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Evaluation of Ultra-Low-Dose Chest CT Images to Detect Lung Lesions

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Abstract

Background: The present study was conducted to examine the possibility of detecting different types of lung lesions, such as cancer, using ultra-low dose (ULD) chest computed tomography (CT) images.

Method: In this basic (experimental) study with CT images, 20 patients with different lung disease indications were scanned with ULD and routine dose chest CT protocols. ULD and routine dose CT images were reconstructed utilizing iDose and iterative model reconstruction. CT images were evaluated by two expert radiologists. Volume CT dose index ($CTDI_{vol}$), dose length product, and effective dose were used for dose assessment in both protocols.

Results: $CTDI_{vol}$ and dose length product for ULD protocol were 98% less compared to those for routine chest CT. The chest CT images for ULD and routine dose were diagnosed as normal in three patients with lung lesions, such as nodules, masses, plural effusion, fibrosis, diffuse ground glass opacities, bronchiectasis, and infiltration, in 17 patients. Patient dose of ULD chest CT (0.11mSv) is comparable to Poster-Anterior plus Lateral (0.1 mSv) chest radiograph, while the effective dose due to routine chest CT is about 5.1 mSv.

Conclusion: Diagnostic findings regarding ULD chest CT images with 98% of dose reduction were compared to those for routine dose. We concluded that it may be utilized as a very useful tool for screening and the follow-up of different lung diseases, malignancy for instance. ULD chest CT with 98% of dose reduction could be a suitable substitute for chest radiograph, with higher diagnostic values.

Keywords: Lung disease, Computed tomography, Ultra-low dose, Dose reduction

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Introduction

Different types of lung lesions, such as malignancies, bronchiectasis, pulmonary emboli, and so forth, could be detected with computed tomography (CT). CT is known as a

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non-invasive diagnostic tool which can reveal even very small lung lesions without tissue overlapping and is thus more versatile and accurate than plain chest x-ray.[1-3] Recent studies have also shown that "CT provides the best diagnosis for corona virus disease or 2019 coronavirus (Covid 19)" and could be used as a useful tool to diagnose patients affected by coronavirus in early stages.[4, 5] In spite of justified diagnostic usefulness of CT scanning for patients with heart and lung problems, the radiation dose hazards, called stochastic effects that include genetic and carcinogenesis, should not be neglected, specifically in pediatric, pregnant women, and young patients.[6]

Recent developments in CT systems utilize iterative reconstruction (IR) which allows a considerable dose reduction, yet produces an acceptable diagnostic image quality.[7, 8] The hybrid IR (iDose) and knowledge-based iterative model reconstruction (IMR) are the two reconstruction algorithms installed in Philips CT systems in addition to filtered back projection (FBP). Results of a previous study have indicated that the noise level of IMR reconstructed CT images are lower and as a result, their image qualities are better than those in iDose reconstructed images.[9]

CT with the minimum dose to the patient, comparable to that in plain radiography (about 0.1 mSv), is known as ultra-low-dose (ULD) CT or ULD-CT.[10] Huber et al. reported that ULD chest CT (with IR) has a potential to diagnose lung cancer at an early stage and replace plain chest radiograph as a screening tool in susceptible or vulnerable cancer patients. They deduced that the morbidity and mortality rate decreased considerably by substituting ULD chest CT as a screening tool instead of plain chest x-ray.[11] It was shown that chest CT with over 94% dose reduction could serve as a useful tool to detect lung nodules,[12, 13] cancer,[14] emphysema, and lung tissue density.[15] They also reported that dose reduction did not deteriorate diagnostic image quality.

In this study, we aimed to examine whether the iterative reconstruction algorithm (IRA) would allow us to use ULD-CT protocols and achieve a result satisfactory enough for reliable diagnostic purposes. Even though the normal chest X-ray uses the minimum possible dose, it only gives a projected image on a plane; in other words, in radiographic images, it is not possible to avoid overlapping of different layers of lung tissues.[10] With CT, cross-sectional images of lung give more accurate methods to detect lung lesions. The main problem of employing CT instead of chest radiograph is that in spite of its much higher diagnostic accuracy, it gives much higher dose to the patient.

