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The Diagnosis of Small Solitary Pulmonary Nodule:
Comparison of Standard and Inverse Digital Images on a High-Resolution Monitor using ROC Analysis[1]

Byeong-Kyoo Choi, M.D., In Sun Lee, M.D., Joon Beom Seo, M.D., Jin Seong Lee, M.D., Koun-Sik Song, M.D., Tae-Hwan Lim, M.D.

Purpose: To study the impact of inversion of soft-copy chest radiographs on the detection of small solitary pulmonary nodules using a high-resolution monitor.

Materials and Methods: The study group consisted of 80 patients who had undergone posterior chest radiography; 40 had a solitary noncalcified pulmonary nodule approximately 1 cm in diameter, and 40 were control subjects. Standard and inverse digital images using the inversion tool on a PACS system were displayed on high-resolution monitors (2048×2560×8 bit). Ten radiologists were requested to rank each image using a five-point scale (1=definitely negative, 3=equivocal or indeterminate, 5=definite nodule), and the data were interpreted using receiver operating characteristic (ROC) analysis.

Results: The area under the ROC curve for pooled data of standard image sets was significantly larger than that of inverse image sets (0.8893 and 0.8095, respectively; $p < 0.05$). Interpretation of both standard and inversion images did not lead to more accurate detection of small pulmonary nodules (area under the ROC curve: 0.8835 and 0.8893, respectively; $p > 0.05$).

Conclusion: For detecting small solitary pulmonary nodules, inverse digital images were significantly inferior to standard digital images.

Index words : Diagnostic radiology, observer performance
Lung, nodule
Radiography, digital

Recent developments in picture archiving and communication systems (PACS) have facilitated the manipulation of soft-copy images using inversion, magnification, and sharpening. During the previous decade, several studies compared standard and inverse-intensity digitized images, using video monitors or film display of 1K×1K (1 - 3). However, their results were controversial. To our knowledge, it is not known whether or how diagnostic quality is influenced by the use of inverse digital images using a high-resolution 2K monitor for the detection of small solitary pulmonary nodules.

The purpose of our study was to compare soft-copy standard (white-bone) images and soft-copy inverse-intensity (black-bone) images to determine their usefulness for detecting small (about 1- cm diameter) solitary pulmonary nodules using a high-resolution monitor.

Materials and Methods

During a period of three years, 40 chest radiographs of

[1]Department of Radiology, Asan Medical Center, University of Ulsan College of Medicine
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Address reprint requests to : Joon Beom Seo, M.D., Department of Radiology, Asan Medical Center, University of Ulsan College of Medicine, 388-1 Poongnap-dong, Songpa-gu, Seoul 138-040, Korea.
Tel. 82-2-3010-4383 Fax. 82-2-476-4719 E-mail: seojb@amc.seoul.kr

patients with a small, non-calcified solitary pulmonary nodule (approximately 1cm in maximum diameter) were collected by reviewing the medical records of our institution. Forty chest radiographs without any pulmonary abnormalities were selected for the control group. CT images of the same study group served as the gold standard. Two Board-certified radiologists with at least eight years ' clinical experience screened each image to insure that the following specifications were met: acceptable diagnostic quality; acquired no more than two weeks before or after CT examinations; no evidence of other pulmonary parenchymal abnormalities. These images were then assigned study identification numbers.

An FCR-9000 unit (Fuji, Tokyo, Japan) was used to obtain all direct digital projectional radiographic images. We used 14×17-inch ST-V imaging plates (Fuji) (202 μm/pixel) with a matrix of 1760×2140×10 bits and a pixel size of 0.2 mm. Each image file was 2 Mbytes in size. The digital data were sent to a PACS server (Radpia; HyndaeTech, Seoul, Korea) and distributed to display workstations. In this study we used a high-resolution video monitor with 2048×2560×8-bit pixels (BARCO; Dataray, Denver, Col., U.S.A.) for soft-copy display. The monitor operated at 71 Hz in an interlaced mode and had a maximum brightness level of 100 foot-lamberts. Inverse digital images were obtained using the inversion tool on the PACS viewer (Radpia; HyndaeTech), and the files were saved separately.

