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FULL PAPER

Detectability of simulated interstitial pneumonia on chest radiographs: comparison between irradiation side sampling indirect flat-panel detector and computed radiography

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Objective: To compare the detectability of simulated interstitial pneumonia on chest radiographs between an irradiation side sampling indirect flat-panel detector (ISS-FPD) and computed radiography (CR).

Methods: Simulated interstitial pneumonia findings (ground-glass opacity, reticular opacity and honeycomb lung) were superimposed on an anthropomorphic chest phantom. Chest radiographs were acquired under three exposure levels (4.0, 3.2 and 2.0 mAs) with an ISS-FPD and with CR. 5 thoracic radiologists evaluated 72 images for the presence or absence of a lesion over each of 6 areas. A total of 1296 observations were analysed in a receiver-operating characteristic analysis. A jackknife method was used for the statistical analysis.

Results: The areas under the curves (AUCs) for the detection of simulated honeycomb lung obtained with the

ISS-FPD were significantly larger than those obtained with CR at all exposure conditions. For the detection of simulated ground-glass opacity and reticular opacity, there were no significant differences between the two systems. In addition, the AUCs for the detectability of simulated honeycomb lung obtained with the ISS-FPD at all exposure levels were significantly larger than those obtained with CR at 4 mAs.

Conclusion: The ISS-FPD was superior to CR for the detection of simulated honeycomb lung. Provided that the chosen model is representative of interstitial pneumonia, the use of an ISS-FPD might reduce a patient's exposure dose during the detection of interstitial pneumonia.

Advances in knowledge: The ISS-FPD has shown its advantage compared with CR in the detection of honeycombing, one sign of interstitial pneumonia.

Computed radiography (CR) and flat-panel detector (FPD) systems have been widely used as digital chest radiography systems. FPDs provide excellent inherent physical image quality; their modulation transfer function (MTF) and detective quantum efficiency (DQE) were found to be superior to those of a CR system.¹ For chest radiographs, the detectability of abnormalities by general FPDs has been compared with that obtained by CR systems and screen-film systems; some studies showed that the FPD was superior for the detectability of some nodules, but other studies showed the detectability of chest abnormalities, including nodules and interstitial pneumonia, to be equal.²⁻⁶ To further improve image quality, irradiation side sampling (ISS) technology was developed and was made commercially available in 2010.⁷ In the original indirect FPD, the luminescence converted from the X-rays was attenuated and diffused by

the scintillator before photodiodes read it. This caused a significant degradation of resolution and efficiency in using the X-rays. An ISS-FPD can reduce the diffusion and the attenuation of the light converted from the X-rays because the photodiodes are placed on the X-ray incident side of the scintillation layer; in the original FPD, the photodiodes are located on the X-ray penetration side.⁸ This change improved the physical imaging properties,⁷⁻¹⁰ and it might affect the detectability of chest abnormalities, including nodules and interstitial pneumonia.

The lung disease interstitial pneumonia has several findings on chest radiographs, including ground-glass opacity, reticular opacities, linear or strand-like opacities, granular shadow and honeycomb lung. It is difficult to identify these findings at an early stage of the disease because they

Figure 1. Images of a simulated interstitial pneumonia. (a) Ground-glass opacity, 50 mm in diameter, simulated with agar. (b) Reticular opacity, 40 × 80 mm in size, simulated with plastic sponge firmed with glue (chloroprene rubber and organic solvent). (c) Honeycomb lung, which was simulated by an assembly of sliced cores of ballpoint pens (6 mm in diameter and 2 mm wall thickness) arranged in four columns × two lines.

are low-contrast and subtle structures on chest radiographs. CT is more sensitive for the visualization of interstitial pneumonia than are chest radiographs. However, CT entails higher radiation exposures, and frequent follow-up CT entails further exposure. It is therefore thought that the monitoring of interstitial pneumonia requires chest radiography, and evaluation of the detectability of interstitial pneumonia and the possibility of exposure-dose reduction are very important.

The objectives of the present study were to compare the detectability of simulated interstitial pneumonia on chest radiographs between ISS-FPD and CR.

METHODS AND MATERIALS

Study design

This study was an observer performance study. Simulated interstitial pneumonias were superimposed on a chest phantom. Images were acquired with an ISS-FPD and a CR system. Each image was divided into six areas. Radiologists observed 432 areas on 72 images. Their observations were evaluated by a receiver-operating characteristic (ROC) analysis. Our institutional review board (Kyushu University, Fukuoka, Japan) does not require approval or informed consent for experimental studies such as the present one, which do not employ human or animal subjects.

Chest phantom and simulated lesions

Simulated interstitial pneumonias were superimposed on an anthropomorphic chest phantom (Multipurpose Chest Phantom N1 “LUNGMAN”™; Kyoto Kagaku Co., Ltd, Kyoto, Japan).

