ROC Analysis of Simulated Chest Lesions for Computed Radiography and Digital Radiography at Various Tube Voltages

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Current digital radiographic systems are rapidly growing in clinical applications. The purpose of this study was to evaluate the diagnostic performance of computed radiography (CR) and digital radiography (DR) at different tube voltages in the detection of simulated chest lesions. Patterns of simulated interstitial lung disease, incipient infiltration, and nodules were superimposed over an anthropomorphic chest phantom. A simulated chest phantom radiograph was obtained with CR and DR at different tube voltages (70 kV, 90 kV, and 120 kV). A total of 18,000 observations were analyzed using a receiver operating characteristic (ROC) analysis. The detection of all lesions showed higher A_z values at 70 kV than 120 kV with CR. For the DR, mean A_z values at 70 kV were higher than other tube voltages not all lesions but for micro-nodule interstitial lung disease, linear interstitial lung disease, and incipient infiltration. Based on these results, a clinical study should be performed to judge the use of suitable tube voltage according to the type of detector system and lesions.

Key Words: ROC, CR, DR, Tube voltage, Simulated lesions

INTRODUCTION

As digital and computer technology advances, the various digital radiographic techniques have been developed as an alternative to the existing film-based radiology system.[1,2] Two digital detector systems have been introduced for clinical use in chest imaging: computed radiography (CR), since 1981, and digital radiographic (DR) systems, since 1992.[3] Digital radiography provides advantages regarding image quality and workflow such as a linear signal response, wide dynamic range, flexibility in image display, post-processing, and interface to a picture archiving and communication system (PACS) for digital image management.[2-5] Digital detectors also showed significant better for adequate viewing of the peripheral parts of the lungs and regions with higher attenuation.[3,6]

Sensitivity and specificity are the basic index of the accuracy of a diagnostic test.[7] The receiver operating characteristic (ROC) curve is a plot of lesion sensitivity versus its false-positive rate (1-specificity). One of the widely used measures is the area under the ROC curve (Az) which its values are ranging between 0 and 1. Az value is getting closer to 1 for better performance of diagnostic test.[7,8] Most previous reports focused on comparing screen-film images with digital images[3,9] or comparing digital detector images with computed radiographic images in the same conditions.[1,3,4,10] Digital systems as digital selenium radiography and cesium iodide amorphous silicon (CsI/a-Si) flat panel detector have been assessed for dose reduction and showed significant better results for the detection of nodules compared with CR.[1,2,5,11] However, a patient and simulated phantom study for simulated lung disease at the same exposure setting showed no significant difference for the DR compared with CR.[1,3,10]

High-voltage techniques are widely used to chest radiography. Advantages of these techniques in chest radiography include shorter exposure times reduced movement unsharpness and better transmission to an adequate visualization of areas of complicated structures.[6,12] Therefore, chest radiographs in

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adults are performed at hih-voltage techniques (100～150 kV) with an exposure time less than 40 msec according to the American College of Radiology standards.

A phantom study of DR that compared different tube voltages gave first evidence for superior ability to detail detection of lesions on images at lower tube voltage.[12,13] Furthermore, the diagnostic performance of CsI/a-Si flat-panel detector and CR increased at lower peak voltage with higher A_z values and visual grading analysis score, respectively.[6,14]

The aim of this phantom study was to compare the two digital detectors in the detection of patterns of simulated interstitial lung disease, nodules, and incipient infiltration at various tube voltages using receiver operating characteristic (ROC) analysis.

MATERIALS AND METHODS

1. Phantom and test lesions

An anthropomorphic chest phantom (3 Dimensional Torso Phantom, CIRS, Virginia, USA) was divided, by using wires, into 12 areas (six pulmonary, three mediastinal, and three sub-diaphragmatic). The following patterns of simulated interstitial lung disease, incipient infiltration, and nodules were used: (a) reticular interstitial lung disease, which was simulated with gauze soaked with contrast media (Iopromide (Ultravist 300), Schering AG, Berlin, Germany); (b) micro-nodule interstitial lung disease, which was simulated with clusters of 15～30 grains of bird seed soaked with diluted contrast media; (c) linear interstitial lung disease, which was simulated with silk thread soaked with contrast media; (d) low-contrast patchy opacity with a 2～3 cm diameter resembling an incipient infiltration, which was simulated with plasticine; and (e) nodules, which were simulated with paraffin and which were 10～15 mm in diameter (Fig. 1).

