

Image Quality and Pulmonary Nodule Detectability at Low-dose Computed Tomography (low kVp and mAs): A phantom study

Abstract

Background: Nowadays, there has been a growing demand for low-dose computed tomography (LDCT) protocols. CT has a critical role in the management of the diagnosis chain of pulmonary disease, especially in lung cancer screening. There have been introduced several dose reduction methods, however, most of them are time-consuming, intricate, and vendor-based strategies that are hardly used in clinics routinely. This study aims to evaluate the image quality and pulmonary nodule detectability of LDCT protocols that are feasible and easy implemented. Image quality was analyzed in a general quality control phantom (Gammex) and then in a manmade lung phantom with nodules-equivalent objects. **Methods:** This study was designed in a two steps, in the first step, a feasible low-dose lung CT protocol was selected with quality assessment of accreditation phantom image. In the second step, the selected low-dose protocol with an appropriate image quality was performed on a manmade lung phantom in which there were objects equivalent to the pulmonary nodule. Finally, image quality parameters of the phantom at the appropriate scan protocol were compared with the standard protocol. **Results:** A reduction of about 17% of kVp and 46% in tube current leads to dose reduction by about 70%. The contrast-to-noise ratio in the low-dose protocol remained almost unchanged. The signal-to-noise ratio in the low-dose protocol decreased by approximately 32%, and the noise level has increased by about 1.5 times. However, this reduction method hardly affected the detectability of nodules in man-made pulmonary phantom. **Conclusions:** Here, we demonstrated that the LDCT scan has an insignificant effect on the perception of lung nodules. In this study, patient dose in lung CT was reduced by modifying of kVp and mAs about approximately 70%. Hence, to step in toward low-dose strategies in medical imaging clinics, using easy-implemented and feasible low-dose strategies may be helpful.

Keywords: Computed tomography, image quality, low-dose radiation, lung cancer screening

Submitted: 05-Sep-2020

Revised: 04-Jun-2021

Accepted: 27-Aug-2021

Published: 28-Dec-2021

Introduction

Nowadays, there is a growing demand for low-dose computed tomography (LDCT) protocols, especially in lung cancer screening. There have been a lot of researches strive to redefine scan settings in low-dose strategies.^[1-5] Lung cancer screening program with LDCT is a more effective approach in early detection of cancer in high-risk population.^[1,4] However, its low specificity that leading to overdiagnosis has remained still as crucial challenge.^[6,7] In lung cancer screening program that involves a large population, cumulative radiation dose should be considered that can rise radiation-induced

cancer.^[3,8] Based on the Biological Effects of Ionizing Radiation VII (BEIR VII) report, radiation-induced cancer risk estimation of a LDCT scan procedure is approximately 0.01%–0.06% during an individual's lifetime, depending on the sex, age, and smoking status of the individual.^[9] However, standard CT scans at the age of 50–75 increase this risk by 0.2% to 0.85%.^[10]

Due to radiation risks and low specificity of CT scan in lung cancer detection, there is controversy about usefulness of LDCT in screening.^[3-5,8,11,12] However, to cope with this challenge, dose reduction strategies will be an important priority in CT screening for lung cancer.^[4,13,14] Furthermore, chest LDCT is a crucial aspect because of the management of breasts dose; in a standard

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How to cite this article: Iranmakani S, Jahanshahi AR, Mehnati P, Mortezaazadeh T, Khezerloo D. Image quality and pulmonary nodule detectability at low-dose computed tomography (low kVp and mAs): A phantom study. *J Med Sign Sens* 2022;12:64-8.

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Access this article online

Website: www.jmssjournal.net

DOI: 10.4103/jmss.JMSS_65_20

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protocol of chest CT scan, the dose of breast is about 20–60 mSv, which is not negligible.^[14] Various techniques have been proposed to reduce the dose in CT such as mA modulation (20% dose reduction) and image reconstruction algorithms such as iterative reconstruction (30% dose reduction).^[15,16] In addition, it was concluded that iterative reconstruction (IR) algorithm in lung scans can reduce dose about 23%–76%.^[17] Moreover, low-dose protocols conducted with IR algorithm and high pitch factor (about 3.2) can produce images with suitable quality.^[16] In a qualitative analysis study, the lung CT images of 50 mAs and 150 mAs were compared. It concluded that in low-dose protocol (50 mAs), pulmonary parenchymal and soft tissue abnormalities including high opacity objects (ground-glass opacity), low opacity objects (emphysema), pulmonary nodules (>5 mm), micronodules (<5 mm), irregular linear opacities (reticular opacity), pulmonary fibrosis, and bronchiectasis were appropriately detectable.^[13] In another study, the effective dose of LDCT for lung cancer screening with a 256-slice CT scanner for a normal person was reported about 0.77 mSv.^[8]

Most vendor-based dose reduction strategies that rely on reconstruction algorithm modification are often time-consuming and too intricate to use in clinics routinely. Hence, the purpose of this study is to evaluate the image quality with a feasible and easy-implemented LDCT scan protocols. Image quality was analyzed in a general quality control phantom (Gammex). Then, in a manmade lung phantom with nodules-equivalent objects, image quality and detection performance of the nodules in low-dose condition were evaluated.

