

Efforts to Reduce Exposure Dose in Chest Tomosynthesis – Targeting Lung Cancer Screening –

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1. Introduction

The National Cancer Center Hospital East introduced a Shimadzu SONIALVISION safire R/F System with direct-conversion FPD that is mainly used for gastrointestinal examinations. This system incorporates a tomosynthesis function that allows the attending physician to take chest tomosynthesis images when required.

Since November 2008, Dr. Moriyama of the Research Center for Cancer Prevention and Screening, National Cancer Center Hospital, and the Division of Thoracic Oncology and the Department of Radiology at this hospital have been undertaking joint research and development with Shimadzu Corporation into the utility of chest tomosynthesis for lung cancer screening and to investigate the optimal radiography conditions to reduce exposure dose.

This paper reports on the results of research into reducing exposure dose, which is an important topic for screening.

2. Lung Cancer Screening

Lung cancer is the major cause of cancer deaths in Japan. Screening plays an important role in the early detection and treatment of lung cancer, which has a significant effect on the prognosis.

Currently, general chest radiography is widely used as a simple method that offers low exposure dose. However, it can be difficult to recognize shadows in the lung field due to superimposed images of ribs, collar bone, heart, or liver.

Recently, the utility of lung cancer screening using low-dose CT has been reported. However, the exposure dose is greater than for a general chest radiography and the higher detection capacity for abnormal shadows leads to concerns about the possibility of over-diagnosis.

3. Utility of Chest Tomosynthesis

A feature of tomosynthesis is that it reduces the shadows of ribs and collar bones, giving superior visibility of lesions that are difficult to recognize in general chest radiography images (**Fig. 1**). In clinical image interpretation tests by doctors, tomosynthesis is superior to general chest radiography in terms of sensitivity, specificity, and FROC analysis.

At the Joint Industrial-Academic Seminar in JRC2009, Mr. Ikeno (formerly at the National Cancer Center Hospital East) reported that when imaging was performed on a lung cancer screening CT (LSCT) phantom under low-dose CT screening conditions, the simulated tumors simulating ground-glass opacity could be detected down to 6 mm in the left lung, and that tomosynthesis achieves equivalent visibility to low-dose CT but at a lower exposure dose.

Therefore, tomosynthesis is thought to offer utility to pick up lung lesions to be treated for lung cancer screening.

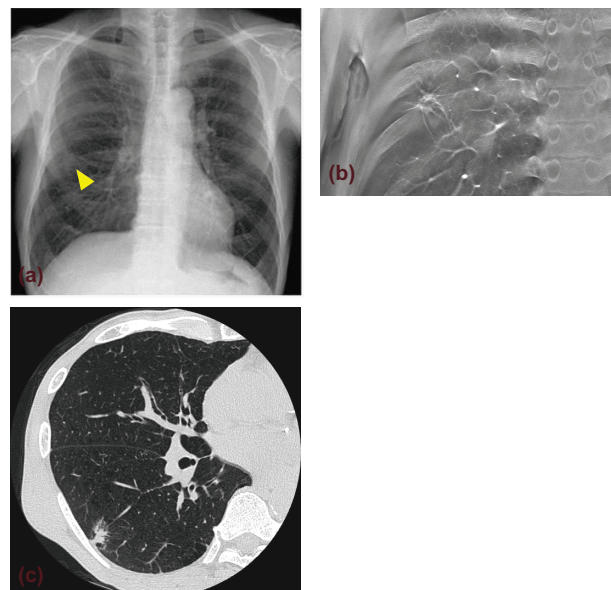


Fig. 1 Comparison of General Chest Radiography, Tomosynthesis, and CT Images
(a) General Chest Radiography Image, (b) Tomosynthesis Image, (c) CT Image

4. Efforts to Reduce Exposure Dose

4.1 Background and Aims

When tomosynthesis is used for lung cancer screening, it must provide images of high diagnostic capacity at a low exposure dose, as the subjects are healthy individuals.

SONIALVISION safire increases the analog gain (AG) of the amplifier that amplifies the signals output from the flat panel detector (FPD) to reduce the exposure dose for radiography.