The main objective of the present work was to compare the diagnostic findings of chest CT

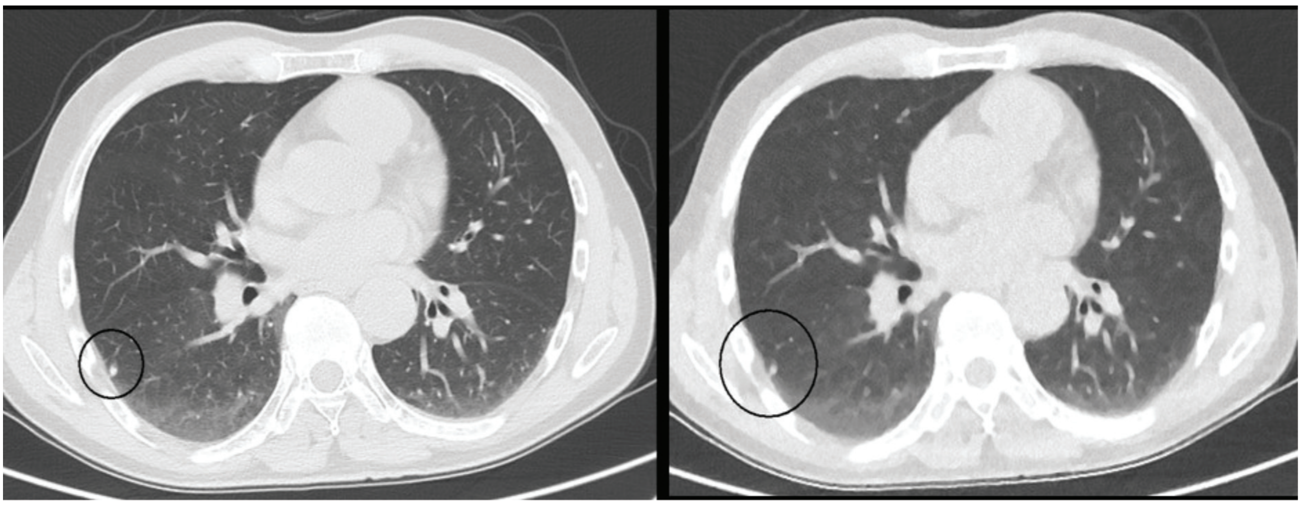

Figure1. This figure shows the standard dose (a) and Ultra-low dose (b) chest CT in a patient with cough and over 30 years of smoking (the black circle shows small lung nodule at the center).
CT: Computed tomography

Table 1. The volume of CT dose index ($CTDI_{vol}$ in mGy), dose length product (DLP in mGy.cm) and effective dose (ED in mSv) for standard dose and ultra-low dose chest CT

Variables	$CTDI_{vol}$ (mGy)		DLP (mGy.cm)		ED (mSv)	
	Standard dose	Ultra-low dose	Standard dose	Ultra-low dose	Standard dose	Ultra-low dose
Average	9.6	0.2	354.6	7.6	5.1	0.11
Standard deviation	3	0.0	123	0.5	1.7	0.01

$CTDI_{vol}$: Volume computed tomography dose index; DLP: Dose length product; ED: Effective dose

images of ULD to those of routine or standard dose, with further dose reduction as compared to routine dose chest CT.

Materials and Methods

In this perspective study, 20 patients (equal number of both genders with the mean age of 57 years) referred to our institution hospital with different indications, such as definite and suspected lung cancer. They were recruited for examination with ULD-CT. The Ethical Committee of Shiraz University of Medical Sciences approved this project (1398.184). The patients were informed about scanning with standard and ULD chest CT protocols and were explained about the increased total dose. All of them signed the consent form. They were scanned with 128-MDCT Philips Ingenuity system. The surview image was taken and used for both chest scanning protocols, routine and ULD-CT. Routine dose CT protocol was employed to take chest CT images in our department and is mentioned as standard dose (SD), in this paper. SD protocol used 3D current modulation with 150 mAs (on an average), 120 kVp, Pitch 1.17, collimation width 64 × 0.625 mm. The ULD chest CT was taken with 10 mAs (fixed), 80 kVp, pitch factor 1.5, collimation width 32 × 1.25 mm, without contrast. Without changing the position of the patient, the scanning was repeated with a SD-CT according to the routine protocol available in the CT system. This was done with or without contrast injection, as was requested by the referral physician. As stated earlier, chest CT images with ULD protocol were taken, before SD chest CT protocol, without contrast agent for all the 20 cases in this study. SD chest CT protocol was performed injecting contrast agent for 12 cases

