Low-dose CT screening with adaptive iterative reconstruction: the confidence rating of diagnosis for simulated lesions other than lung cancer

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Aims and objectives

The efficacy of lung cancer screening with low-dose CT has been discussed, but the National Lung Screening Trial (NLST) Research Team released a report relevant to a randomized clinical trial comparing chest X-ray and low-dose CT. They reported that screening with the use of low-dose CT reduces mortality from lung cancer in groups at high risk for lung cancer [1]. With regard to dose-reduction techniques on CT, a new method of image reconstruction, iterative reconstruction (IR), has been developed and widely used for various clinical purposes. Although filtered back projection (FBP) has been used as a conventional image reconstruction method of CT, it has the disadvantage of containing quantum noise. In contrast, IR reduces quantum noise by repeatedly comparing between projection data, including quantum noise or primary reconstruction image data, and ideal models of anatomy or statistics [2-4].

Neroladaki et al. recently reported that the detection rate of pulmonary nodules is maintained on ultra-low-dose chest CT with radiation exposure in the range of a posterior-to-anterior (PA) and lateral chest X-ray (radiation dose, 0.16 ± 0.006 mSv) by using IR [5]. Therefore, IR is expected to be applied to lung cancer screening on low-dose CT. On CT screening for lung cancer, it is also important to detect chest diseases other than lung cancer, including emphysema, mediastinal mass, and interstitial pneumonia.

Thus far, studies have reported on detectability for pulmonary diseases including ground-glass opacity nodules [6], emphysema and interstitial disease [7], and quantification of emphysema [8] using low-dose CT and IR. However, it is difficult to evaluate detectability or diagnostic performance with various dose levels in in vivo studies because of the considerable radiation exposure, and there has been no report on the accurate evaluation of CT values of mediastinal masses or confidence ratings of diagnoses of emphysema, reticular opacity, and honeycombing.

Thus, the purpose of our study was to evaluate the image quality or confidence ratings of diagnoses of simulated lesions other than lung cancer on low-dose CT screening for lung cancer with hybrid iterative reconstruction.
Methods and materials

Phantom and simulated lesions

We used a chest phantom, and made simulated lesions (emphysema; mediastinal masses with cystic, solid, and fat components; and interstitial pneumonia including ground-glass opacity, reticular opacity, and honeycombing) [9]. Figures 1-2 are photographs of simulated lesions and simulated lesions in the chest phantom on CT. The simulated lesions of emphysema were two balloons made from part of a finger of a medical glove (maximum diameters, 13 mm and 18 mm). Simulated mediastinal masses with cystic, solid, and fat components were plastic hollow spheres containing water, water-diluted contrast agent with a CT value of 100 Hounsfield Units (HU), and oil, respectively. With regard to interstitial pneumonia, ground-glass opacity was simulated by a cotton ball, while honeycombing and reticular opacity were simulated by sponges of different coarseness. Simulated lesions of emphysema, mediastinal masses, and interstitial pneumonia were set at the apex of the lung, the anterior mediastinum, and the lower lung, respectively. All simulated lesions except ground-glass opacity were set in the left lung of the phantom.
Fig. 1: Simulated lesions. a. Emphysema b. Mediastinal masses (left, cystic; middle, solid; right, fat component) c. Interstitial pneumonia (left, ground-glass opacity; middle, reticular opacity; right, honeycombing)

References: Department of Health Sciences, Graduate School of Medical Sciences, Kyushu University - Fukuoka/JP
Fig. 2: CT findings of simulated lesions. The CT images show simulated emphysema (a); mediastinal masses with solid (b), cystic (c, left), and fat (c, right) components; and interstitial pneumonia including ground-glass opacity (d), reticular opacity (e), and honeycombing (f). Images (b) and (c) were displayed with mediastinum window setting (window level, 0 HU; window width, 400 HU). The others were displayed with lung window setting (window level, -600 HU; window width, 1500 HU).