The simulated interstitial pneumonias were as follows: ground-glass opacity, which was simulated with agar (Figure 1a); reticular opacity, which was simulated with plastic sponge firmed with glue (chloroprene rubber and organic solvent) (Figure 1b); and honeycomb lung, which was simulated by an assembly of sliced cores of ballpoint pens (Figure 1c). The simulated honeycomb lung was 6 mm in diameter with 2-mm thick walls in accord with the Fleischner Society’s glossary of terms for thoracic imaging.¹¹ Three different objects were prepared for each type of simulated interstitial pneumonia.

The chest phantom was divided, by using thin wires, into six pulmonary areas^{3–6,12} (Figure 2). Mediastinal areas were not

included for the observations. Each area corresponded to one observation, and thus one image included six observations. Each area could be empty or could contain one or more types of simulated lesions, but a single area could not contain two or more of the same type of lesions. We prepared 12 patterns of locations of the simulated lesions, and a total of 90 simulated lesions of 3 types (30 lesions × 3 types) were located. A total of 72 areas (12 patterns × 6 areas) contained 30 simulated lesions of each type, thus the existing probability of each lesion in each area was 41.7% (30/72), and a single pattern contained 7.5 lesions on average (90/12). The results of the ROC analysis were not influenced by disease prevalence.¹³

Figure 2. An example of a posteroanterior radiograph of the anthropomorphic chest phantom. Thin wires divided the total lung field into six areas. Mediastinal areas were not included in the observations. ○, ground-glass opacity; ◇, reticular opacity; □, honeycomb lung.

Table 1. Comparison of observer performances in detecting simulated ground-glass opacity, reticular opacity and honeycomb lung on the irradiation side sampling indirect flat-panel detector (ISS-FPD) and computed radiography (CR)

Observer number	4.0 mAs		3.2 mAs		2.0 mAs	
	ISS-FPD	CR	ISS-FPD	CR	ISS-FPD	CR
Ground-glass opacity						
1	0.860	0.907	0.863	0.916	0.898	0.917
2	0.693	0.733	0.698	0.731	0.793	0.754
3	0.830	0.918	0.838	0.791	0.841	0.865
4	0.881	0.871	0.892	0.881	0.787	0.858
5	0.929	0.947	0.956	0.965	0.855	0.911
All	0.839	0.875	0.849	0.857	0.835	0.861
<i>p</i> -value	0.0877		0.689		0.409	
Reticular opacity						
1	0.886	0.932	0.844	0.919	0.906	0.899
2	0.941	0.930	0.890	0.908	0.896	0.841
3	0.953	0.935	0.911	0.895	0.875	0.872
4	0.925	0.981	0.969	0.929	0.907	0.954
5	0.993	0.972	0.961	0.944	0.923	0.975
All	0.940	0.950	0.915	0.919	0.901	0.908
<i>p</i> -value	0.573		0.858		0.775	
Honeycomb lung						
1	0.847	0.655	0.866	0.809	0.792	0.762
2	0.845	0.797	0.894	0.729	0.906	0.671
3	0.891	0.807	0.848	0.682	0.875	0.667
4	0.962	0.884	0.915	0.889	0.919	0.825
5	0.916	0.776	0.930	0.826	0.881	0.688
All	0.892	0.783	0.890	0.787	0.875	0.723
<i>p</i> -value	0.0103		0.0151		0.0105	

Image acquisition

Images were acquired with two digital detector systems: a CR system (PROFECT CS; Fujifilm, Tokyo, Japan) was used with an imaging plate (ST-VI, single-side reading system; Fujifilm) of size 35 × 35 cm, with a 3520 × 3520 matrix, 12 bits per pixel, and a 0.1-mm pixel size. An ISS-FPD (CALNEO MT; Fujifilm) with gadolinium oxysulfide (GOS) as a scintillator was used. The size of the images of the chest phantom were 35 × 35 cm with a 2372 × 2372 matrix, 12 bits per pixel, a 0.15-mm pixel size and a fill factor of 75%. An X-ray generator (KXO-50G; Toshiba Medical Systems, Ohtawara, Japan) and an X-ray tube (DRX-2724HD; Toshiba Medical Systems) were used with both the CR and ISS-FPD systems.

Posteroanterior chest radiographs were acquired with the following parameters: 120 kV; 4.0, 3.2 and 2.0 mAs (incident doses to the chest phantom: 230, 180 and 115 µGy); and an antiscatter grid (grid ratio of 12:1, 60 lines per centimetre, 180-cm focus-to-detector distance). The Bucky blende (Mitaya Manufacturing Co., Ltd, Kawagoe, Japan) and Lysholm® (Mitaya Manufacturing

Co., Ltd) blende were used for the ISS-FPD and CR systems, respectively. The same image processing was performed for all data using the same workstation (Console Advance; Fujifilm).