Materials and Methods

The study was designed in two steps; in the first step, some easy-implemented low-dose protocols were performed on quality control phantom (CT ACR 464 Gammex, Sunnuclear, Melbourne, Florida, United States), and then, image quality parameters such as contrast, resolution, signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR), and noise level were evaluated for each image. In the second phase, the low-dose protocols with the acceptable image quality were implemented on a manmade lung phantom, in which there were objects equivalent to the pulmonary nodule. Finally, the image quality parameters of phantom in low-dose scan protocol were compared with standard protocol.

There are 4 modules embedded inside the phantom that can evaluate several quality control parameters of CT scan such as spatial resolution, low contrast detectability, noise, image uniformity, CT number accuracy, slice thickness.^[18] The detail of the phantom is described in the reference.^[19] The scans were performed on a 8 slice CT scan (Bright Speed 8; GE Healthcare, Chicago, Illinois, United States). The system was recently installed in the clinic and had previously calibrated.

All scans were performed with spiral mode, lung reconstruction kernel, rotation time 0.5s, and slice thickness 3 mm, and automatic exposure control system (CARE Dose4D) was disabled. For each protocol, CT dose index (CTDI) and dose-length product (DLP) were obtained, then the effective dose was calculated from DLP and conversion factor.^[15] To reduce statistical uncertainties, each scan was repeated three times.

To determine the suitable scan protocol, the quality of the images was compared together. The low-contrast detectability, contrast percentage, and spatial resolution were directly obtained from the CT quality control Software (ACTS) v. 21, and then, CNR, SNR, and noise level were measured from the images. A circle with a 20-mm diameter was delineated for all ROIs. The CNR was measured by using equation (1), in which S_{inside} and SD_{inside} are the mean signal and standard deviation of the ROIs inside the object, and $S_{outside}$ and $SD_{outside}$ are mean signal and standard deviation of ROIs outside the object, respectively.^[20]

$$CNR = \frac{S_{inside} - S_{outside}}{\sqrt{SD_{inside}^2 - SD_{outside}^2}} \quad (1)$$

The SNR and noise level were measured by equations (2) and (3), where CT_i and SD_i show CT number and standard deviation of peripheral and central ROIs, respectively. The ROIs were delineated in the center and periphery positions of the image.

$$SNR = \frac{1}{5} \sum_i \frac{CT_i}{SD_i} \quad (2)$$

$$Noise = \frac{1}{5} \sum_i \frac{100 \times SD_i}{CT_i} \quad (3)$$

A manmade lung phantom was made in the Radiology Department of the Paramedical Faculty of Tabriz University of Medical Sciences with the consulting of Clinical Skills and Research centers. Eight nodules-equivalent objects were embedded in a cork context as the lung parenchyma. The nodules were made from a specific combination of silicone, polyethylene, and industrial wood glue. The percentages of the components were selected so that their Hounsfield units (CT numbers) in routine CT scan equal to real nodule's HU (40–60 HU). According to nodule size threshold in “Guidelines for Management of Incidental Pulmonary Nodules Detected on CT Images,” in this designed phantom, nodules-equivalent objects size were 14, 13, 11, 10, 10, 6.5, 6.5, and 5 mm.^[21] The phantom was scanned once with the standard lung CT protocol and then with the scan protocol that had been determined in the previous step as the protocol with the acceptable diagnostic image quality with the lowest dose. Then, the results of the image quality of the two protocols were compared together by determining the CNR, SNR, and noise level parameters.

According to the Fleischner Guideline,^[21] because of lung nodules diameter has a critical role in the diagnosis and treatment of pulmonary disease, ultimately nodules' diameter was measured and compared in the two protocols.

Results

Among of 12 low-dose scan protocols, three feasible protocols were finally selected. Characteristics of selected CT scan protocols are summarized in Table 1. With compromise between radiation dose and image quality parameters, protocol 3 was selected as a low-dose scan protocol. The standard protocol has the highest CTDI (16.8 mGy) and effective dose (4.34 mSv), while the values for the low-dose protocol were (3.2 mGy) and (1.3 mSv), respectively. According to image analysis with ACTS software, the highest low contrast detectability was seen at protocol 1 with (0.3% at 2 mm), however, for other protocols, contrast detectability was obtained 0.6% at 2 mm. The spatial resolution at the lowest dose scan protocol (No. 3) was 6 lp/cm, while the standard scan protocol showed 4 lp/cm. The effective dose of the main scan protocols, SNR, CNR, and noise level was demonstrated in Figure 1. A reduction of about 17% in kVp and 46% in X-ray tube

current compared to the standard CT scan protocol reduced the radiation dose by about 70%. In this low-dose protocol, the noise level has increased by about 1.5 times, which is quite reasonable and expected.