Our study consisted of three sessions: 1) interpretation of standard digital radiographs (standard session); 2) interpretation of inverse digital radiographs (inverse session); and 3) interpretation of both standard and inverse digital radiographs where real-time inversion of the standard image was allowed (combined session). The images in each set were ordered differently. Ten radiologists participated in this study; six of the ten were Board-certified radiologists and the other four were senior residents. All were accustomed to the PACS viewer because they used it in their daily practice. Each was blinded to the patients ' histories and CT findings, and during each session worked independently and separately. Four readers interpreted the standard image set first, while the others interpreted the inverse image set first. The combined session was always last. To diminish learning effects, a minimum of one week was allowed to elapse between each major reading session, and the same image was never shown twice during any session. To simulate the routine clinical interpretation environment, readers were allowed to adjust the brightness and contrast of the images interactively. The use of other tools, such as magnifiers or edge enhancers, was not allowed; all functions needed for interpretation were included in the PACS viewer software. All digital operations were performed using a computer mouse.

The presence or absence of a small solitary pulmonary nodule was evaluated using the following five-grade scoring system: 1 = definitely negative; 2 = probably negative; 3 = indeterminate; 4 = probably positive; and 5 = definitely positive. These responses were recorded and re-sorted by each system for statistical analysis.

Data were interpreted using a LABMRMC receiver operating characteristic (ROC) (4 - 9) (*Chicago University, Charles. E. Metz*). The mean area under the ROC curves (Az value) was compared for each image set using the one-way ANOVA test to determine the best method for detecting a small non-calcified pulmonary nodule. In addition, in order to ascertain the effect of experience on interpreting inverse digital images, the data of the Board-certified radiologists and that of the senior residents were compared.

Results

For each radiologist, the results determined using the ROC are given in Table 1. For all radiologists but only one senir resident, the Az-values obtained during the standard session were greater than those from the inverse session (Fig. 1). The ANOVA test showed that for the inverse session, the Az value was statistically less

Table 1. Summary of Individual Results: Comparison of the Area Under the ROC Curve (Az value) in Each Session

Reader	Area under the ROC curve (Az)		
	Inverse	Standard	Combined
1	0.8836	0.9503	0.9673
2	0.7791	0.8897	0.9005
3	0.8427	0.8918	0.9149
4	0.8205	0.8884	0.9249
5	0.7552	0.8996	0.8737
6	0.8578	0.8653	0.9422
7*	0.9092	0.8949	0.8708
8	0.7952	0.8644	0.7305
9	0.8061	0.9095	0.8702
10	0.6464	0.8394	0.8399

Reviewer 1 - 6: Board-certified Radiologists
Reviewer 7 - 10: Senior Residents in Department of Diagnostic Radiology
*Only one reader who had more greater Az-value in the inverse session than those in the standard session

than for the standard and combined sessions ($p < 0.05$, respectively) (Table 2).

When the standard and combined session were compared, the Az values of the combined session were found by five of the six Board-certified radiologists to be greater than those of the standard session, while combined image interpretation improved the performance of only one of the four senior residents. The radiologists' overall performance was better in the standard than in the combined session, though the difference was not statistically significant.

Discussion

In this study, we found that for detecting small solitary non-calcified pulmonary nodules using a high-resolution monitor, inverse digital imaging is inferior to standard imaging. MacMahon et al. (1) reported that for a variety of radiographic findings, including these of pneumothorax, interstitial disease, bone lesions and pulmonary nodules, diagnostic accuracy was greater with conventional films than with video display, and that standard digitized images were more accurate than inverse images. The authors of that study did not permit reader manipulation of the video controls, window width, or brightness. Oestmann et al. (2) concluded that edge enhancement and image inversion could impair the detection of subtle lung cancers on digitized radiographs of medium resolution. Sheline et al. (3), on the other hand, suggested that inverse imaging may be advantageous for the detection of pulmonary nodules. However, those studies involved the use of hard-copy or digitized images instead of digital image data acquisition on a low-resolution 1K monitor (1 - 3).

