Detection of Interstitial Lung Abnormalities on Picture Archive and Communication System Video Monitors

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The purpose of this study was to compare the detection of interstitial lung abnormalities on video display workstation monitors between radiologists experienced with video image interpretation and radiologists who lack this experience. Twenty-four patients with interstitial lung abnormalities documented by high-resolution computed tomography (HRCT) and lung biopsy, and 26 control patients with no history of pulmonary disease or a normal HRCT and normal chest radiographs were studied. Images were acquired using storage phosphor digital radiography and displayed on 1,640 × 2,048 pixel resolution video monitors. Five board-certified radiologists evaluated the images in a blinded and randomized manner by using a six-point presence of abnormality grading scale. Three radiologists were from 1 to 4 years out of residency and considered to be experienced workstation monitor readers with between 1 to 3 years of video monitor image interpretation. For the inexperienced readers, one radiologist had no prior experience with reading images from a video monitor and was direct out of residency, and the other radiologist had less than 4 months of intermittent exposure and was 1 year out of residency. Sensitivity and specificity were determined for individual readers. Positive predictive values, negative predictive values, accuracy, and receiver-operating curves were also generated. A comparison was made between experienced and inexperienced readers. For readers experienced with video monitor image interpretation, the sensitivity ranged from 87.5% to 92%, specificity from 69% to 92%, positive predictive value (PPV) from 73% to 87.5%, negative predictive value (NPV) from 87% to 90%, and accuracy from 80% to 88%. For inexperienced readers, these values were sensitivity 58%, specificity 50% to 65%, PPV 52% to 61%, NPV 56.5% to 63%, and accuracy 54% to 62%. Comparing image interpretation between experienced and inexperienced readers, there were statistically significant differences for sensitivity ($P < .01$), specificity ($P < .01$), PPV ($P < .05$), NPV ($P < .05$), accuracy ($P < .05$), and area under the receiver operator curve (Az) ($P < .01$). Within the respective experienced and inexperienced groups, no statistical significant differences were present. Our results show that digitally acquired chest radiographs displayed on high-resolution workstation monitors are adequate for the detection of interstitial lung abnormalities when the images are interpreted by radiologists experienced with video image interpretation. Radiologists inexperienced with video monitor image interpretation, however, cannot reliably interpret images for the detection of interstitial lung abnormalities.

KEY WORDS: picture archive and communication systems, computers, interstitial lung disease.

THE CHEST RADIOGRAPH is usually the first imaging step in the evaluation of patients with suspected interstitial lung disease. Film-screen radiographs have been the mainstay in chest radiography; however, film has certain limitations, the most significant of which is the limited range of optical densities that can be recorded at the same time. This creates a problem in chest radiography, where there are large differences in attenuation between the lung and the mediastinum.[1] Storage phosphor radiography is a form of digital radiography that is slowly replacing conventional film-screen techniques. Digital radiographs have many advantages over film-screen radiographs, including a wide dynamic range, automatic density optimization, and flexible image processing.[2] A drawback of storage phosphor digital images, however, is that they lack the spatial resolution of film-screen systems, which could affect detection of fine linear abnormalities such as septal lines, pneumothorax, and interstitial lung disease.[3] Previous studies of the performance of storage phosphor radiography in the evaluation of interstitial lung disease have focused on the comparison of film-screen systems to hard copy storage phosphor images.[2-4] No studies have been found that directly evaluate only video monitor interpretation with pathologically proven interstitial disease. Since these prior studies, workstation video monitors have advanced to the point where there is little loss of spatial

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information when digital images are displayed on video screens.[1] Workstation video monitors have the advantage of allowing the radiologist to manipulate the digital image to improve its appearance while it is viewed. Unfortunately, video monitors lack the luminance of a standard viewbox. As a result, image contrast is decreased, and the image is also adversely affected by ambient light to a greater degree than radiographs displayed on a viewbox.[5-7] The use of workstation video monitors introduces another variable in the debate regarding the interpretation of digitally acquired chest radiographs for the evaluation of interstitial lung abnormalities. We compared the detection of interstitial lung abnormalities on video display workstations between radiologists with at least 1 year's experience with workstation image interpretation and those who lacked this experience.