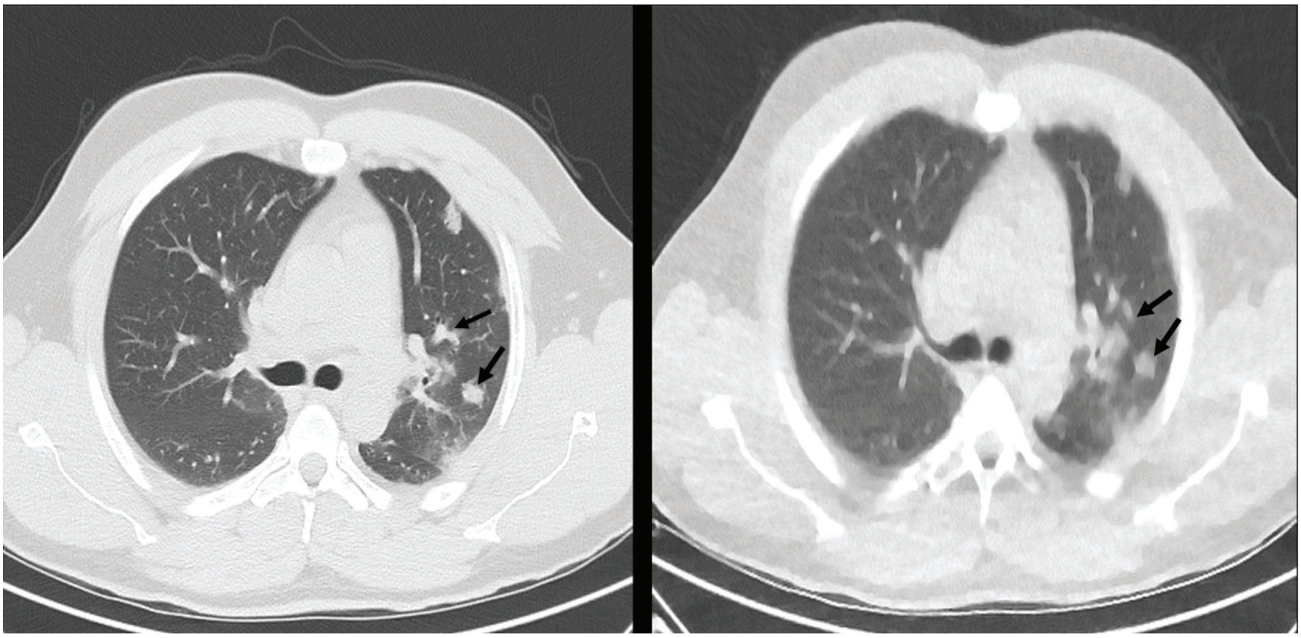

Figure 2. This figure shows the appearance of multiple lung nodules in (a) standard dose and (b) ultra-low dose chest CT (black arrows) images.

CT: Computed tomography

Table 2. Mean Hounsfield Unit (HU_{mean}), its STD, SNR(I) and SNR(I_{mean}) of blood inside the aorta for the images taken based on standard and ultra-low dose chest CT protocols

No.	Standard dose				Ultra-low dose			
	HU_{mean}	STD	SNR(I)	SNR(I_{mean})	HU_{mean}	STD	SNR(I)	SNR(I_{mean})
1	42	77	14	157	66	36	30	306
2	44	71	15	156	35	19	54	563
3	52	60	18	202	56	52	20	217
4	43	60	17	168	50	44	24	244
5	45	50	21	260	30	32	32	371
6	52	60	18	202	50	36	29	248
7	43	60	17	168	54	38	28	274
8	45	50	21	260	51	31	34	342
9	38	54	19	200	50	36	29	248
10	54	38	28	288	54	38	28	274
11	41	51	20	229	51	31	34	342
12	44	44	24	247	53	20	53	421
13	42	77	14	157	66	36	30	306
14	44	71	15	156	35	19	54	563