With the advent of computer and digital imaging technology, more hospitals with PACS system are now using soft-copy images in clinical practice. To our knowledge,

Table 2. Comparison of Mean Area Under the ROC Curve in Each Session: One-way ANOVA test

Modality	Mean	Duncan	Tukey	p-value
Inverse	0.8095±0.0743	B	B	< .05
Standard	0.8893±0.0297	A	A	> .05
Combined	0.8835±0.0660	A	A	> .05

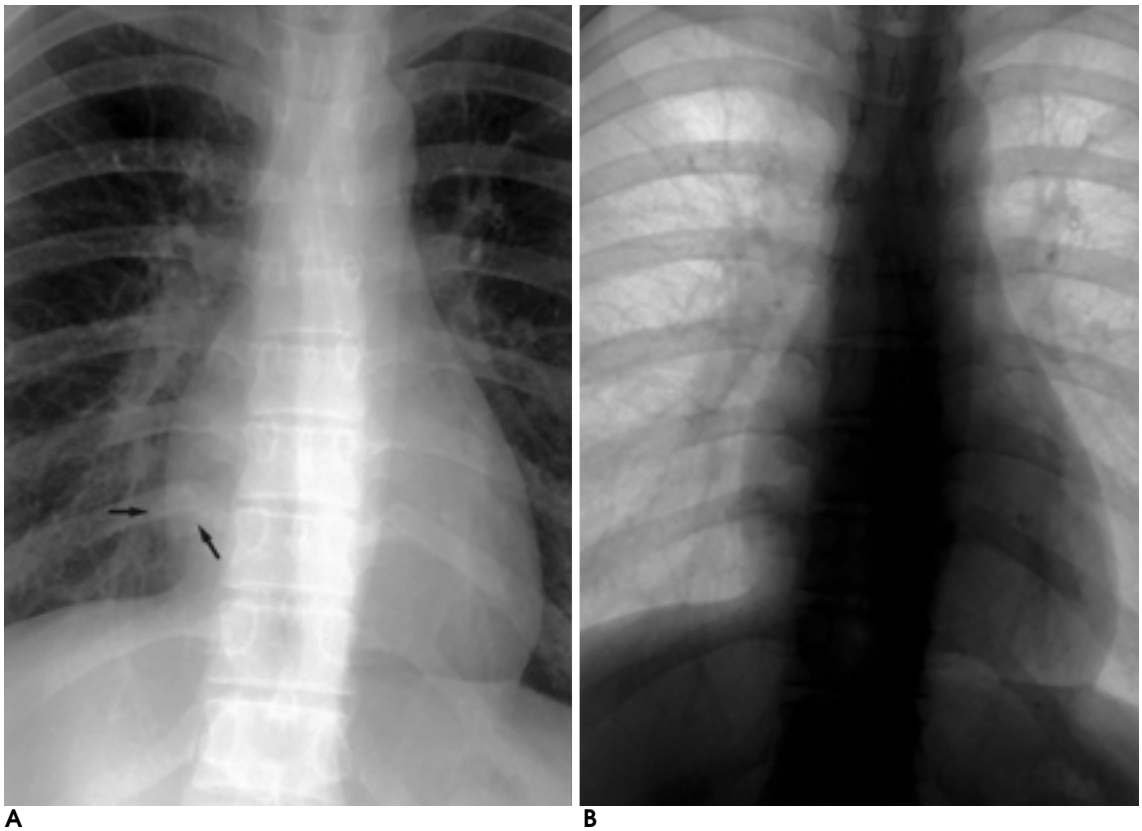

Fig. 1. A case that the readers showed better performance for standard digital image than inverse digital image.
A, B. Standard digital image of chest (**A**) and inverse digital image (**B**) show solitary pulmonary nodule in the right lower lung zone (arrow in **A**). Five of ten reviewers scored 4 or 5 for the standard digital image, where as only two reviewers detected the nodule on inverse digital image.

