Comparsion of Doses and Image Quality among Various Chest X-ray Systems for optimization using our original phantoms of lung adenocarcinoma according to Noguchi’s classification

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Abstract. The aim of our study is to compare evaluation of image quality and doses among various chest X-ray systems using the phantom of lung adenocarcinoma. Pulmonary adenocarcinoma is characterized by an area of ground-glass opacity (GGO) and it is difficult to detect GGO by chest X-ray examination. We examined the imaging performance on conventional radiography (HD-M2, Fuji Film), photofluorography (CXM5-100, Canon Inc), computed radiography systems (FCR XU-D1, Fiji Film/Konica Regius 330, Konica Co. Ltd) and a flat-panel detector digital radiography system (CXD-11 X-ray Digital Camera, Canon Inc) using receiver operating characteristic (ROC) analysis. We used the type A and B phantoms of lung adenocarcinoma according to Noguchi’s classification. The shape of lung adenocarcinoma was assumed to be spherical with different density in the core. The shapes of phantoms were obtained by calculating equivalent thickness to X-ray transmission leading to the same shadow as the sphere in order to practically perform visual evaluation using chest lung phantom on which the phantoms were attached. The materials of the phantoms were tough water phantom made by Kyotokagaku Co. Ltd. The performance of the phantoms developed was validated for chest radiographs of the phantoms attached to the surface of the chest lung phantom. The result of visual evaluation of tumor detectability by 13 radiologists and technicians showed a broadly good agreement with previous clinical data. Using these phantoms, we have studied the relation between detection rate of lung adenocarcinoma and the doses of various chest X-ray systems.

1. Introduction

Recent studies show that adenocarcinoma has become the most common type of lung carcinoma [1]. In some institutions, the newly developed helical CT is used to screen for lung cancer [2,3]. However,
the high dose and cost high of helical CT have meant that chest X-ray examination using a variety of X-ray systems remains the screening method of choice. Pulmonary adenocarcinoma is characteristically demonstrated as an area of ground-glass opacity (GGO)[4,6], which is difficult to detect using chest X-ray examination [7]. Noguchi et al reported [8] that in the classification of small adenocarcinomas into Types A–F, Type C appears to be an advanced stage of Types A and B. In that study, the 5-year survival rate for Types A and B were 100%, while that for Type C was 74.8%. Thus, evaluation of chest X-ray image quality among the various X-rays systems is important. The evaluation of simulated chest lesions varies among the chest radiography systems [9,11]. However, in previous phantom studies for simulated lung adenocarcinoma, no theoretical consideration was given to the pathologic and biological features of lung adenocarcinoma. The shape and density of a simulated phantom strongly influence performance in detection of lung adenocarcinoma. We developed a phantom based on clinical CT data in order to compare both image quality and doses among various chest radiography systems [12]. The objective of the present phantom study was to compare lesion detection and lung dose among a flat-panel detector digital radiography system, conventional radiography, photofluorographic radiography, and storage phosphor radiographs.

2. Materials and methods

2.1. Test phantom

Our study setup was similar to that of previous reports [9,11]. We used an anthropomorphic chest phantom (PBU-S-21, Kyotokagaku Co. Ltd, Japan) and our 15 types of phantoms of lung adenocarcinoma, defined according to Noguchi’s classification (Table I, FIG. 1). The shape of lung adenocarcinoma was assumed to be spherical with a different density in the core. The core corresponds to foci of structural collapse of alveoli and active fibroblastic foci. The shapes of the phantoms were obtained by calculating equivalent thickness to X-ray transmission leading to the same shadow as the sphere in order to practically perform visual evaluation using an anthropomorphic chest phantom onto which the phantoms were attached. The phantoms consisted of tough water phantoms manufactured by Kyotokagaku Co. Ltd., Japan.
Table I. The parameters of our phantom of small adenocarcinoma

<table>
<thead>
<tr>
<th>No.</th>
<th>Noguchi’s classification</th>
<th>1</th>
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<td>Diameter (mm)</td>
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<td>Area of core(%)</td>
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<td>15</td>
<td>30</td>
<td>40</td>
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<tr>
<td>CT value of core</td>
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<td>50</td>
<td>50</td>
<td>50</td>
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<tr>
<td>CT value on the circle with radius fr</td>
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<td>-300</td>
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<td>-300</td>
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<tr>
<td>CT value on the circle with radius R</td>
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Phantom No.1; diameter: 7mm, area of core: 15%, CT value of core: -50HU, CT value on the circle with radius fr: -300HU, CT value on the circle with radius R: -750HU. Phantom No.8; diameter: 10mm, area of core: 30%, CT value of core: -50HU, CT value on the circle with radius fr: -300HU, CT value on the circle with radius R: -750HU. Phantom No.12; diameter: 15mm, area of core: 15%, CT value of core: -50HU, CT value on the circle with radius fr: -300HU, CT value on the circle with radius R: -750HU. Phantom No.13; diameter: 15mm, area of core: 30%, CT value of core: -50HU, CT value on the circle with radius fr: -300HU, CT value on the circle with radius R: -750HU. Phantom No.15; diameter: 20mm, CT value on the circle with radius fr: -300HU, CT value on the circle with radius R: -750HU. The phantom numbers correspond to those shown in Table I.