These lesions were taped randomly onto each of 10 prepared 3 mm thick acrylic plates so that 50% of the 12 defined phantom areas were covered with these lesions and 50% were

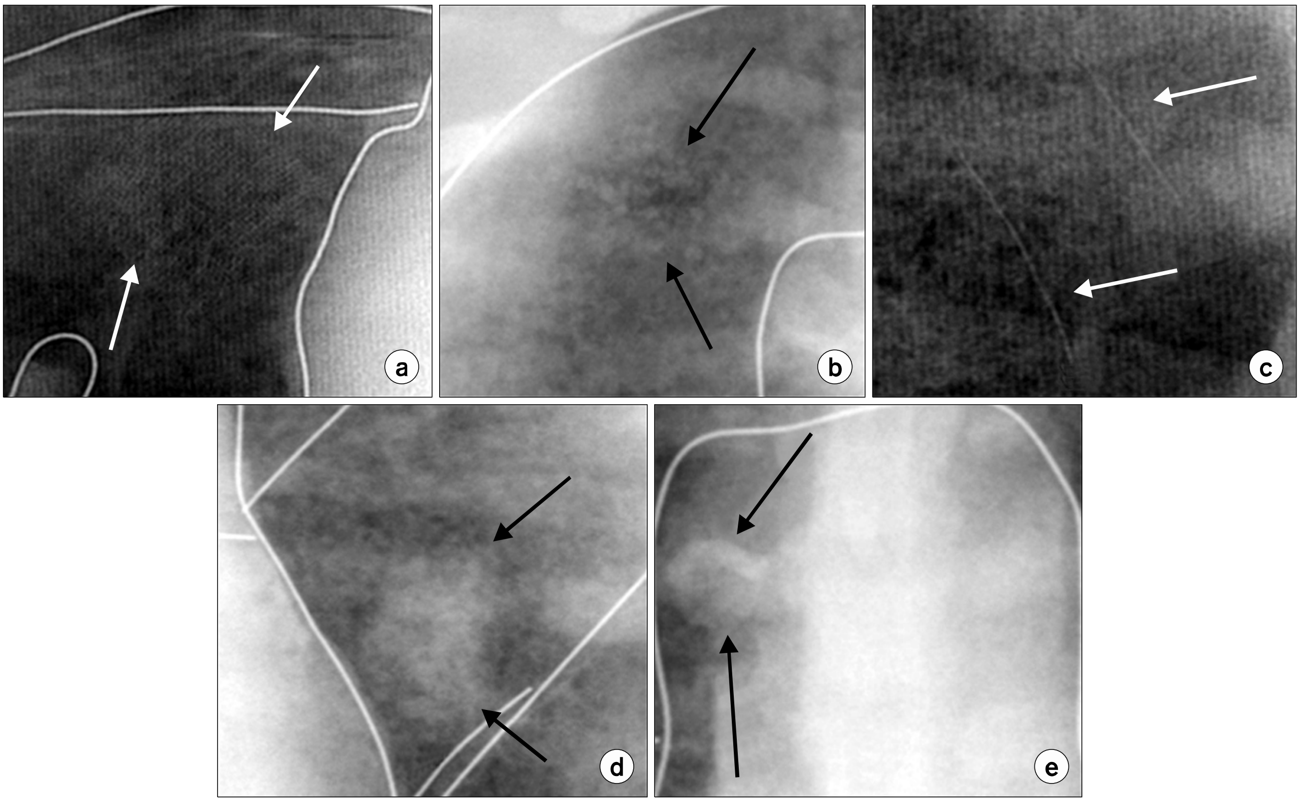

Fig. 1. The radiographic images of simulated patterns (arrows). (a) reticular interstitial lung disease, (b) micro-nodule interstitial lung disease, (c) linear interstitial lung disease, (d) incipient infiltration, and (e) nodules.

not. The areas could be empty or could contain one or more lesions. Each of the 10 acrylic plates was superimposed over the phantom.[3)]

2. Detector systems

Posteroanterior chest radiographs were obtained by using two digital detector systems. CR images were obtained (ADCR2.5, Agfa-Gevaert, Antwerp, Belgium) by using 35×43 cm imaging plates (Agfa MD 4.0), a 2,320×2,828 matrix, and 0.15 mm pixel size. DR images were obtained (FDXD-1417, DRTECH, Seoul, Korea) by using a 35.6×42.7 cm solid-state detector, a 2,560×3,072 matrix, and 0.139 mm pixel size.