PATIENTS AND METHODS

Study Group

The study group consisted of 50 patients who underwent posteroanterior and lateral storage phosphor digital radiography of the chest. Because our institution uses only computed radiography for image interpretation, conventional film-screen radiographs were not available for all patients. Therefore, comparison with film-screen chest radiographs was not performed. Twenty-four patients had interstitial lung abnormalities documented by high-resolution computed tomography (HRCT) and lung biopsy (14 men and 10 women; age range, 27 to 76 years; average age, 57.5), and 26 patients had no history of underlying lung pathology or a normal HRCT, and a normal digital chest radiograph (20 men, and 6 women; age range, 24 to 59 years; average age, 45). Normal images were interpreted separately as normal before inclusion in the study by an independent board-certified radiologist reading the images on a video workstation monitor. Of the 24 patients with interstitial lung abnormality, there were 19 cases of nonspecific interstitial inflammation or fibrosis, two cases of usual interstitial pneumonitis, one case of sarcoidosis, one case of idiopathic pulmonary hemosiderosis, and one case of lymphangitic spread of cancer. Varying severity of interstitial lung abnormalities were represented by this group.

Image Acquisition and Display

All storage phosphor digital images used for the study were acquired using the same exposure technique: 120 kVp, 72-inch film focus distance, a 12:1 stationary grid, and a phototimed exposure. At our institution, after exposure the storage phosphor imaging plates (ST-V; Fuji, Kanagawa, Japan) are scanned by a helium-neon laser into a 0.2-mm matrix, and luminescent radiation is emitted. This emitted light is detected by photomultiplier tubes, which convert the emitted light into an analog electrical signal. A histogram of this electric signal profile is analyzed by an exposure data recognizer (EDR) to maximize information from only the image data contained in the profile. The EDR will select minimum and maximum histogram values used for image normalization based on a standard preselected profile that provides an approximate representation of the location and magnitude of signal variations for the specific type of imaging examination (in this case, the chest radiograph). A pattern recognizer for iris of exposure field (PRIEF) scans the profile before the EDR to detect image collimation borders beyond which the profile contains nonimage information. After EDR reading, the useful image information contained within the electronic profile is digitized into 10 bits or 1,024 levels of gray scale.

Through the use of the EDR and PRIEF, image density is consistently reproducible over a wide range of exposures. Digitized images are then stored on a Kodak Model 6800 optical juke box (Rochester, NY), which form the storage unit of the Medical Diagnostic Imaging Support picture archiving and communications system (PACS) system in use at our institution (Loral Medical Imaging Systems, Hoffman Estates, IL). Images are displayed on a PACS interactive workstation video monitor with a 1,640 × 2,048-pixel matrix and 10-bit resolution. No postprocessing of the image occurs before display on the video workstation. Using a computer mouse, manipulation of the image can be performed by the radiologist at the workstation when the image is viewed. Compression algorithms (10:1) are used for storage of digital images in the permanent archive, and this compression is not reversible. Images used for interpretation in this study were retrieved from the permanent archive before display on the workstation monitor. All images were placed into a single reading folder at the workstation to be read independently of the daily work routine.

Reading Methods

Images were independently interpreted by five board-certified general radiologists. Three radiologists, with between 1 and 4 years postresidency experience, had between 1 and 3 years of experience reading digital images from workstation video monitors. These individuals composed the experienced reader group. In the inexperienced reader group, one radiologist just out of residency had no prior experience with video monitor image interpretation, and the other radiologist, 1 year out of residency, had less than 4 months of intermittent exposure to the system while in training as a nuclear medicine fellow. The inexperienced readers were given a brief instruction period regarding operation of the system before initiation of image interpretation. The images were intermixed in random order in a single reading folder, and the readers were instructed to subjectively interpret the radiographs for only the presence or absence of interstitial lung disease. To aid in interpretation of the radiographs, the readers were asked to subjectively grade the severity of interstitial abnormalities on a six-point grading scale (0 = definitely negative, 1 = minimal prominence to the interstitial markings, 2 = mild, but definite interstitial prominence, 3 = moderate interstitial prominence, 4 = severe interstitial prominence, and 5 = end-stage interstitial lung disease). No limit was imposed on the reading time, and the radiologists were encouraged to manipulate the images on the monitor as they normally would for examination interpretation to include altering gray scale and magnification. All images were interpreted in one reading session. No timing of individual interpretations was done.