Image evaluation

Images were displayed on a workstation (DxMM; Medasys Japan, Tokyo, Japan) with a three-megapixel monochrome liquid-crystal display (RadiForce GS320; EIZO, Ishikawa, Japan). The maximal luminance was 450 cd m⁻². The illuminance at the centre of the display was 30 lux, as measured with a calibrated photometer (ANA-F9 Lux Meter; Tokyo Photo-Electric, Tokyo, Japan). A total of 72 images (12 patterns × 2 detectors × 3 exposure levels) were analysed by 5 board-certified thoracic radiologists with 6–29 (mean, 17.4) years' experience in chest radiology.

The observers reported their confidence regarding whether each area was "positive" or "negative" for each type of simulated lesion.¹⁴ Each observer assessed images independently. The observers were blinded to the exposure settings and detectors. A total of 72 areas (12 patterns × 6 areas) contained 30

Figure 3. Receiver-operating characteristic curves for the detectability of simulated ground-glass opacity with computed radiography (CR) at 4 mAs (the areas under the curves value = 0.875) and the irradiation side sampling indirect flat-panel detector (ISS-FPD) at 4.0 (0.839), 3.2 (0.849) and 2.0 mAs (0.835). There were no significant differences ($p = 0.0877, 0.231$ and 0.236).

simulated lesions of each type, thus the existing probability of each lesion was 41.7% (30/72). Observers were informed about the lesion type prior to a reading test. Training sessions were held before the scoring sessions to allow the observers to become familiar with the chest phantom and the range of simulated lesions, in order to reduce learning bias. To reduce or eliminate reading-order effects, all images were displayed in random order.¹⁵ No limit was imposed on the reading times (mean time, 2 h).

Data and statistical analysis

A total of 6480 observations (12 patterns $\times$ 6 areas $\times$ 3 lesions $\times$ 2 detectors $\times$ 3 exposure levels $\times$ 5 observers) were evaluated by a ROC analysis. The detection performance was estimated with the area under the ROC curve (AUC).¹⁵ A comparison of the ISS-FPD and CR was performed for each simulated lesion and each exposure level. We also investigated how much the exposure level could be reduced while maintaining detectability by the ISS-FPD.

For the calculation of the AUC, we used a statistical program (DBM MRM v. 2.2 Build 3; University of Chicago, Chicago, IL). This statistical program is based on the jackknife method, which is suitable for random-reader and random-case analyses.¹⁶ Differences were considered significant at $p < 0.05$.

RESULTS

Table 1 shows the AUC values for the detection of three simulated lesions with the two different systems at each exposure level.

Ground-glass opacity

In the detection of the ground-glass opacity, the AUC values for the ISS-FPD (AUC = 0.839, 0.849 and 0.835) were smaller than those for CR (AUC = 0.875, 0.857 and 0.861) at each exposure level. However, there were no significant differences in the diagnostic performance between the two systems ($p > 0.05$).

In the comparison between the ISS-FPD at lower exposure levels (3.2 and 2.0 mAs) and CR at 4.0 mAs as a standard, there was no significant reduction in the detectability of ground-glass opacity ($p > 0.05$) (Figure 3).

Reticular opacity

The AUC values for simulated reticular opacity with the ISS-FPD (AUC = 0.940, 0.915 and 0.901) were only slightly smaller than those obtained with CR (AUC = 0.950, 0.919 and 0.908) at each exposure level. These differences were not significant ($p > 0.05$).

Figure 4 shows the ROC curves for the detectability of simulated reticular opacity with the ISS-FPD at 3.2 and 2.0 mAs and those with CR at 4.0 mAs. There was no significant difference between CR at 4.0 mAs and the ISS-FPD at 3.2 mAs ($p > 0.05$). The AUC value for the ISS-FPD at 2 mAs was significantly lower than that for CR at 4 mAs ($p = 0.0011$).

Figure 4. Receiver-operating characteristic curves for the detectability of simulated reticular opacity with computed radiography (CR) at 4 mAs [the areas under the curves (AUCs) value = 0.950] and the irradiation side sampling indirect flat-panel detector (ISS-FPD) at 4.0 (0.940), 3.2 (0.915) and 2.0 mAs (0.901). There was no significant difference between CR at 4.0 mAs and the ISS-FPD at 4.0 and 3.2 mAs ($p = 0.573$ and 0.0703). The AUC value for the ISS-FPD at 2 mAs was significantly lower than that for CR at 4 mAs ($p = 0.0011$).