References: Department of Health Sciences, Graduate School of Medical Sciences, Kyushu University - Fukuoka/JP

Image acquisition

Simulated lesions (emphysema; mediastinal masses with cystic, solid, and fat components; and interstitial pneumonia including ground-glass opacity, honeycombing, and reticular opacity) in the chest phantom were scanned by a 320-detector-row ADCT. The scans were performed by 64-detector-row helical scans (13, 9.7, 6.4, 3.2, and 1.1 mGy) and 160-detector-row helical scans (12.9, 9.7, 6.5, 3.2, 1.4, and 0.9 mGy), and were reconstructed by filtered back projection (FBP) and iterative reconstruction (IR, standard and strong). Each scan was repeated consecutively six times. The images for percentage values of ground-glass opacity relative to total lung (%GGO) evaluation were reconstructed with 0.5 mm thickness to avoid partial volume effects. The others
were reconstructed with 2 mm thickness because of their use for lung cancer screening. Other scan parameters were as follows: peak tube voltage, 120 kV; gantry speed, 0.5 s/rotation; pitch factor, 0.828 or 0.869; reconstruction interval, 0.5 mm. All datasets were reconstructed by using a standard reconstruction algorithm.

Visual assessment

The data sets for visual assessments of emphysema, honeycombing, and reticular opacity were randomized in order and were independently evaluated by six thoracic radiologists (range of experience in thoracic radiology, 6-23 years; average, 15.2 years). All ADCT images were displayed with lung (level, -600 HU; width, 1500 HU) window setting. Each observer was asked whether a lesion could be diagnosed on the basis of a four-point scale defined as follows:

4 points: structure of lesion clearly visible with complete diagnosis
3 points: structure of lesion visible with degrading image quality but without restriction for diagnosis
2 points: structure of lesion visible, with degrading image quality and uncertainties about diagnosis
1 point: diagnosis is difficult

The images at the level of maximum dose in this study (13 mGy or 12.9 mGy), which were reconstructed by FBP (to avoid the effects of IR and a shortage of radiation dose), were used as reference assessment criteria, because we predicted that the standard of the criteria would be changed during assessment. All images were displayed on a 3-megapixel monochrome liquid-crystal display with a workstation. The observer study was performed at a maximum luminance of 450 cd/m². The illuminance environment was 30 lux, the same level as in the reading room of our hospital.

Quantitative assessment

%Ground-glass opacity

%GGO was used to evaluate the activity of interstitial pneumonia. %GGO was calculated for quantitative assessment of ground-glass opacity by a three-dimensional image analysis system. We calculated the mean %GGO of six images obtained by each scanning. Manual adjustment was not used in the measurements for %GGO, and we measured %GGO from the right lung only. Thus, other simulated lesions, such as reticular opacity or honeycombing, had no effect on the measurements.
**CT value and CNR**

We calculated the CT values and contrast-to-noise ratios (CNR) of the mediastinal masses. Regions of interest (ROIs) were set on the simulated mediastinal masses by one author (N.S.) who located all ROIs on the same place for each measurement by copying and pasting. Figure 3 shows equation for calculation of the CNR [3].

\[
\text{CNR} = \frac{\text{CT}_m - \text{CT}_b}{\text{SD}_b}
\]

**Fig. 3**: Equation for calculation of the CNR.

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CT\(_m\) and CT\(_b\) were the CT values of the ROIs placed on the simulated mediastinal masses and the mediastinum, respectively. SD\(_b\) was defined as the mean standard deviation (SD) of the CT value for the six areas of soft tissue. CT\(_m\), CT\(_b\), and SD\(_b\) were measured at the same axial level. With regard to mediastinal masses with a cystic component, CT\(_b\) was the CT value of the ROI placed in the air because there was
no contrast between mass and mediastinum on the chest phantom. We calculated the
average of the measured values of six images obtained by each scanning.