Conventional chest tomosynthesis images offer satisfactory graininess, even in high-absorption areas such as the heart and liver, and achieve further reductions in exposure dose with respect to image quality.

We investigated increasing the FPD gain to reduce the exposure dose without diminishing the conventional lesion visibility.

4.2 Equipment

- Shimadzu SONIALVISION safire R/F System
- Model 9015 Thimble Chamber Dosimeter / Plane Parallel Chamber Dosimeter (Toyo Medic)
- Burger phantom (Kyoto Kagaku Co., Ltd.)
- LSCT-001 phantom (Kyoto Kagaku Co., Ltd.)
- Acrylic sheet (40 cm × 40 cm × 1 cm)

4.3 Investigation Method and Items

4.3.1 Calculation of Optimal Dose with Respect to Analog Gain (AG)

The 10 cm-thick acrylic sheet was imaged using settings AG × 3 (conventional), AG × 10, ×20, and ×30. The exposure dose that achieves an equal FPD output digital value at each setting was determined and used as the optimal dose. A 10 cm-thick acrylic sheet was used to model chest radiography. The other conditions were fixed and common for all investigated items.

Table 1 shows the radiography, imaging, and reconstruction conditions.

X-ray tube voltage	120 kV
Resolution	High Resolution mode Number of frames captured: 74
Matrix size	1440 × 1440 (17 inch)
Tomography speed	Slow mode Exposure time: 5.0 sec
Tomography angle	40°
Reconstruction method	FBP method Reconstruction function: Thickness++

Table 1 Radiography, Imaging, and Reconstruction Conditions

4.3.2 Graininess Measurement

The 10 cm-thick acrylic sheet was mounted, the AG was set to AG × 3, ×10, ×20, and ×30, and radiography performed at the optimal dose for each setting.

The noise power spectrum (NPS) was calculated on the tomographic plane at five points (center and four corners of the image).

4.3.3 Contrast Noise Ratio Calculation

A burger phantom was placed between acrylic sheets and images taken at the optimal dose using the settings AG × 3 to AG × 30.

The ROI was set on the signal areas and background of the image obtained, and the contrast noise ratio (CNR) calculated using the expression below.

$$CNR = \frac{(\text{signal mean pixel value}) - (\text{background mean pixel value})}{\text{background standard deviation}}$$

4.3.4 Absorbed Dose Measurement and Visual Evaluation of Simulated Tumor

A dosimeter was positioned at the center and surface of the LSCT phantom, the AG was set to AG × 3, ×10, ×20, and ×30, and radiography performed at the optimal dose. The absorbed dose measurements were performed by CT at the level of the bifurcation of trachea.

Visual evaluation was performed on the 6, 8, and 10 mm-diameter simulated tumors with $\Delta CT = 270$ HU near the left lung apex and left diaphragm of the LSCT phantom.

4.3.5 Visual Evaluation of Images of Volunteers

Radiography was performed on approximately 20 volunteers at the optimal dose with the AG set to AG × 3 and ×30.

The images were visually evaluated for graininess in the lung field by three physicians from the Respiratory Disease Division and five X-ray technologists from the Radiology Division at this hospital.

4.4 Results

4.4.1 Calculation of Optimal Dose with Respect to Analog Gain (AG)

Table 2 shows the calculated optimal dose with respect to the analog gain (AG). The values in **Table 2** are the dose per frame (fixed). The dose decreases as AG increases.