HU_{mean}: Mean Hounsfield Unit; STD: Standard deviation; SNR(I) is the signal to nosie ratio of gray level i.e. the intensity of the pixels as defined in Eq. (2); SNR(I_{mean}) is the signal to noise ratio of the mean gray level of a group of pixels inside the Region of Interest (ROI) as is defined in Eq. (3); CT: Computed tomography

out of 20 just following the ULD chest CT. Axial CT images were reconstructed with iDose level 4 with 3 mm slice thickness and IMR level 1 with 2 and 5 mm slice thickness for SD and ULD-CT protocols, respectively. The images were sent and saved in PACS system of the institute for further evaluation.

The first two authors of the paper, who are specialist radiologists, with more than 10 years' experience, examined the images while they were not aware of each other's conclusions. They reported ULD chest CT images and compared their results to those of routine or SD chest CT (as gold standard).

Volume CT dose index ($CTDI_{vol}$ in mGy) and dose length product (DLP in mGy.cm) were recorded from the page of dose report, available at the end of CT image series. The conversion factor utilized to convert DLP to effective dose (in mSv) were 0.0145 mSv/mGy.cm and 0.0147 mSv/mGy.cm for 120kVp and 80 kVp, respectively.[16, 17]

Quantitative study

This analysis aimed to justify that a lower dose does not lead to image degradation due to reduction of the signal-to-noise ratio (SNR). It was to be noted that the SNR due to photon noise varies as $SNR \sim \sqrt{n}$, where n is the number of X-ray

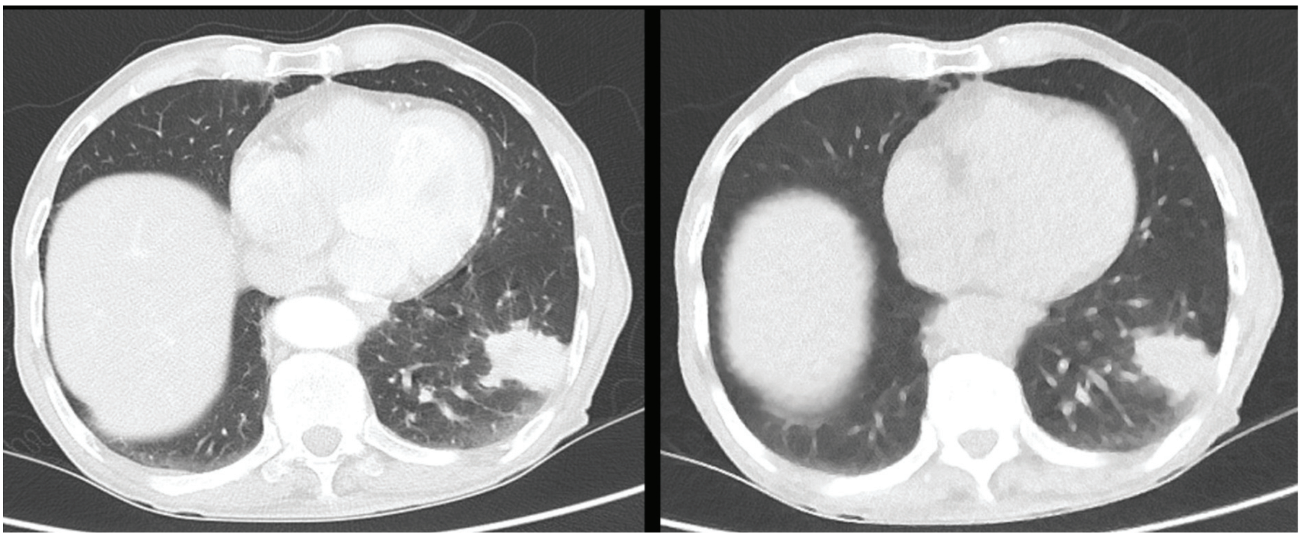

Figure 3. This figure shows the appearance of lung mass in (a) standard dose and (b) ultra-low dose chest CT images.
CT: Computed tomography