this is the first study to evaluate the usefulness of soft-copy inverse digital images for detecting small solitary pulmonary nodules using a high- resolution 2K monitor. This study was designed to simulate daily clinical practice: observers used a commercial PACS viewer, and real-time adjustment of contrast and brightness, common in daily practice at our hospital, was allowed.

Our study showed that additional interpretation of inverse digital images does not generally increase the accuracy with which small solitary pulmonary nodules are detected. However, the effect of additional interpretation of these images varied according to the experience of the readers. Although it was not statistically significant, for Board-certified radiologists the Az value of the combined session was higher than that of the standard session. For three of the four senior residents, on the other hand, the Az value of the combined session was lower than that of the standard session. Interpretation of the raw data showed that this phenomenon is probably due to the increased false-positive fraction rate among less-experienced radiologists who they interpret inverse digital images.

There may be several reasons for the inferiority of inverse digital images for detecting small lung nodules. Not all our readers are as accustomed to inverse digital images as they are to standard images, even though we offer a brief teaching session for inverse digital image interpretation. In addition, the inverse digital images initially displayed were not optimized for the detection of pulmonary nodules, whereas the standard images were displayed at optimal brightness and contrast settings, as recommended for our PACS system. Even though observers were allowed to adjust the contrast and brightness, these differences may have affected the results of our study.

In conclusion, soft-copy inverse digital images are inferior to standard images for the detection of small solitary non-calcified pulmonary nodules using a high-resolution 2 K monitor. Additional interpretation of inverse digital images does not improve the outcome.

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단일 소 폐 결절의 진단: ROC 분석을 이용한 고해상도 모니터에서의 고식적 디지털영상과 반전 디지털 영상간의 비교[1]

[1]울산대학교 의과대학 서울아산병원 방사선과

최병규 · 이인선 · 서준범 · 이진성 · 송군식 · 임태환

목적: 저자들은 반전 디지털 영상이 고해상도 모니터에서 단일 소폐결절을 발견하는데 어떤 영향을 주는 지를 알고자 하였다.

대상과 방법: 총 80명의 후 전 디지털 흉부 촬영술을 시행 받은 환자들이 연구 군에 포함되었으며 이중 40명은 석회화가 없고 장 경이 1 cm 내외인 단일 폐결절을 가졌고, 나머지는 정상 대조군 이었다. 표준 디지털 영상과 PACS system에서 반전 기법을 이용하여 획득된 반전 디지털 영상이 고해상 모니터 (2048×2560×8 bit)에서 디스플레이 되었다. 10명의 방사선과 의사가 각 영상에 대하여 5단계 기록법을 이용하여 점수를 주었다 (1=절대음성, 3=불확정, 5=절대양성). 이러한 방법으로 얻어진 결과에 대하여 ROC 분석을 이용하여 어떤 방법이 단일 소폐결절을 발견하는데 있어 우위에 있는지 비교하였다.

결과: 표준 디지털 영상에서 얻어진 ROC 곡선하 면적이 반전 디지털 영상에서 얻어진 면적보다 통계적으로 유의하게 컸다 (각각 0.8893과 0.8095, p - value < 0.05). 표준 디지털 영상과 반전 디지털 영상을 모두 보도록 했을 때도 단일 소폐결절을 발견하는데 정확성을 향상시키지는 못하였다 (곡선하 면적 각각 0.8835와 0.8893, p - value > 0.05).

결론: 단일 소폐결절을 발견하는데 있어, 반전 디지털 영상은 표준 디지털 영상에 비하여 통계적으로 유의하게 좋지 않다.