Gain (AG)	kV	mA	msec	mAs	Absorbed dose at phantom surface (mGy)	Absorbed dose at phantom center (mGy)
×3 (conventional)	120	160	3.2	0.51	4.2	1.2
×10	120	80	1.6	0.13	1.5	0.42
×20	120	25	1.6	0.04	0.71	0.21
×30	120	10	1.4	0.014	0.55	0.14

(Reference) General chest radiography: 140 kV, 5 mAs 0.22 0.09

CT (scanning): 120 kV, 30 mA, 0.5 s/rot (Aquilion64) - 2.05

Mean value in CR at each facility: 0.28 mGy (The Grasp of Patient Exposure in CR)
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Table 2 Optimal Dose with Respect to AG and Absorbed Dose Measurements

4.4.2 Graininess Measurement

Fig. 2 shows the measured noise power spectrum (NPS) results. The horizontal axis represents the spatial frequency (lp/mm) and the vertical axis represents the NPS value. The Nyquist frequency is 1.7 lp/mm. The most satisfactory image graininess was obtained at AG × 3. As AG increases, the exposure dose decreases, resulting in deterioration in graininess. No positional dependence was observed.

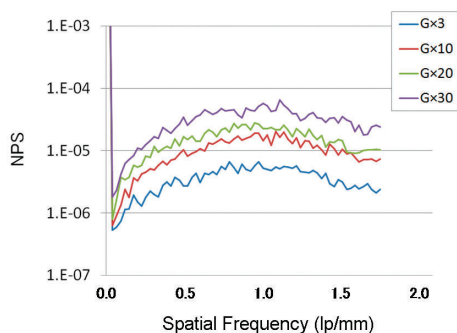


Fig. 2 NPS Measurement Results at Each AG Value

4.4.3 Contrast Noise Ratio Calculation

Fig. 3 shows the calculated contrast noise ratio (CNR) results. The horizontal axis represents the analog gain (AG) and the vertical axis represents the CNR value. The image obtained at AG × 3 exhibited the highest contrast noise ratio (CNR) but the CNR values decreased as the AG value increased (i.e., as the exposure dose decreased).

Physical evaluations were previously conducted, including graininess measurements and CNR calculations.

Next, the following visual evaluations were performed to evaluate what low-dose radiography lies within

the permitted range to ensure a level of image quality that does not impair diagnosis. The results are shown below.

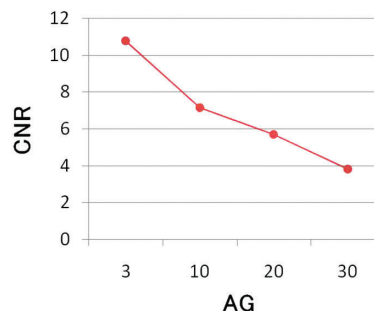


Fig. 3 Calculated CNR Value at Each AG Value

4.4.4 Absorbed Dose Measurement and Visual Evaluation of Simulated Tumors

Table 2 shows the measured absorbed doses at the phantom center and surface.

The absorbed dose at the phantom center and surface exhibit the same trends with respect to the analog gain (AG): the absorbed dose decreases as AG increases.

The 6, 8, and 10 mm-diameter simulated tumors near the lung apex in the images obtained at AG × 3 revealed that AG × 10 and AG × 20 achieved equivalent visibility to the AG × 3 images. Graininess was poor in the AG × 30 image. The 6 mm-diameter simulated tumor, in particular, is hidden by noise and is barely visible.

Equivalent visibility was achieved from AG × 3 to AG × 20 for the 6, 8, and 10 mm-diameter simulated tumors near the diaphragm, similar to the tumors near the lung apex. However, the 6 and 8 mm-diameter simulated tumors in the images obtained at AG × 30 are hidden by noise and are difficult to recognize (**Fig. 4**).