Table 3. HU_{mean}, its STD, SNR(I) and SNR(I_{mean}) of the air inside the trachea for the images taken based on standard and ultra-low dose chest CT protocols

No.	Standard dose				Ultra-low dose			
	HU_{mean}	STD	SNR(I)	SNR(I_{mean})	HU_{mean}	STD	SNR(I)	SNR(I_{mean})
1	-956	52	0.85	5	-934	19	3.47	22
2	-970	54	0.56	4	-965	33	1.06	8
3	-958	52	0.81	5	-980	45	0.44	3
4	-979	39	0.54	4	-981	42	0.45	3
5	-994	32	0.19	1	-959	29	1.41	9
6	-978	39	0.56	4	-973	33	0.82	5
7	-979	39	0.54	3	-972	32	0.88	5
8	-994	32	0.19	1	-976	30	0.80	5
9	-978	39	0.56	3	-968	35	0.91	5
10	-991	29	0.31	3	-966	47	0.72	6
11	-960	46	0.87	8	-972	45	0.62	6
12	-984	36	0.44	4	-963	49	0.76	8
13	-991	29	0.31	3	-957	46	0.93	9
14	-962	41	0.93	8	-959	49	0.84	7

HU_{mean}: Mean Hounsfield Unit; STD: Standard deviation; SNR(I) is the signal to nosie ratio of gray level i.e. the intensity of the pixels as defined in Eq. (2); SNR(I_{mean}) is the signal to noise ratio of the mean gray level of a group of pixels inside the region of interest (ROI) as is defined in Eq. (3); CT: Computed tomography

photons, incident upon the detector. Thus, with the number of photons in the ULD-CT case being reduced to 2% (2/100) of that in the SD case (in 98% dose reduction protocol), the obtained reduction was $SNR(ULD)/SNR(SD)=\sqrt{2/100}=0.14$; in other words, the SNR(ULD) reduced to 14% of that for the SD case. The display on the CT screen; however, took place after being processed by the IRA, which forms the basis for the radiologist's diagnosis. This necessitates the estimation of the extent of SNR seen on the screen.

As is known, the grey level of the pixel is proportional to the corresponding average linear attenuation coefficient:

$$\mu=\mu_w\,[1+(HU/1000)] \qquad (1)$$

, where μ_w is the average attenuation coefficient of water, integrated over the source spectrum of the x-ray tube and detector efficiency. Thus, the SNR in the grey level in the pixel, presented by HU value, is proportional to the attenuation coefficient in the pixel. Therefore, the SNR in the grey level, or the intensity (I) of the pixels, would be:

$$SNR(\mathrm{I})=1000\,[1+(HU/1000)]/(\sigma(HU)) \qquad (2)$$

, where σ(HU) shows the standard deviation in the HU values, found within a pixel.

The mean grey level (I_{mean}) in the ROI is proportional to the mean HU value. The standard