Data Analysis

Readers' interpretations were characterized as negative (grade 0) or positive (grades 1 to 5) concerning whether interstitial lung disease was present. Sensitivity, specificity, positive predictive value, negative predictive value, and accuracy were determined from the individual data. Observer performance was tested according to receiver-operating characteristic (ROC) analysis. Perceptual accuracy was described by the area under the ROC curve (Az). Comparison was made between experienced and inexperienced readers using the chi-square test. The kappa value allows an upper limit of 1.0 with perfect agreement. A kappa value greater than 0.75 was considered excellent agreement, between 0.40 and 0.75 good agreement, and less than than 0.40 was poor agreement between readers.

RESULTS

Individual reader interpretations for each case are presented in Tables 1 and 2. Summarized results are tabulated in Table 3. The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), accuracy, AZ, and kappa values are given in Table 4.

There were statistically significant differences in the ability of the experienced readers to detect interstitial lung abnormalities when compared with the inexperienced group: sensitivity ($P < .01$), specificity ($P < .01$), PPV ($P < .05$), NPV ($P < .05$), accuracy ($P < .05$), and Az ($P < .01$). Within the respective experienced reader (n = 3) and the inexperienced reader (n = 2) groups, no statistically significant differences were present.

Table 1. Severity Grading of Patients With Interstitial Abnormalities

Case	Diagnosis	1 E	2 E	3 E	1 I	2 I
1	IPF	3	2	3	3	0
2	Sarcoid	1	1	1	4	4
3	IPF	5	3	5	3	2
4	IPF	4	3	4	4	3
5	IPF	3	4	3	1	0
6	IPF	3	2	3	4	3
7	IPF	2	2	2	2	2
8	IPF	1	1	1	0	0
9	UIP	1	2	1	4	4
10	IPF	0	0	0	2	2
11	IPF	2	1	2	0	0
12	IPF	4	4	4	0	0
13	LM	4	4	4	1	0
14	IPF	5	4	5	0	0
15	IPF	0	0	0	0	2
16	IPF	3	3	3	0	0
17	IPF	3	4	3	2	2
18	UIP	4	3	3	0	0
19	IPH	2	1	2	4	1
20	IPF	3	2	2	3	3
21	IPF	1	1	3	0	2
22	IPF	2	2	2	1	1
23	IPF	2	0	2	0	3
24	IPF	2	1	2	0	0

Abbreviations: E, experienced reader; I, inexperienced reader; IPF, idiopathic pulmonary fibrosis; IPH, idiopathic pulmonary hemosiderosis; UIP, usual interstitial pneumonitis; LM, lymphangitic metastases.

Table 2. Severity Grading of Patients With Normal Chest Radiographs

Case	1 E	2 E	3 E	1 I	2 I
1	0	0	0	3	2
2	0	0	0	4	4
3	0	0	0	2	0
4	0	0	0	4	2
5	0	0	0	4	4
6	1	0	1	0	0
7	0	0	0	4	3
8	0	0	0	4	3
9	0	0	0	2	0
10	0	0	0	0	0
11	0	0	0	3	3
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	1	0	0
16	0	0	0	1	0
17	0	1	0	0	0
18	0	1	0	0	2
19	0	1	1	0	2
20	0	2	1	2	0
21	0	0	2	2	0
22	1	1	3	0	0
23	0	0	3	0	0
24	0	0	0	0	0
25	0	1	3	0	0
26	0	0	0	1	0

Abbreviations: E, experienced reader; I, inexperienced reader.

DISCUSSION

With the expansion in the use of digital imaging, there has logically followed a growing interest in the development of PACS and video monitor image display. PACS applies digital technology to the problems of film storage and printing. By storing digitized images on an optical disc, PACS expedites access to radiographic images, prevents image loss, and allows multiple physicians at different

Table 3. Individual Reader Results

Reader	1 E	2 E	3 E	4 I	2 I
TP	22	21	22	14	14
FP	2	6	8	13	9
TN	24	20	18	13	17
FN	2	3	2	10	10
Total	50	50	50	50	50

Abbreviations: E, experienced reader; I, inexperienced reader.

