Tumor or residual tumor at lung cancer follow-up	3	***The uncertain findings on CXR confirmed on ULDCT***	**1**
Coronary atherosclerosis with aortic aneurism	1		

FIGURE 2. CXR and the chest ULDCT images of a 72-year-old patient



Explanations: A. Posteroanterior projection, CXR image; B. Lateral projection, CXR image; C and D. ULDCT images with evidence of pulmonary infection.

False-positive or uncertain results were reported in 12 patients with chest abnormalities on CXR, subsequently ruled out by ULDCT (Tab.1).

The radiological findings of a myasthenic 70-year-old man are shown in Fig. 3, which may serve as an example of the uncertainty of CXR in some cases.

Two nodules on the posteroanterior projection (Fig.3A, indicated by the arrows), and one possibly in the lower lobe

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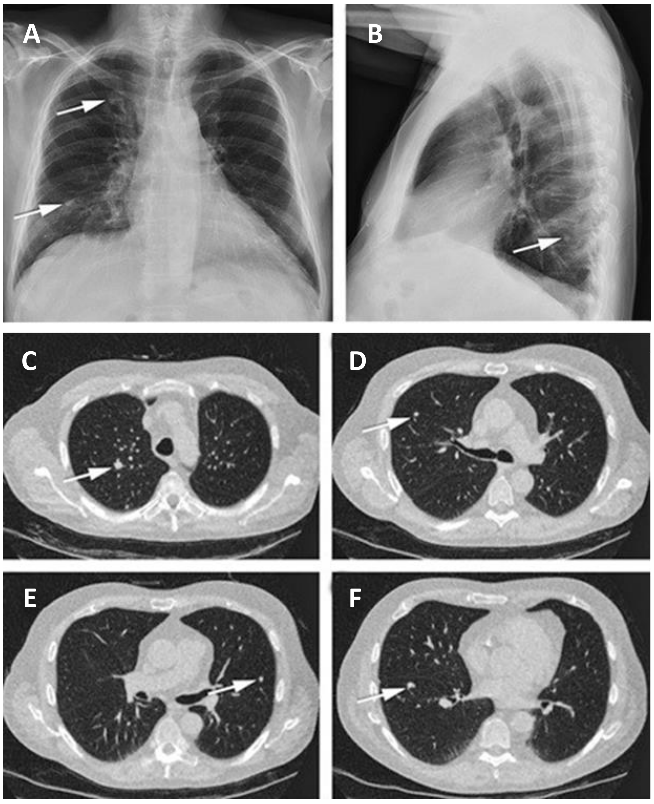
on the lateral view (Fig.3B, indicated by the arrow) were found on CXR with an effective dose of 0.4 mSv.

Multiple intrapulmonary smooth-walled nodules (Fig.3C-F, indicated by the arrows) were found in the case of the same patient after ULDCT with an effective dose of 0.7 mSv. We proposed differentiating the common causes of radiological changes, such as autoimmune disease (myasthenia gravis), azathioprine, or a lung infection.

FIGURE 3. CXR and the chest ULDCT images of a 70-year-old patient with myasthenia gravis



Explanations: A. Posteroanterior projection, CXR image; B. Lateral projection, CXR image; C, D, E, and F. ULDCT images with multiple intrapulmonary smooth-walled nodules.

Based on our data analysis, the diagnostic sensitivity of chest X-ray radiography (CXR) was 88±12% versus 98±2% diagnostic sensitivity of ultra-low-dose computer tomography (ULDCT).

DISCUSSION

During screening or targeted chest radiography, lung nodules are frequently found accidentally. Determining the etiology of these nodules and making a radiological diagnosis can be challenging and require multiple use of different modalities, even with an established diagnosis.[1]

Conventional imaging methods fail to differentiate malignant from benign nodules in many cases. For example, CT follow-up is necessary for cancer patients with pulmonary nodules after initial treatment to check the effectiveness of cancer management. However, repeated exposure to ionizing radiation from CT scans might increase the chance of secondary cancer induction.[1-5]

According to the International Commission on Radiological Protection (ICRP), every mSv increase in radiation might raise the lifetime risk of cancer by 0.005%. (Ogawa) Therefore, developing a CT scanning protocol with low-dose radiation is recommended to monitor lung nodules. The 2013 recommendations advocated a regular low-dose CT scan for patients needing extended follow-up, particularly younger patients.[10]

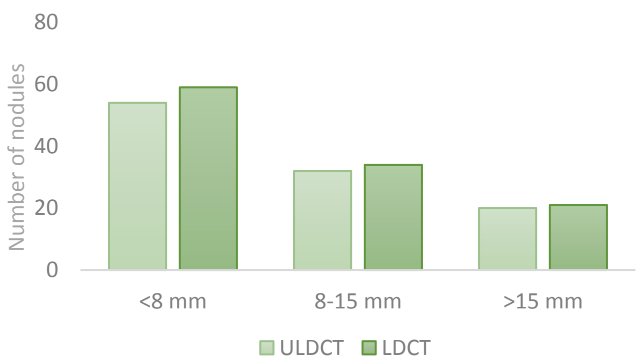
Low-dose CT scan is typically achieved by fixing the tube voltage, lowering the tube current, or reducing the scan length. In addition, the automatic tube current modulation is gaining much attention. It has been reported to be an effective auto-exposure control system by minimizing radiation exposure to patients while maintaining adequate image quality. It is well known that the tube voltage has an exponential relationship with radiation dose, and thus, lowering the tube voltage can result in a significant decrease in radiation dose.[7]

Lowering the tube voltage to 80 kV can obtain high-quality and evaluable CT images while significantly reducing radiation dose by 32% to 60%. However, it is still uncertain whether the lung nodule images scanned with low tube voltage are of comparable diagnostic accuracy as those scanned with standard tube voltage.[2,8,9]

In order to be sure that ULDCT is as informative as standard low-dose CT, we investigated the imaging characteristics of lung nodules with a range of 4 to 30 mm in diameter with low (80 kV) and standard voltage (120 kV) CT scans.

CT scan images acquired from 80 and 120 kV exhibited a clean margin that facilitates an accurate detection of lung nodules. Moreover, no apparent differences were observed for the images obtained from the two voltage protocols (Fig.4). However, a few beam hardening artifacts were found in some images acquired with 80 kV.

FIGURE 4. Lung nodules detection accuracy with LDCT and ULDCT



Abbreviations: LDCT, low-dose computer tomography; ULDCT, ultra-low-dose computer tomography.

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In our study, the difference in effective dose between CXR and ULDCT was small and negligible, considering the mean effective dose of 0.10 mSv for CXR. Compared with the typical effective doses for routine CT chest in Europe (~5.5 mSv) and the United States (~8 mSv), our ULDCT dose is significantly lower. Techniques such as tube current modulation for ULDCT acquisitions and iterative reconstruction techniques may reduce the effective dose even further.8. The effective dose range of 0.011-0.8 mSv for ULDCT will not be a limiting factor for introducing ULDCT of the chest on a broad scale in clinical practice.

CONCLUSIONS

Our findings strongly suggest that the CT scan with low voltage allows a safe and accurate assessment of lung nodules in cancer patients. ULDCT voltage CT represents an effective method for evaluating lung nodules of different sizes or densities. Furthermore, this newly identified approach is appropriate for patients who require extended chest CT follow-up.

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