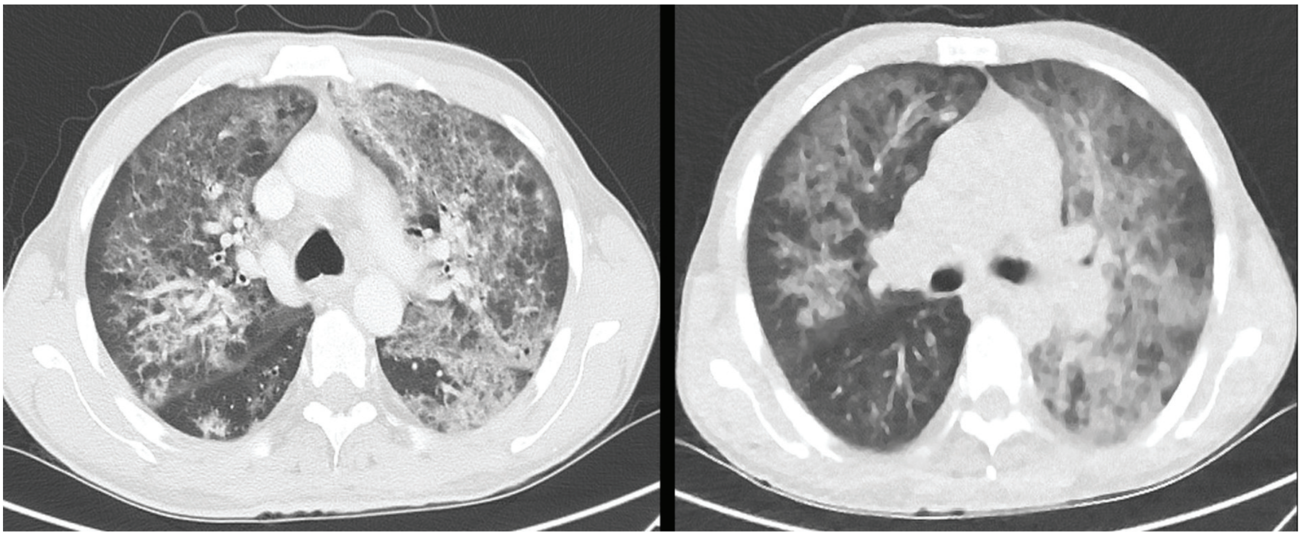

Figure 4. This figure shows the appearance of diffuse ground glass opacity, bronchiectasis, and lung fibrosis in: (a) standard dose and (b) ultra-low dose chest CT image.

CT: Computed tomography

deviation of the gray level is proportional to the standard deviation of the HU value. $SNR(I_{mean})$ could be determined by Eq. (3) as follows:

$$SNR(I_{mean})=[1000\sqrt{N}\,[1+HU_{mean}/1000)](\sigma(HU)) \quad (3)$$

, in which N is the total number of pixels in the ROI.

Image quality would be determined via the quantities, $SNR(I)$ and $SNR(I_{mean})$, as defined in equations (2) and (3) as given above.[18] The former determines the reliability of assigning a given mean grey level for a given ROI, while the latter describes how the grey levels in different patches would be reliably distinguishable from each other.

The values of $SNR(I)$ and $SNR(I_{mean})$ are calculated in two different regions in the lungs, that differ widely from each other in terms of their physical characteristics, namely, the air-filled trachea and aorta which is filled with blood (in un-enhanced chest CT image). It has to be mentioned that all the data analysis was done employing MATLAB (Mathworks R2015a).

Results

The results of the objective study of axial slices of chest CT images revealed that all the types of lesions detected in routine SD chest CT images, could be seen without any difficulty in the corresponding ULD-CT images of the same patient. The axial images of three cases were diagnosed normal, without any lung lesion, in SD and ULD chest CT images. 17 patients, out of 20, were diagnosed with lesions, such as lung nodules (irregular, speculated, and solitary), masses, fibrosis, lymphadenopathy, infiltration, ground glass opacity, pleural effusion, bronchiectasis and pneumonia, in SD and ULD-CT images by the two radiologists.

Few typical representative axial CT images are given below. As could be seen in figure 1, even very small lung lesions (about 3 mm diameter) could be diagnosed in both protocols-in SD figure 1a and in ULD (Figure 1b) in a patient suspected of lung cancer.

It could be seen in figure 2 (a and b), the diagnostic value of ULD chest CT was good enough to detect multiple lung nodules as clearly as seen in a SD chest CT. The radiologist compared these two images by keeping them next to each other and examining them visually.

Typical axial CT images of lung can detect lesions, such as masses (Figure 3) and diffuse ground glass opacities, bronchiectasis, lung fibrosis (Figure 4). The appearance of these lesions is very similar in SD (Figures 3a, 4a) and ULD (Figures 3b, 4b) chest CT images.

In a sample case shown in figure 5(a-c), the diagnostic efficiency of ULD chest CT (Figure 5c) was comparable to that of SD (Figure 5b) and was much more valued than the plain chest radiograph (Figure 5a) for the detection of lung pathologies.