3. Image acquisition

Posteroanterior chest phantom radiographs were obtained with three different tube voltages (70 kV, 90 kV, and 120 kV). The ratio of anti-scatter grid was 13 : 1 and the focus-detector distance was 1.8 m. The acrylic plates consisting of the simulated lesions and a wire grid to subdivide the lung regions were placed between the detector and the anthropomorphic phantom during image acquisition. For the different tube voltages, a fixed surface entrance dose (with backscatter) was used, which was equivalent to an exposure for a chest radiograph of the phantom at 120 kV. This was achieved using different milliampere second values until the intended surface dose was reached for the phantom surface at lower tube voltage (Table 1). The surface entrance doses were measured using an ionization chamber (Radcal 10×9-60 ion chamber/ Radcal 9095 radiation monitor, Radcal Corporation, Monrovia, CA). Total of 60 radiographs were obtained (10 acrylic plates×3 different tube voltage×2 detector systems).

4. Image processing and display

All images with CR and DR were processed with each fixed set of parameters in the system-integrated program. The image processing is the routine image processing set which the same technique used in a general hospital for patient chest radiographs. All DR and CR images were sent to a PACS server and distributed to workstations (STARPACS, INFINIT, Seoul, Korea). The digital images were downloaded onto a display workstation before evaluation. A 5 M pixel monochrome monitor (ME551i2-B/C, TOTOKU, Tokyo, Japan) was used in the ambient room light subdued. Magnification of the images was not allowed. Each image was displayed one by one in random order.

Table 1. Exposure times and dose measurements.

	Tube voltage		
	70 kV	90 kV	120 kV
Exposure time (ms)	40.00	25.00	16.00
Surface entrance dose (Gy)	255×10^{-6}	254×10^{-6}	268×10^{-6}

5. Evaluation

All radiographs were analyzed by five imaging experts who specialize in radiological imaging science. All observers were familiar with using PACS. Training sessions were held before the scoring sessions to allow the observers to become familiar with the chest phantom image and the simulated lesions. To avoid learning bias, the interval between each session was held at least a week. Prior to each sitting, a normal image was presented to the observers. No limit was imposed on reading time and viewing distance. Reading conditions were kept constant with in a darkened room. The observers did not know the rate of simulated abnormalities and the different tube voltages. A continuous rating scale of 0~100 was used to represent each observer's level of confidence regarding the presence or absence of interstitial lung disease, incipient infiltration, and nodules.[1)]

6. Data and statistical analysis

A total of 18,000 observations (10 acrylic plates×12 areas×5 observers×3 different tube voltage×2 detector systems×5 test lesions) were analyzed using a ROC analysis. Detection accuracy of the simulated lesions was described by the area under the ROC curve (A_z).[1,4)] For the calculation of the A_z values, the program ROCKIT was used (ROCKIT, Charles E. Metz, PhD, University of Chicago, IL).[15)] The program was used for each system, tube voltage, and lesion separately. The mean A_z values were calculated along with their standard deviation. A statistical program (SPSS version 12, Chicago, IL) was used to calculate the significance of the differences between the mean A_z values by using a two-way factorial analysis of variance method.