The mean CT number of the nodules in different scan protocols was approximately 50-55 HU. Figure 2 illustrates a same slice of lung phantom images in two scan protocol, the left one is for standard lung protocol and the right image is for the low-dose protocol. In the manmade lung phantom, the value of SNR, CNR, and noise level in standard protocol was 12.7, 0.37, and 7.9%, respectively; and for selected low-dose protocol, the values were 15.8, 0.41, and 6.4%. The results of diameters estimation of the nodules in two scan protocols are presented in Table 2.

Discussion

This study aimed to evaluate the image quality of lung CT scan in a straightforward low-dose scan protocol by simply modifying of kVp and mAs. To achieve this goal, the study was performed on a quality control phantom and then on a man-made lung phantom with several embedded nodule equivalent objects. In a selected low-dose protocol, the radiation dose decreased about 70% and the noise level increased by about 1.5 times, which is quite reasonable and expected. The CNR in the low-dose protocol remained

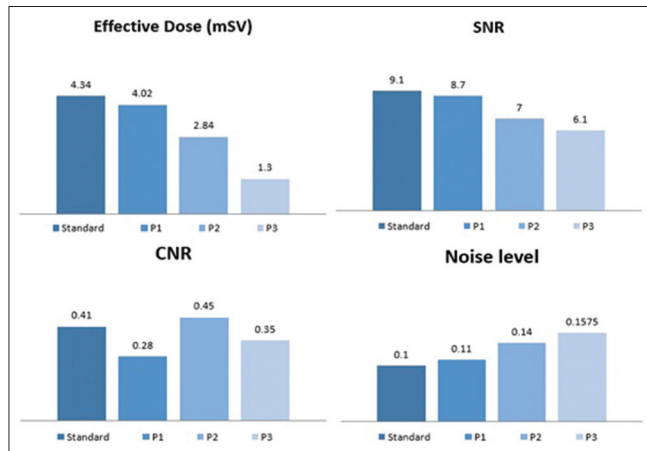


Figure 1: Effective dose, signal-to-noise ratio, contrast-to-noise ratio, and noise level of scan protocols

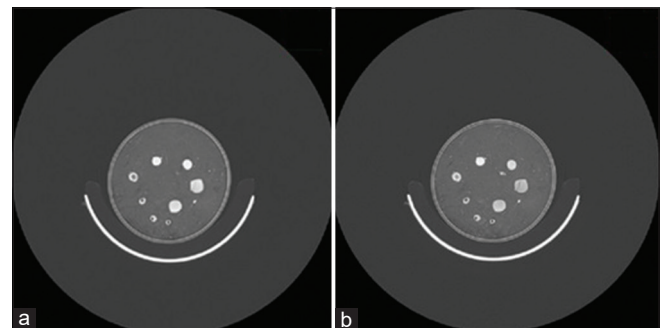


Figure 2: A same slice of lung phantom images in two scan protocol, (a) is the image of standard protocol, (b) is the image of the lowest dose protocol in which the effective dose is about 54% lower than standard protocol

Table 1: The characteristic of selected low-dose computerized tomography scan protocols

Protocol	Voltage (kVp)	Current-time product (mAs)	Pitch	CTDI _{vol} (mGy)	DLP (mGy.cm)	Effective dose (mSv)
Standard protocol	120	130	1	16.8	310	4.3
P1 (protocol 1)	120	100	1.2	15.6	288	4
P2 (protocol 2)	100	100	1	10.8	203	2.8
P3 (protocol 3)	100	70	1.35	3.22	91.7	1.3

CTDI – Computerized tomography dose index; DLP – Dose-length product

Table 2: The results of measured nodule size in the best low-dose scanning protocol and standard protocol

	Nodule 14 (mm)	Nodule 13 (mm)	Nodule 11 (mm)	Nodule 10 (mm)	Nodule 10 (mm)	Nodule 6.5 (mm)	Nodule 6.5 (mm)	Nodule 5 (mm)
Standard protocol	13.8	12.7	10.6	10	9.8	6.3	6.4	0.9
Low-dose1 protocol P3	13.5	12.6	10.3	0.8	10	6.3	6.3	0.7

almost unchanged and was similar to the standard chest CT protocol. The SNR in the low-dose protocol decreased by approximately 32%. However, this low-dose protocol hardly affected the image quality of the diagnosis of nodules in the man-made phantom. The low-dose protocol of this study is fully evaluated nodules size inside the range of Fleischner Society Guideline.