Table 4. Individual Reader Results

Reader	SENS	SPEC	PPV	NPV	Accuracy	Az	Kappa
1 E	0.875 (±0.014)	0.88 (±0.13)	0.875 (±0.14)	0.88 (±0.12)	0.88 (±0.1)	0.923	0.76 (±0.18)
2 E	0.875 (±0.14)	0.77 (±0.17)	0.78 (±0.16)	0.87 (±0.15)	0.82 (±0.11)	0.885	0.641 (±0.21)
3 E	0.92 (±0.12)	0.69 (±0.19)	0.73 (±0.16)	0.90 (±0.14)	0.80 (±0.11)	0.861	0.603 (±0.21)
4 I	0.58 (±0.2)	0.50 (±0.20)	0.52 (±0.20)	0.565 (±0.22)	0.54 (±0.14)	0.538	0.083 (±0.27)
5 I	0.58 (±0.2)	0.65 (±0.19)	0.61 (±0.21)	0.63 (±0.19)	0.62 (±0.14)	0.598	0.238 (±0.27)

Abbreviations: E, experienced reader; I, inexperienced reader.

locations to view the same images simultaneously.[8] Video workstation monitors form the display apparatus for images stored on PACS. These workstations offer the radiologist the opportunity to further manipulate gray scale and contrast while interpreting the image, thereby taking full advantage of the wider contrast resolution offered by digital imaging.[3] Despite these benefits, digital imaging and the video monitors used for digital image display lack the resolution that can be achieved with film-screen radiographic systems. Additionally, video monitors suffer from decreased luminance compared with standard viewboxes, display fewer levels of gray scale compared with film-screen systems, and may be adversely affected by random and structural noise associated with the video electronics.[5-7] As a result of these drawbacks, there is justifiable concern that digital images displayed on video monitors may lack the ability to resolve the fine linear abnormalities that characterize early interstitial lung disease.

The results of our study indicate that the overall detection of interstitial lung abnormalities is not compromised by the display of storage phosphor digital images on high-resolution video monitors when the images are interpreted by radiologists experienced with video monitor image interpretation. Sensitivities for experienced readers in the detection of interstitial lung abnormalities ranged from 87.5% to 92%. Similarly, the exclusion of interstitial lung abnormalities was also very good, with specificity ranging from 69% to 88%. These numbers appear to correlate very well with sensitivity of 78% and specificity of 70% using film-screen radiography.[3] Inexperienced readers, however, demonstrated a dramatically decreased sensitivity (58% for each reader) and decreased specificity (50% to 64%). Differences between the experienced and inexperienced group were statistically significant for both sensitivity and specificity ($P < .01$).

The severity of interstitial changes were further characterized during image interpretation based on a defined scoring method. Detection of interstitial lung abnormalities using digital radiography has previously been shown to increase with increasing disease severity.[3] In our study, experience was shown to affect the detection of interstitial lung abnormalities at all levels of severity. Interstitial lung abnormalities were correctly identified in a total of 65 of the 72 interpretations by the experienced group. In 22 of the 24 cases of interstitial lung abnormalities, experienced readers assigned severity grades that were the same or within one grade of each other (Table 1). There was generally good consensus among the experienced readers even for cases that would be considered to demonstrate the presence of mild interstitial abnormality (grade 1 or 2). This suggests that once a standard threshold is learned, it is very reproducible. Results were less favorable for the inexperienced reader group, which correctly identified interstitial abnormalities in only 28 of 48 interpretations.