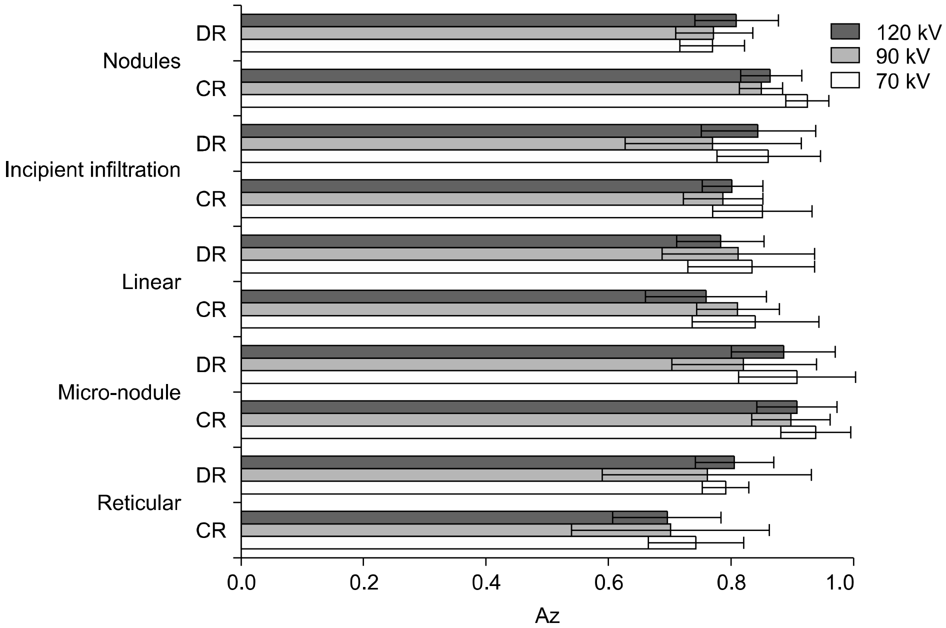

Fig. 2. Mean A_z values for the detection of simulated lesions. Numbers and standard deviations are given for the two detector systems. The higher the A_z value, the better the detection performance.

Table 2. Two-way analysis with detector and tube voltage as the analysis of variance factors for each pattern.

	Lesion type	F Ratio	P-Value
Detector	Reticular	3.21	0.09
	Micro-nodule	2.00	0.17
	Linear	0.03	0.86
	Incipient infiltration	0.14	0.72
	Nodules	25.09	0.00
Tube voltage	Reticular	0.27	0.77
	Micro-nodule	1.47	0.25
	Linear	1.16	0.33
	Incipient infiltration	1.83	0.18
	Nodules	1.25	0.30
Detector* Tube voltage	Reticular	0.22	0.81
	Micro-nodule	0.31	0.74
	Linear	0.07	0.94
	Incipient infiltration	0.25	0.78
	Nodules	2.51	0.10

RESULTS

The mean Az values and standard deviations for the three tube voltages are shown in the Fig. 2 to illustrate observer performance for the detection of simulated lesions on the DR and CR. Table 2 shows the P-Values and F ratios for the five lesions, two detectors, and three tube voltages. A_z values for the DR at 70 kV were higher than those with other tube voltages for micro-nodule, linear, and incipient infiltration. However, these results were not significantly different ($P>.05$). The detection of all lesions showed higher A_z values at 70 kV than 120 kV with CR. These results were not statistically significant ($P>.05$).

1. Reticular pattern

In the detection of a reticular interstitial lung disease, A_z values for the DR at three tube voltages were higher than those for CR. The higher A_z values were found at 120 kV (A_z=0.81) and 70 kV (A_z=0.74) with the DR and CR, respectively. No statistically significant differences were found for detectors and tube voltages.

2. Micro-nodule pattern

The observers' ability to detect micro-nodule interstitial lung disease was inferior with the DR compared with the CR with same tube voltages. The A_z values at 70 kV (A_z=0.91; A_z=0.94) with two systems were equal to higher compared with 90 kV (A_z=0.82; A_z=0.90) and 120 kV (A_z=0.89; A_z=0.91). These differences were not statistically significant.

3. Linear pattern

For the detection of a linear interstitial lung disease, the A_z value with the DR (A_z=0.83 ; A_z=0.81 ; A_z=0.78) was similar to the CR (A_z=0.84 ; A_z=0.81 ; A_z=0.76) at three tube voltages setting. Higher A_z values were obtained at 70 kV than other voltages with the two systems. However, these results were not statistically significant.

4. Incipient infiltration

In the detection of a incipient infiltration, higher A_z values were found at 70 kV (A_z=0.85) than those at 90 kV (A_z=0.79) and 120 kV (A_z=0.80) with the CR. The differences were not significant. Moreover, there was no statistically significant difference between DR and CR at corresponding tube voltages.