FIG. 1. Photograph of the phantoms of small adenocarcinoma.

2.2. Compared systems

Posteroanterior chest radiographs were obtained using a photofluorographic system, conventional screen-film system, and digital detector systems. All imaging techniques were those used at each hospital in routine clinical imaging of the human chest wall.

2.2.1. Photofluorography
The photofluorographic system (CXM5-100; Canon, Japan) and automatic radiographic systems (PD-5C-4, Hitachi, Japan) were used at the Oita Area Health Support Center. Studies were photo-timed at 130 kVp using a 4.5-mm aluminium filter and a focus-film distance of 150 cm. For all examinations, a fixed antiscatter grid (10:1, with 34 lines per centimeter) was used. The photofluorography and MIFA film (Fuji, Japan) were processed in an FMT5000 processor (Fuji, Japan) with a cycle time of 90 seconds developed with CE-DE1 (Fuji, Japan) at 34.5°C. Film size was 100 × 100 mm.

2.2.2. Conventional radiography

The conventional screen-film system consisted of combination (HD-M2 Screen and UR-1 film; Fuji, Japan) and automatic radiographic systems (PD-5C-4, Hitachi, Japan) used at the Oita Area Health Support Center. Studies were photo-timed at 130 kVp using a 4.5-mm aluminium filter and a focus-film distance of 200 cm. For all examinations, a fixed antiscatter grid (12:1, with 60 lines per centimeter) was used. The conventional radiography was processed in a FMT5000 processor (Fuji, Japan) with a cycle time of 90 seconds developed with CE-DE1 (Fuji, Japan) at 34.5°C. Film size was 35 × 35 cm.

2.2.3. Storage phosphor radiography

The storage phosphor images (35 × 43 cm) were obtained using two radiographic systems. One consisted of both FCR XU-D1 unit (Fuji, Japan) and an automatic radiographic radiography system (SPT-XD-F4A; Shimazu, Japan), with images printed on film (35 × 43 cm, DI-AL; Fuji, Japan) by a laser imager (FM-DPL; Fuji, Japan) at Oita Prefectural Hospital. Exposure was at 120 kVp using a 3.0-mm aluminium filter plus a 0.1-mm copper filter and a focus-detector distance of 200 cm. For all examinations, a fixed antiscatter grid (12:1, with 60 lines per centimeter) was used. The other system was a Konica Regius 330 unit (Konica, Japan), with images printed on film (35 × 43 cm, DR-P; Konica, Japan) by a laser imager (DRYPRO MODEL 722; Konica, Japan) at Shinbeppu Hospital. Exposure was at 100 kVp using a 1.1-mm aluminium filter and a focus-detector distance of 200 cm. For all examinations, a fixed antiscatter grid (10:1, with 60 lines per centimeter) was used. The actual images on the digital hard copies were 32.5 × 40.5 cm.

2.2.4. Flat-Panel Detector Digital Radiography

The flat-panel detector images were obtained using a CXDI-11 X-ray Digital Camera (Canon, Japan)
Automatic radiographic radiography systems (SPT-XD-S01; Shimazu, Japan/PDS-CXDI-11; Hitachi, Japan) were used and images printed on film (35×43 cm, DI-AL; Fuji, Japan/35×43 cm, DI-AT; Fuji, Japan/25.7×36.4 cm, DI-AL; Fuji, Japan/35×43 cm, DVB; Kodak, Japan) by a laser imager (FM-DPL; Fuji, Japan/DRY PIX3000; Fuji, Japan/Dry View 8700, Kodak, Japan). The actual image on the digital hard copies were 32.5×40.5 cm and 25.7×36.4 cm. Exposure was at 130 kVp/120kVp using a 2.5-mm aluminum filter and a focus-detector distance of 180 cm. For all examinations, a fixed antiscatter grid (12:1, with 34 lines per centimeter) was used.

2.3. Image evaluation

All images were assessed independently by 4 radiologists and 2 general thoracic surgeons, who recorded the presence or absence of a lesion and ranked each image according to the following five-point confidence scale: 1=definitely no lesion, 2=probably no lesion, 3=indeterminate, 4=lesion probably present, and 5=lesion definitely present. There was no limit imposed on reading time. There were a total of 816 observations (15 images×6 readers×8 imaging modes = 720 observations for abnormality). Readers had no prior knowledge of exposure setting or imaging system. Photofluorographic radiography was viewed exclusively using a light box, while all other images were viewed on the same light box with adjustable shutters under subdued ambient light. The observers were asked to evaluate the presence of abnormal features.