**Statistical analysis**

In this study, we could not assume the normal probability distribution for the obtained
data, and they were the paired data of two groups because the same chest phantom
was scanned. Therefore, Wilcoxon’s signed-rank sum test was used for the statistical
analyses. Differences with a P value of < 0.05 were considered significant. Interobserver
agreement in visual assessments was evaluated by weighted # statistics (slight < 0.21,
fair 0.21-0.40, moderate 0.41-0.60, substantial 0.61-0.80, almost perfect 0.81-1.00). We
calculated the # values for pairs of readers and calculated an average # for all possible
pairs, because our study used multiple observers [10].
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Fig. 3: Equation for calculation of the CNR.

\[ CNR = \frac{CT_m - CT_b}{SD_b} \]

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Results

Visual assessment

Regarding the reliability of interobserver agreement, the weighted # values were 0.93, 0.92, 0.91, and 0.93 for emphysema with 13 mm and 18 mm maximum diameters, reticular opacity, and honeycombing, respectively. To compare between FBP and IR, the visual scores assessed by the six observers were averaged for each simulated lesion. The results of visual assessment are shown in Fig. 4. There were no significant differences between FBP and IR in any simulated lesions (emphysema, reticular opacity, honeycombing) at all dose levels, but IR tended to degrade the visual score of every simulated lesion. At the minimum low-dose level of our study (0.9 mGy), however, visual scores with IR tended to be higher than those with FBP.

**Fig. 4:** Visual assessment of simulated lesions on 160-detector-row helical CT. Graphs show the results of visual assessment of simulated emphysema (a), reticular opacity (b), and honeycombing (c). There were no significant differences in visual scores between IR and FBP images, but IR tended to degrade the visual score of every
simulated lesion. At the lowest dose level (0.9 mGy), visual scores tended to be higher with IR than with FBP. FBP: filtered back projection STD: iterative reconstruction with standard noise reduction level STR: iterative reconstruction with strong noise reduction level

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%Ground-glass opacity

Figure 5 shows the results of %GGO. The %GGO using FBP and IR significantly increased as dose level decreased (P <0.05), but the elevation of %GGO using IR was significantly suppressed compared to that using FBP at low-dose levels (0.9, 1.1 mGy).

Fig. 5: Percentage value of ground-glass opacity relative to total lung (%GGO) by using 160-detector-row helical scan. The %GGO with FBP at low dose levels (0.9 and 1.4 mGy) was significantly elevated; however, IR suppressed the elevation (P <0.05).

References: Department of Health Sciences, Graduate School of Medical Sciences, Kyushu University - Fukuoka/JP
CT value and CNR

Figure 6 shows CT values of mediastinal masses. At all dose reduction levels (FBP, Standard, Strong), the CT values of the mediastinal masses were almost equivalent between FBP and IR, even at the lowest dose level (P < 0.01). Figure 7 shows the distributions of CNR for mediastinal masses. The CNR of the mediastinal masses with IR was significantly higher than that with FBP on both 64-helical and 160-helical scans (P < 0.05).

Fig. 6: CT values of mediastinal masses with cystic, solid, and fat components by using 64-detector-row helical CT. Graphs show the results obtained from the images reconstructed by FBP (a) and reconstructed by IR with a standard noise reduction level (b) and with a strong noise reduction level (c). CT values of mediastinal masses were almost equivalent between FBP and IR. All three types of mediastinal masses were clearly separated by CT value in all types of reconstruction (P < 0.01).

References: Department of Health Sciences, Graduate School of Medical Sciences, Kyushu University - Fukuoka/JP
Fig. 7: CNR of mediastinal masses with cystic, solid, and fat components by using 64-detector-row helical CT. Graphs show the results of CNR of mediastinal masses with cystic (a), solid (b), and fat (c) components. CNR of mediastinal masses was significantly higher with IR than that with FBP (P <0.05).