Computed tomography scans play a major role in the diagnosis of lung disease. Hence, the efforts should be focused on the development of feasible and user-friendly low-dose scan techniques. Because of the low attenuation coefficient of thorax, low-dose techniques may have suitable results in terms of image quality.^[13,17,20,21] Most dose reduction strategies used in lung CT are often based on vendor-based reconstruction algorithms that often their results and recommendations are hardly feasible for all scanners; they are often time-consuming, expensive, and too intricate for used in clinics routinely.^[4,5,13,16,17,22] Although reconstruction algorithms have the potential to reduce the dose, their time-consuming process is still a challenge in clinical stages. For instant, model-based iterative reconstruction (MBIR) algorithm in low-dose technique could achieve a suitable image quality. Nevertheless, MBIR often is considered as a time-consuming algorithm.^[23] In another study, Afadzi *et al.* assessed the low-dose technique at three dose levels of $CTDI_{vol} = 0.25, 0.49, 0.74$ mGy, with the adaptive statistical iterative reconstruction (ASIR-V) algorithm.^[17] In this study, to evaluate a straightforward and feasible low-dose technique, kVp, mAs, and pitch scan parameters were modified to reduce dose because they are common in all scanners. The study was performed on a CT quality control phantom and also on a pulmonary manmade phantom with equivalent lung nodules in different diameters. The assessment method in this study was an objective study with evaluation of quantitative image quality parameters including SNR, CNR, and noise level in the low-dose techniques.

In this study, despite a 70% dose reduction in the selected low-dose protocol, image quality parameters such as SNR, CNR, and noise were still obtained suitable in both quality phantom and lung phantom. This suitable image quality in low-dose techniques may be because the thorax region has a little tissue volume, so with a small amount of radiation, an acceptable quality of image produced. In another low-dose technique on cadaver, Macri *et al.* have concluded that image quality parameters such as SNR, CNR, and noise levels of the low-dose protocol were close to results of standard protocol.^[22] Takeshi *et al.* performed the low-dose technique by just changing the tube current from 150 mAs to 50 mAs; although the dose reduced to 67%, the final interpretation results of the low-dose technique were close to the standard technique.^[13]

Although low-dose techniques are widely advisable, moving from standard scan techniques to low-dose techniques

have confronted with several challenges.^[13] Perhaps, one of the most reasons for unwilling to use of dose reduction techniques in the clinic is the lack of courage and daring to use of such ultra-low-dose levels as reported in articles. Therefore, it is necessary to move slowly and step-by-step toward the use of low-dose protocols in clinics. In other words, users need to slowly become familiar with low-dose techniques to implement their inherently, moreover, time-consuming and complexity of performing the techniques may be another reason.

Although volumetric assessment of lung nodules is increasingly important, in small lung nodules, their growth may remain unnoticed with manual diameter measurements and they may grow asymmetrically. In the present study, the measured pulmonary nodule size in the low-dose protocols was almost close to the results of standard protocol. Similar to Macri *et al.* results, anatomical intervals with ultra-low-dose technique were not significantly changed in comparison to standard technique.^[22,24]

The study has several limitation. The first one is that the study was performed on a unilateral lung phantom, so in the future, such study could be expanded on real patient lung CT images as a qualitative subjective analysis. Another limitation was that the reconstruction algorithms which can reduce noise level were kept unchanged in this study, therefore, it is recommended that noise reduction algorithm could be used along with other scan protocols that suggested in this study. The third limitation is that the results of the study were obtained only for one CT scan system, Hence, it is suggested that such this study could also be prepared with another vendors of CT scan systems.

Conclusions

Here, we demonstrated that the LDCT scan has an insignificant effect on the perception of lung nodules. In this study, patient dose in lung CT was reduced by modifying of kVp and mAs about approximately 70%. Optimization of kVp and tube current may be a straightforward and feasible strategy for performing a low-dose scan with a suitable quality of the image. Hence, to crawl to low-dose strategies in medical imaging clinics, using easy-implemented and feasible low-dose strategies may be helpful.

Acknowledgment

This research has been supported by the Vice-Chancellor for Research of Tabriz University of Medical Sciences and approved in the Ethics Committee of Tabriz University of Medical Sciences (code: IR.TBZMED.VCR.REC.1398.194). We would also like to thank Clinical Skills and Research Centers of Tabriz University of Medical Sciences for their invaluable consulting in the lung phantom materials.

Financial support and sponsorship

None.

Conflicts of interest

There are no conflicts of interest.

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