The results of our study revealed that ULD

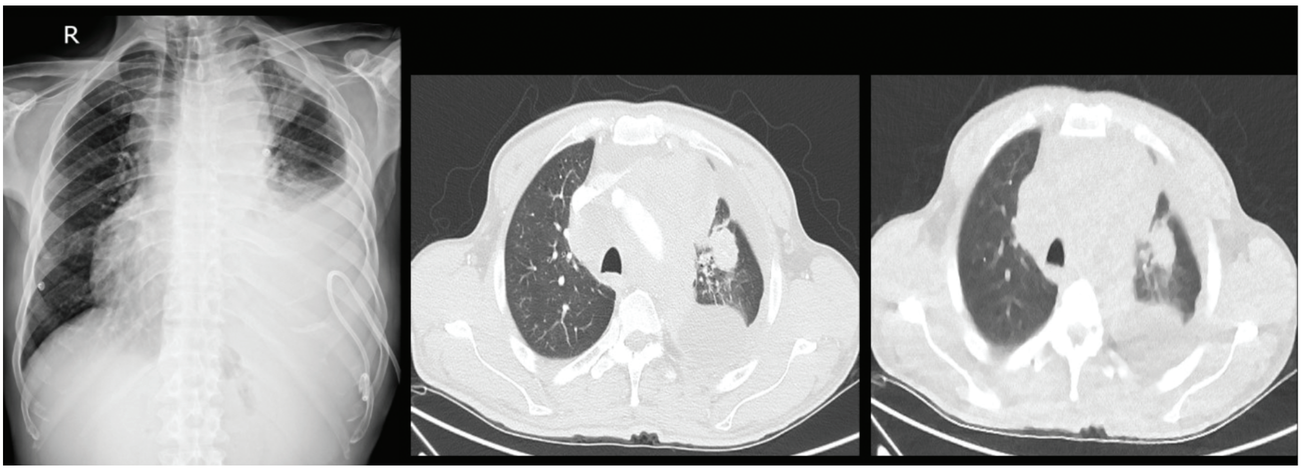

Figure 5. This figure shows the plain chest radiograph (a), standard dose (b), and ultra-low dose (c) chest CT of an adult patient with lung mass, pleural effusion and mediastinal lymphadenopathy.
CT: Computed tomography

chest CT is able to reveal different types of pathologies, such as small lung nodules, which could not be diagnosed in plain chest x-ray. The effective dose of chest radiograph (AP & Lat) is about 0.1mSv (PA+Lat),[19] while the mean effective dose of ULD chest CT in the present paper was found to be about 0.11mSv (Table 1). These two values are comparable and are much lower than the typical dose for a normal chest CT which was 5.1 mSv (the mean effective dose found in this study). The reduced dose is thus 1/50th of the typical normal dose.

Table 1 represents the results of dose measurement. It could be seen that the $CTDI_{vol}$ of ULD chest CT was consistent for all the cases and equaled 0.2 mGy, whereas its DLP varied from 6.2 to 8.4 mGy.cm (9.6 ± 3). The range of $CTDI_{vol}$ and DLP in SD chest CT protocol are between 5.2 to 17.8 mGy and 205 to 720 mGy.cm. The effective doses for SD and ULD chest CT were 5.1 ± 1.7 mSv and 0.11 ± 0.01 mSv, respectively. The $CTDI_{vol}$, DLP, and effective dose differed significantly, about 98% between SD and ULD chest CT as shown in table 1.

SNR estimates

The results of SNR measurement, SNR(I), and SNR(I_{mean}) via equations (2) and (3), for 14 cases are given as samples in tables 2 and 3 for both protocols, routine and ULD, in aorta and trachea (air).

In the above-mentioned tables (Table 2 for aorta and table 3 for trachea), it is indicated that the standard deviation of HU values and as a result, SNR(I) and SNR(I_{mean}) were higher in ULD compared with those in routine dose chest CT images.

Discussion

The present study shed light on the fact that ULD chest CT with 98% dose reduction is capable of detecting different types of lung lesions with an acceptable image quality, comparable to that found in the SD-CT.