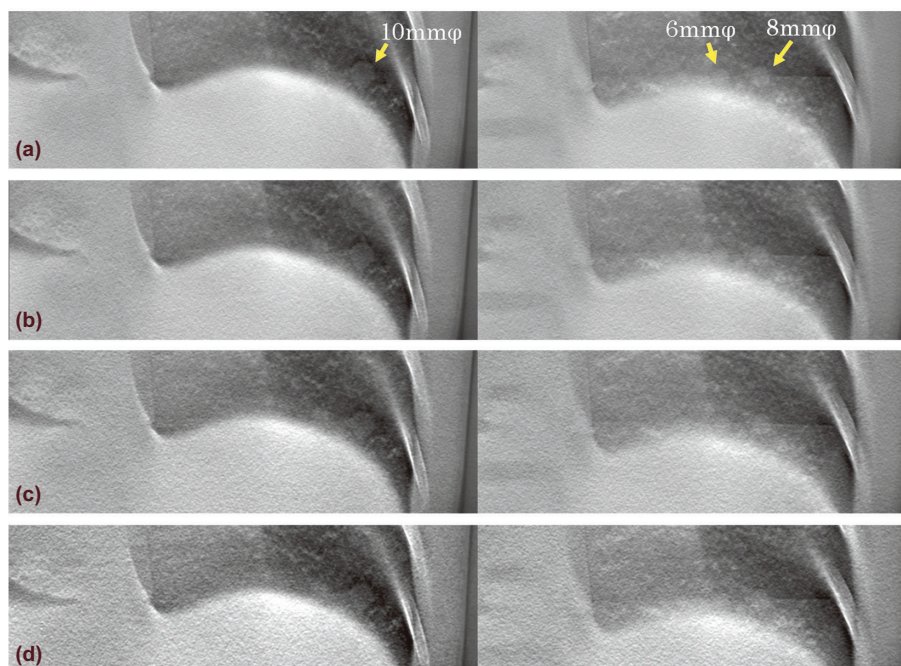


Fig. 4 Visual Evaluation of Simulated Tumors near the Diaphragm
(a) AG × 3, **(b)** AG × 10, **(c)** AG × 20, **(d)** AG × 30

The absorbed dose at the phantom surface at AG \times 3, \times 10, \times 20, and \times 30 was 4.2, 1.5, 0.71, and 0.55 mGy, respectively.

4.4.5 Visual Evaluation of Images of Volunteers

As previous evaluations indicated that the lesion visibility obtained at AG \times 3 can be maintained at low dose levels down to AG \times 20, the analog gain was set to AG \times 3 and AG \times 20 for radiography of volunteers.

Compared to AG \times 3, the images obtained at AG \times 20 maintained the graininess in the lung field (**Fig. 5**), but with slightly inferior graininess in high absorption areas such as the heart, liver, and vertebra, and achieved equivalent visibility to the AG \times 3 images (**Fig. 6**).

4.5 Discussion

We investigated increasing the FPD gain to reduce the exposure dose in chest tomosynthesis for lung cancer screening applications.

As tomosynthesis sums the captured projected images to obtain arbitrary tomographic images, it is said that each projected image does not have to be taken at an adequate exposure dose. For

conventional tomosynthesis, the analog gain is set to AG \times 3 and the exposure dose per frame is determined according to the patient's body thickness. This study allows a lower minimum exposure dose per frame to be set by increasing the FPD gain.

However, excessively low-dose radiography results in poorer graininess and lower CNR, which affects the visual evaluation. When CNR decreases, the contrast between the signal areas and background of the images obtained at each AG remains approximately constant, but poorer graininess occurs in low-dose radiography. Consequently, in addition to improving the graininess, we wondered if investigating the X-ray tube voltage with respect to the subject contrast would lead to improved CNR, that is, to greater visibility of faint shadow images.

The visibility of all the simulated tumors near the lung apex and diaphragm was approximately identical in AG \times 10 and AG \times 20 low-dose radiography as in conventional AG \times 3 images.

While poor graininess is unavoidable with low-dose radiography in high-absorption areas such as the heart and liver, the high X-ray transmittance of the lung field is thought to maintain good graininess and high visibility of the simulated tumors.