Figure 5. Receiver-operating characteristic curves for the detectability of simulated honeycomb lung with computed radiography (CR) at 4 mAs [the areas under the curves (AUC) value = 0.783] and the irradiation side sampling indirect flat-panel detector (ISS-FPD) at 4.0 (0.892), 3.2 (0.890) and 2.0 mAs (0.875). Even when lower exposure levels were used with the ISS-FPD, the AUC values were significantly higher than that for CR at 4 mAs ($p = 0.0103$, 0.0338 and 0.0081).

Honeycomb lung

The AUC values in the detection of simulated honeycomb lung with the ISS-FPD (AUC = 0.892, 0.890 and 0.875) were higher than those obtained with CR (AUC = 0.783, 0.787 and 0.723) at each exposure level. There were significant differences in the diagnostic performance ($p = 0.0103$, 0.0151 and 0.0105).

Figure 5 shows the ROC curves for the detectability of simulated honeycomb lung with the ISS-FPD at 3.2 and 2.0 mAs and with CR at 4.0 mAs. The AUC values for the ISS-FPD at 3.2 and 2.0 mAs were significantly higher than that for CR at 4.0 mAs, even with lower exposure levels ($p = 0.0338$ and 0.0081).

In the comparison between the ISS-FPD at lower exposure levels (3.2 and 2.0 mAs) and the ISS-FPD at 4.0 mAs as a standard, there were no significant reductions in the detectability of simulated honeycomb lung ($p > 0.05$) (Figure 5).

DISCUSSION

The results of the present study demonstrated that the ISS-FPD was an excellent tool to detect simulated lesions of interstitial pneumonia. The ISS-FPD was superior to CR in the detection of simulated honeycomb lung and has a statistically equivalent ability in the detection of simulated ground-glass opacity and reticular opacity. The results also suggest the possibility of dose reduction by using the ISS-FPD. This was supported by the results of an experimental study of physical imaging properties:¹⁰ the DQE of an ISS-FPD was superior to that of CR, and the Wiener spectrum of the ISS-FPD obtained at a half-dose level was comparable to or slightly lower than that of CR.¹⁰ In the present study, the

detectability of simulated interstitial pneumonia was obtained under nearly identical conditions as in actual medical practice—that is, an anthropomorphic chest phantom was used, and the observations were made by radiologists.

Regarding the detectability of interstitial pneumonia, we found that the ISS-FPD was superior to CR, as it was for honeycomb lung. However, the detectability of ground-glass opacity and reticular opacity was statistically comparable in the two systems. On chest radiographs, ground-glass opacity appears as an area of usually extensive, hazy increased lung opacity.¹¹ The simulated ground-glass opacity used in the present study was large (50-mm diameter), and we therefore believe that there was little influence of noise on the detectability. Reticular opacity is a collection of innumerable small linear opacities that produce a network appearance by summation;¹¹ therefore, the detectability of reticular opacity is affected by the sharpness provided by an imaging system. The MTF of the ISS-FPD and CR systems, which is a physical parameter to represent imaging systems as spatial frequency response, is comparable.¹⁰

This would explain why there were no significant differences in the detectability of simulated ground-glass opacity and reticular opacity between the two systems in the present study. Here, sliced cores of ballpoint pens (2-mm thick) were arranged in 4 columns $\times$ 2 lines to simulate honeycomb lung. Since these were small structures, we suspect that they were more strongly affected by noise.

If the detectability of simulated ground-glass opacity with CR at 4 mAs is used as the present standard, the use of an ISS-FPD can reduce the dose to 2 mAs. For the detectability of simulated reticular opacity, the use of an ISS-FPD can reduce the dose to 3.2 mAs. In addition, the detectability of simulated honeycomb lung with the ISS-FPD at 2 mAs was superior to that with CR at 4 mAs, and the detectability of simulated honeycomb lung with the ISS-FPD was not degraded when we reduced the exposure level from 4 to 2 mAs. Therefore, the use of an ISS-FPD could reduce a patient's exposure dose for the detection of interstitial pneumonia. It remains unexplained whether a specific dose reduction level in our phantom study could be directly applied in a clinical practice.

The limitation of this study was that we compared the detectability of simulated interstitial pneumonia between CR and the ISS-FPD only. Further work will be needed for comparisons with other systems, such as a conventional indirect FPD with GOS or caesium iodide or direct FPD. There is no guarantee that the simulated lesions really correspond to clinical lesions of interstitial pneumonia. Comparison of ISS-FPD and CR using clinical imaging of interstitial pneumonia is expected in a future study.

CONCLUSION

The ISS-FPD is superior to CR for the detection of honeycombing, one component of interstitial pneumonia, and it might allow for reduction of a patient's exposure dose.

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