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Fig. 4: Visual assessment of simulated lesions on 160-detector-row helical CT. Graphs show the results of visual assessment of simulated emphysema (a), reticular opacity (b), and honeycombing (c). There were no significant differences in visual scores between IR and FBP images, but IR tended to degrade the visual score of every simulated lesion. At the lowest dose level (0.9 mGy), visual scores tended to be higher with IR than with FBP. FBP: filtered back projection STD: iterative reconstruction with standard noise reduction level STR: iterative reconstruction with strong noise reduction level

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**Fig. 5:** Percentage value of ground-glass opacity relative to total lung (%GGO) by using 160-detector-row helical scan. The %GGO with FBP at low dose levels (0.9 and 1.4 mGy) was significantly elevated; however, IR suppressed the elevation (P <0.05).

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Fig. 7: CNR of mediastinal masses with cystic, solid, and fat components by using 64-detector-row helical CT. Graphs show the results of CNR of mediastinal masses with cystic (a), solid (b), and fat (c) components. CNR of mediastinal masses was significantly higher with IR than that with FBP (P < 0.05).

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Conclusion

Our visual assessment showed that IR tended to degrade visual scores for all simulated lesions compared to FBP, although there was no significant difference. We think this tendency was caused by the difference in the modulation transfer function (MTF) of the image reconstructed by IR and FBP. MTF of the image reconstructed by IR is reported to be lower than that by FBP due to the iteration of the smoothing procedure for quantum noise reduction [11], and the degradation of MTF might obscure lesions of thin linear structure enough to make visual assessment difficult. In our study, IR tended to improve visual scores compared to FBP at a minimum low-dose level (0.9 mGy). We speculated that the increase in quantum noise might be affected more adversely than decreased MTF by using IR at the lowest dose [12, 13].

Our study also revealed that %GGO was significantly increased at low-dose levels with FBP (P <0.05); however, IR suppressed the elevation of %GGO. In addition, CNR of mediastinal masses with IR was significantly higher than that with FBP on both 64-helical and 160-helical scans (P <0.05). We think that these results were caused by reducing the quantum noise by using IR. CT values of mediastinal masses were almost equivalent between FBP and IR even at a minimum low-dose level in our study. This indicates that a differential diagnosis based on the CT value of mediastinal masses is not affected by methods of image reconstruction and radiation dose in the range of our study (0.9-12.9 mGy).

This study has several limitations. Firstly, this was a phantom study. The CT value of human lung parenchyma is approximately -800 to -900 HU because it contains numerous alveolar walls [14], but the CT value of the lung parenchyma of the chest phantom we used is approximately -1000 HU, because it includes only air. This is why we could not assess the percent low-attenuation area (%LAA), which is used to quantify emphysema with this phantom. This also indicates that we may have overestimated visual assessments in our study, because the contrast between a lesion and air was higher than that between a lesion and normal lung parenchyma. Secondly, the visual assessment in our study did not focus on the detectability of emphysema and interstitial pneumonia, but rather on the confidence rating of the diagnosis of these diseases. Thirdly, we did not assess images reconstructed by using model-based iterative reconstruction (MBIR). In Katsura et al. [15], the radiation dose of chest CT images can be reduced approximately 80% by using MBIR with an acceptable diagnosis. However, Samuel et al. showed that MTF of IR depended on contrast and noise level (tube current) in the image [16]. Therefore, validation studies on diagnostic performance using low to middle contrast materials are needed with regard to low-dose MBIR images. In spite of these limitations, our study is the first to compare the confidence ratings of diagnoses of emphysema, interstitial pneumonia, and mediastinal mass on low-dose CT between adaptive IR and FBP.
In conclusion, the confidence ratings of diagnoses of simulated lesions other than lung cancer on low-dose CT screening were not degraded with adaptive IR compared with FBP. On the basis of our results, thoracic radiologists may become able to analyze images of adaptive IR alone on low-dose CT screening for lung cancer; this could reduce reading time and relieve stress on radiologists.
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