The results of SNR measurement (Tables 2 and 3) implied that the standard deviation and thus, SNR(I) and SNR(I_{mean}) were higher in the ULD case than those in SD chest CT images. Noise reduction ability of IRA (IMR level 1) improved SNR compared with iDose level 4 and as a result, the image quality in ULD was good enough and did not deserve rejection in favor of the SD case.

Noise reduction and SNR enhancement owing to IRA enables technologist to use dose reduction (low and ULD-CT) protocols with an acceptable image quality. The most important benefit was that dose reduction protected the patient and staff from unanticipated, stochastic exposure-related risks.[20,21]

A high number of research on low and ULD-CT images reconstructed by IR have shown their image quality to be diagnostic image, comparable to those obtained by FBP, yet with a significant dose reduction.[8] This study, therefore, tried to test the possibility of using IR (IMR) in order to reduce patient dose in chest CT. This is needed since a large number of cases are referred daily. It is a fact that lung has inherent contrast since it has air in its alveolar tissues. On the other hand, it is known that increasing kVp (maximum kilo-Voltage) not only increases the effective energy of photons in the source spectrum and their effective penetrability, but also increases the number of photons that the source emits.[22, 23] This could be seen from the Boon-Siebert source spectrum formula, which shows that the total number of bare photons (without filtration) emitted by the X-ray source, increases in the proportion of 1.00:1.90:3.50:4.00 once the applied tube voltage increases as V=80,100,120,140 kVp.[24] With the decrease in kVp in fixed tube current, the following phenomena would occur, as done in the present study. It is possible to reduce radiation dose to the patient and still increase the image contrast. This is because the photoelectric attenuation varies as $(Z_{eff}^{3.5})/E^3$ (where E is the photon energy) and hence, small differences in effective atomic number (Z_{eff}) could give rise to perceptible changes in the photoelectric attenuation. In addition, the reduction in SNR due to reducing dose was compensated by IR.[23, 25]

The results of this work demonstrated that ULD-CT images for both reconstructed slice thicknesses, 2 and 5 mm, with IMR level 1 could detect different types of lung lesions, such as small nodules, masses, pleural effusion, mediastinal lymphadenopathy, Patchy infiltration, lung fibrosis, diffuse ground glass opacities, and thick wall cavitation, as could be seen in routine dose (reconstructed by iDose level 4) chest CT (Figures 1-5). This shows that ULD chest CT can be used as a screening tool to detect small masses and nodules in patients with high cancer risk (Figure 1) and is a very useful tool for lung diseases follow-up (Figure 2 as an example).

The results obtained by a group of researchers[26] in 2011 showed that diagnostic protocol with low-dose CT is able to reduce the mortality and morbidity rate of lung cancer as compared with chest X-ray, while Paks et al.[27] stated that solid pulmonary nodules larger than 2mm diameter could be diagnosed in both ULD and low-dose CT images for patients' follow-up, as was also corroborated in the present study.

The radiation dose to the patient in ULD chest CT (ED is about 0.11 mSv) is comparable to the mean effective dose of plain chest radiograph (about 0.1 mSv for PA+Lat), whereas ULD chest CT could give further diagnostic information regarding lung pathologies when compared to chest radiograph. Our finding in this regard is in line with those in kroft et al.[10]

Different types of viral infected lung lesions, such as diffuse ground glass opacities, bronchiectasis, infiltration, and lung fibrosis, can be seen in ULD chest CT (Figure 4). Therefore, the ULD chest CT can be a useful tool, with a minimum dose to the patient in COVID-19 affected patients' diagnosis and follow-up.[28]

The limitation of this study was the number of our subjects which was 20. This is an ongoing research and results of larger number of patients will be communicated soon.

Conclusion

ULD chest CT with IR can reduce radiation dose to the patient up to 98% of that used in SD without losing diagnostic values. ULD chest CT could be used as a lung cancer screening tool for high risk patients. Moreover, ULD chest CT was found to be a useful tool for patients' follow-up for those with lung diseases.

Plain chest x-ray could be recommended to be replaced by ULD chest CT, with higher diagnostic value and comparable dose, as a screening tool and patients' follow-up.

ULD chest CT may be used as a diagnostic or follow-up tool in patients suspected of or having COVID-19.

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Conflict of Interest

None declared.

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