5. Nodules

The observers scored the CR as significantly superior compared with the DR at three tube voltages ($P<.05$). The detection of nodules was worse at DR with a 70 kV (A_z=0.77) and 90 kV (A_z=0.77) compared with 120 kV (A_z=0.81). However, the ability to detect this pattern was superior at CR with 70 kV (A_z=0.92) than 90 kV (A_z=0.85) and 120 kV (A_z= 0.86). These differences were not statistically significant.

DISCUSSION

The advantage of digital radiology in chest radiography is having wide dynamic range for adequate visualization of both high and low attenuation area. Large latitude provide the precise assessment of the peripheral parts of the lungs and regions with higher attenuation.[1,3,6]

High tube voltage techniques are widely used to chest radiography. Recently, many studies have been performed talking about possible dose reduction with digital radiography which the light spreading is greatly reduced as a result of structure.[6,12] Confirmation of the accurate x-ray tube voltage is also an important quality assurance topic in diagnostic radiography.[12] The ideal tube voltage range for a digital radiography was evaluated in a patient trial for DR[13] and in a phantom study for DR[12,13] and CsI/a-Si[6] but not for the CR. Hence, we performed phantom study by using an anthropomorphic chest phantom and simulated lesions at various tube voltages for CR compared with DR.

In our study, all of the simulated lesions resulted in higher Az values for images obtained at 70 kV with CR; however, this was no statistically significant. Chotas et al[16] based on photostimulable CR showed decreased signal-to-noise ratio with increasing tube voltage in lung areas. Bernhardt et al[6] performed a chest phantom study with similar surface dose at three tube voltages using flat-panel detector and found that the effective dose equivalent was lower at 70 kV compared with high tube voltage. These results offered a potential of a dose reduction in digital chest radiography. The dose reduction of CR with lower tube voltage also has to be assessed in a further study. Bernhardt et al[12] showed that the detection of interstitial lung pattern was higher with 70 and/or 90 kV than with 150 kV. Our study showed the detection of lesions except for reticular interstitial lung pattern with DR was slightly increased at 70 and/or 90 kV from that on images obtained at 120 kV. The main reason of different result for reticular interstitial lung pattern with Bernhardt et al[12] was the different simulated lesions and the different experimental setup.

Our results were obtained higher A_z values for the DR at each tube voltages than those for CR in the detection of a reticular interstitial lung disease. The reason for this performance is the difference in spatial resolution. Pixel size is an important parameter in digital radiography because it directly influences the spatial resolution of the images. Other factors being equal, the smaller pixel size make the better image quality, especially in the depiction of fine detail.[10] In our study, the pixel size of the CR was 0.15 mm, and the pixel size of the DR was 0.139 mm.

Our study has several limitations; 1) When acquire the images of the CR, a carbon fiber plate alike with that of the DR was not placed in front of the computed-imaging plate. This setup was same with clinical routine but it can make any bias.[5] 2) A possible bias due to the change of phantom position to each system was avoided by using fixed setting frame. 3) Although readers did not know the two different detectors and tube voltages setting, they were able to distinguish between the different voltage levels on the basis of the impression of image noise. Moreover, images obtained with the CR had a certainly different look than those obtained with DR because of different processing techniques.

CONCLUSION

This phantom study showed that for simulated interstitial lung disease, incipient infiltration, and nodules, a using of the low tube voltage is possible for CR, with improved diagnostic performance. There was no statistically significant difference between CR and DR imaging with the same tube voltage in the detection of simulated lesions except for nodules. Based on these results, a clinical study should be performed to judge the use of suitable tube voltage according to the type of detector system and lesions. Further studies in clinical situation may be needed to generalize these results for other applications.