2.4. Dosimetry

Digital and conventional chest radiographic doses were measured using a thorax phantom (THRA1, Kyotokagaku Co. Ltd, Japan) into which 20 glass dosimeters had been inserted. The RPL glass dosimeters (diameter 1.5 mm) used were the GD-352M model of the RPL system (Dose Ace of Chiyoda Technol Co. Ltd, Japan). Each glass dosimeter was placed in a yellow plastic Sn filter during imaging in order to adjust photon energy dependence. After irradiation, the dosimeters were read using a FGD-1000 reader. The calibration of the reader was automatically performed using an internal calibration glass. Doses were measured doses at 20 points in the lung, and the lung dose calculated as the average of the 20 doses.

3. Results

Of the 96 observations (2 images×6 readers×8 imaging modes) of normal images with no lesions, 95
were ranked as definitely no lesion and 1 as probably no lesion. The detection rates of the Nos. 5, 10, 11, 14 and 15 phantoms (Type A) were 2.1%~14.6%, that of the Nos.1, 2, 3, 8, 9, 12 and 13 phantoms (Type B) were 25.0%~100%, and that of the No. 4 phantom (Type C) was 93.8%, as an average among all the radiography systems. These results were characteristic of the 3 types of phantom. The average performance in the detection of the lung adenocarcinoma phantom by storage phosphor radiography (Mode D) was higher than that of the other radiography systems. Our study indicated that digital radiography (the flat-panel detector digital radiography system and the storage phosphor radiography system) showed no statistically significant difference from the analog radiography systems (the photofluorographic system and conventional screen-film system). The storage phosphor radiography systems in Mode D were superior to those in Mode C for the detection of pulmonary adenocarcinoma (p<0.05). No statistically significant differences were observed among the flat-panel detector digital radiography systems with differences in processing and film size.

The smallest lung dose was 73 $\mu$Gy delivered by the conventional screen-film system. The highest dose was 198 $\mu$ Gy delivered by the photofluorographic system. The dose from the flat-panel detector digital radiography systems ranged from 82 $\mu$Gy to 126 $\mu$Gy. Relation between to dose and detection rate of lesion is shown in Figure 2.

![Figure 2](image)

FIG. 2. Relation between to dose and detection rate of lesion simulated on Type B Phantom No 1.  
(●:Analog system, ▲:Digital system)

4.1. Discussion

To test the diagnostic performance of analog and digital radiography systems, 15 types of phantoms of lung adenocarcinoma, developed according to Noguchi’s classification, located on the surface of an
anthropomorphic chest phantom were used. The detection of the phantom of small adenocarcinoma on the radiographs with visual evaluation is influenced by tumor size and extent of GGO. Tubamoto et al [6] reported that the detection of small peripheral carcinomas on chest radiographs is influenced by tumor size and extent of GGO as seen at thin-section CT. Yang et al [7] reported that the detection rates of adenocarcinoma with lepidic growth (0% for type A, 29% for type B and 68% for type C) were less than those with hiliar growth (100% for types D-F). The present study had similar findings to those of Yang et al. In a phantom study by Andreas [13], no significant difference was found between three imaging systems (a conventional screen-film combination, an asymmetric screen-film system, and storage phosphor radiography) used for the detection of nodules. However, in a patient study, an asymmetric screen-film system was significantly superior to both the storage phosphor radiography and conventional system in the detection of pulmonary nodules. Cornelia et al [14] reported that they compared lesion detection with use of storage phosphor radiography (250 speed), selenium radiography (250 speed) with an antiscatter grid, selenium radiography (450 speed) without an antiscatter grid, an asymmetric screen-film system (400 speed), and a conventional screen-film system (250 speed). It appeared that the selenium detector improves detection of simulated fine linear and low-contrast micronodular details and is superior to other detector systems for chest radiography. Yang et al [15] reported that in the detection of small peripheral lung cancer by storage phosphor chest radiography, the sensitivity increases with tumor size (less than 10mm, 11-15mm, and 16-20mm). Sato et al [16] evaluated the imaging performance of a flat-panel detector digital radiography system and a storage phosphor radiography system, and found that receiver operating characteristic (ROC) analysis indicated that the flat-panel detector digital radiography system was superior in overall performance. Flat-panel detector digital radiography consists of a new detector with a wide dynamic range (1:10,000) that is similar to that of storage phosphor radiography. Awai et al [17] showed that selenium-based digital radiography is superior to high-resolution storage phosphor radiography for the detection of pulmonary nodules. Our study indicates that digital radiography (the flat-panel detector digital radiography system and the storage phosphor radiography system) is not statistically different to the analog radiography systems (photofluorographic system and the conventional screen-film system). For visualization of pulmonary adenocarcinoma, the storage phosphor radiography system was best. However, we observed a significant difference (p<0.05) between the two hospitals for detection of pulmonary adenocarcinoma, and since the kV used differed between the hospitals, we believe that the effect of low kV results in differences in image quality. This study revealed that the exposure conditions for digital radiography may not be properly optimized from the viewpoints of both images and doses in hospitals, most likely because the automatic setup function for exposure conditions in digital systems bring about more marked differences among hospitals compared with analog systems.
5.1. Acknowledgements

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6.1. References