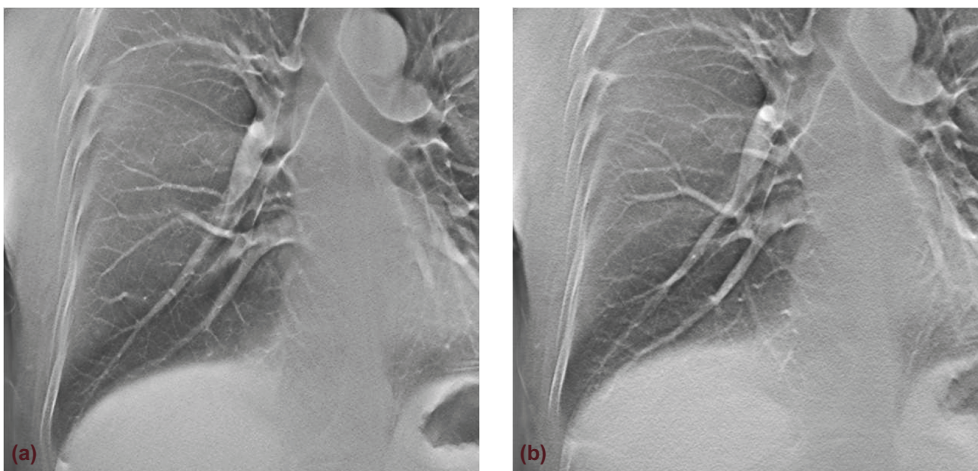


Fig. 5 Visibility of Volunteer Images
(a) AG \times 3, (b) AG \times 20

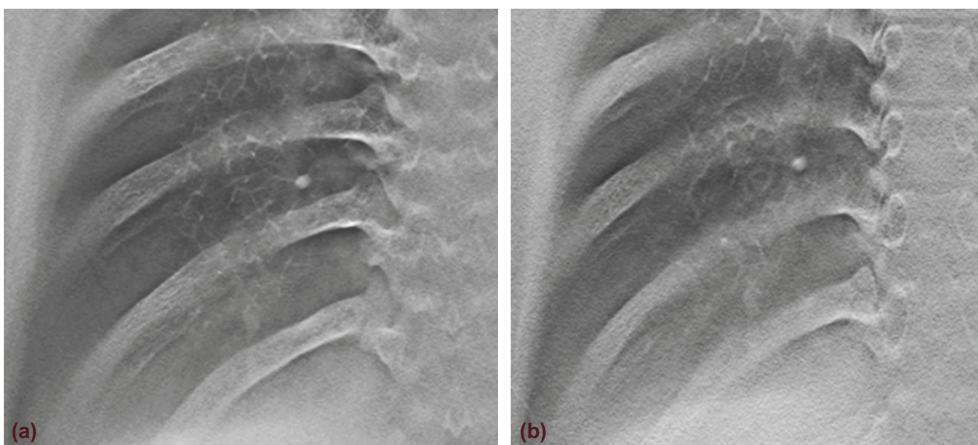


Fig. 6 Visibility of Volunteer Images (with Nodular Shadows)
(a) AG \times 3, (b) AG \times 20

However, poor graininess in the lung field on the AG × 30 low-dose radiography particularly makes the 6 and 8 mm-diameter simulated tumors near the diaphragm impossible to recognize.

This occurs not only due to the low-dose radiography, but due to noise effects related to the position of the simulated tumors next to high-absorption organs. Such differences in lesion visibility according to the position due to reduced exposure dose are unacceptable.

From the results above, an analog gain (AG) of AG × 20 is thought to be appropriate to reduce the exposure dose while maintaining the original lesion visibility. This AG permits a significant 83 % reduction in the patient's skin dose, from the conventional 4.2 mGy to 0.71 mGy.

In contrast with the conventional radiography settings of 120 kV, 160 mA, and 3.2 ms (per frame, fixed), imaging with consideration of the body thickness is currently performed based on 120 kV, 25 mA, and 1.6 ms with an AG × 20 setting.

5. Conclusions

Increasing the FPD gain can significantly reduce the exposure dose.

In the future, functions to automatically set radiography conditions from the patient's body thickness are desirable to further reduce the exposure dose.

Tomosynthesis is a simple procedure that significantly enhances lesion visibility at approximately 2.4 times the exposure dose of a general chest radiography. It achieves detection equivalent to low-dose CT but at just one-tenth the exposure dose. Tomosynthesis could become a new modality for lung cancer screening to pick up lung lesions to be treated.

In the future, we wish to make overall investigations of the radiography conditions, additional filter selection, and image processing to further reduce the exposure dose and enhance image quality.

References

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