REFERENCES

1. **Goo JM, Im JG, Lee HJ, et al**: Detection of simulated chest lesions by using soft-copy reading: comparison of an amorphous silicon flat-panel-detector system and a storage-phosphor system. Radiology 224:242-246 (2002)
2. **Rong XJ, Shaw CC, Liu X, Lemacks MR, Thompson SK**: Comparison of an amorphous silicon/cesium iodide flat-panel digital chest radiography system with screen/film and computed radiography systems - A contrast-detail phantom study. Med Phys 28:2328-2335 (2001)
3. **Bernhardt TM, Otto D, Reichel G, et al**: Detection of simulated interstitial lung disease and catheters with selenium, storage phosphor, and film-based radiography. Radiology 213: 445-454 (1999)
4. **Uffmann MPM EEF, amp, auml, ger MWM S-P C**: Computed radiography and direct radiography: influence of acquisition dose on the detection of simulated lung lesions. Investigative Radiology 40:249-256 (2005)
5. **Hamer OW, Völk M, Zorger N, Feuerbach S, Strotzer M**: Amorphous silicon, flat-panel, x-ray detector versus storage phosphor-based computed radiography: contrast-detail phantom study at different tube voltages and detector entrance doses. Invest Radiol 38:212-220 (2003)
6. **Bernhardt TM, Rapp-Bernhardt U, Lenzen H, et al**: Diagnostic performance of a flat-panel detector at low tube voltage in chest radiography: a phantom study. Invest Radiol 39: 97-103 (2004)
7. **Obuchowski NA**: Receiver operating characteristic curves and their use in radiology. Radiology 229:3-8 (2003)
8. **Park SH, Goo JM, Jo CH**: Receiver Operating Characteristic (ROC) curve: practical review for radiologists. Korean J of Radiology 5:11-18 (2004)
9. **Strotzer M, Gmeinwieser JK, Völk M, et al**: Detection of simulated chest lesions with normal and reduced radiation dose: comparison of conventional screen-film radiography and a flat-panel X-ray detector based on amorphous silicon. Invest Radiol 33:98-103 (1998)
10. **Goo JM, Im JG, Kim JH, et al**: Digital chest radiography with a selenium-based flat-panel detector versus a storage phosphor system: Comparison of soft-copy images. American Journal of Roentgenology 175:1013-1018 (2000)
11. **Rapp-Bernhardt U, Bernhardt TM, Lenzen H, et al**: Experimental evaluation of a portable indirect flat-panel detector for the pediatric chest: Comparison with storage phosphor radiography at different exposures by using a chest phantom. Radiology 237:485-491 (2005)
12. **Bernhardt TM, Rapp-Bernhardt U, Lenzen H, et al**: Low-Voltage digital selenium radiography: Detection of simulated interstitial lung disease, nodules, and catheters--A Phantom Study. Radiology 232:693-700 (2004)
13. **Launders JH, Cowen AR, Bury RF, Hawkridge P**: Towards image quality, beam energy and effective dose optimisation in digital thoracic radiography. European Radiology 11: 870-875 (2001)
14. **Sandborg M, Tingberg A, Ullman G, Dance DR, Carlsson GA**: Comparison of clinical and physical measures of image quality in chest and pelvis computed radiography at different tube voltages. Med Phys 33:4169-4175 (2006)
15. **Metz CE**: Some practical issues of experimental design and data analysis in radiological ROC studies. Investigative Radiology 24:234-245 (1989)
16. **Chotas HG, Floyd Jr CE, Dobbins 3rd JT, Ravin CE**: Digital chest radiography with photostimulable storage phosphors: signal-to-noise ratio as a function of kilovoltage with matched exposure risk. Radiology 186:395-398 (1993)

다양한 관전압에 따른 CR과 DR 모의병변 흉부 영상의 ROC 평가

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본 연구에서는 다양한 관전압 사용에 따른 CR, DR 모의병변 흉부 영상을 이용하여 병변 검출 정도를 ROC 평가하였다. 모의 제작된 미세 폐 병변, 초기 침윤성 병변, 작은 혹 모양의 병변은 아크릴 판을 이용하여 인체형 흉부 팬텀과 포개 놓고 영상을 획득하였으며 CR과 DR에서 각각 3개의 관전압(70 kV, 90 kV, 120 kV) 조건을 사용하였다. 총 18,000개의 관찰결과를 ROC평가 하였다. CR에서는 모든 병변에 대하여 70 kV로 획득한 영상이 높은 A_z값을 나타내었으나 DR에서는 두 개 병변에서만 70 kV로 획득한 영상이 높은 A_z값을 나타내었다. 본 연구내용을 바탕으로 검출기 종류와 관심 병변에 따른 최적의 관전압 조건을 사용하기 위하여 실제 환자에서의 임상 연구가 필요할 것으로 사료된다.

중심단어: ROC, CR, DR, 관전압, 모의병변