In this study, statistical data were determined based on the assumption that all the patients with HRCT and biopsy-proven interstitial lung abnormality enrolled in this study had a detectable radiographic abnormality. Based on this assumption, there were a total of seven false-negative interpretations in which the presence of interstitial lung abnormality was not identified by the experienced reader group. These false-negative interpretations involved only three patients from the study group with interstitial abnormalities ($n = 24$; $3/24 = 12.5\%$). In two cases, all of the experienced readers graded the examination as normal (0), and in one case two of the experienced readers detected interstitial abnormalities, but one did not. Prior reports have shown that film-screen radiographs can appear normal in 9.6% of patients with chronic diffuse infiltrative lung disease.[9] Although patients with false-negative examination interpretations may have had very subtle interstitial changes that went undetected, it is also possible that these patients had normal chest radiographs based on prior studies of interstitial lung disease.[9] In fact, on review of the original interpretation of the chest radiograph in these individuals, all were interpreted as normal.

In contrast to the experienced reader group, there were 20 false-negative interpretations by the inexperienced reader group, which involved 13 different patients. Seven of these patients were interpreted as having normal radiographs by both inexperienced readers. Of these seven cases, three involved patients in which the experienced reader group believed that the patients demonstrated mild interstitial abnormalities (grade 1 or 2); however, there were four cases in which experienced readers believed that more severe abnormalities were present (grade 3 or higher). This finding most likely reflects the lack of an appropriate threshold for the inexperienced readers to distinguish normal from abnormal digital video images.

Because of the consistent reproducibility of image contrast and density over a wide range of exposures with the use of storage phosphor digital images, we have noted that the lung markings are typically better visualized on digital chest radiographs than on film-screen images. Our initial concern was that with improved visualization of the lung markings, there would be a tendency to incorrectly associate this finding with the presence of interstitial lung disease. There were 16 false-positive interpretations made by the experienced reader group, which involved 10 patients. All three experienced readers incorrectly interpreted one examination as positive for interstitial lung abnormality, and there were five cases in which two of the three readers incorrectly concurred. There were 22 false-positive interpretations made by the inexperienced readers, which involved 15 patients. Generally, experienced readers assigned a lower severity grade to their false-positive cases than the inexperienced reader group (Table 2). For the experienced group, there were 11 false-positive cases with a grade of 1, two cases with a grade of 2, and three with a grade of 3. For the inexperienced group there were two cases with a grade of 1, eight with a grade of 2, five with a grade of 3, and seven with a grade of 4.

Because radiologists in this study were instructed to evaluate the images for the presence of interstitial lung disease, there may have been a bias toward identifying subtle findings that might ordinarily be overlooked. Even with this possible bias, the number of false-positive readings in our study was reasonable, and the specificity for the experienced reader group ranged from 69% to 92%. These specificities compare favorably with that reported in other studies.[3] Therefore, when interpreted by radiologists with experience in the use of the high-resolution video workstations, the use of video monitors for digital image display does not affect the exclusion of interstitial lung abnormalities in healthy patients.

Images used for interpretation in this study were retrieved from the PACS archive before display. Data compression (10:1) is used when images are stored in the archive, and this compression is not reversible. Image storage without compression would not be practical, because it would require a large amount of computer memory. Some degree of image degradation is produced through the use of compression; however, compression ratios of 10:1 or even greater have not been shown to affect the diagnostic value of the images.[10] The results of our study would also suggest that image compression ratios of 10:1 do not affect the diagnostic quality of the images.

Although we have found that video monitors can be used to adequately detect the presence of interstitial lung abnormalities, these findings may not be applicable to all institutions. The video monitors used for image interpretation in this study were 1,640 × 2,048 pixel matrix. Lower-resolution monitors, 512 × 512 or 1,024 × 1,024 pixel matrix, are available; however, it has been concluded that a minimum of 1,750 pixels that are 0.2 mm in diameter are required to reproduce the detail of a chest radiograph adequately.[7] The use of lower-resolution monitors may not provide the same sensitivity in the detection of interstitial lung disease; however, the evaluation of low-resolution monitors was beyond the scope of this project.

CONCLUSION

Our results suggest that phosphor storage images displayed on high-resolution video monitors are capable of the detection of even mild interstitial lung disease when the images are interpreted by radiologists experienced with video monitor image interpretation. Radiologists not experienced with video image interpretation showed a statistically significant decreased ability to distinguish normal from abnormal examinations. The length of experience needed to develop these skills was not evaluated, although the inexperienced radiologists relate that they quickly began to feel more comfortable the more they used the workstation. Digital radiology and video display workstations are very expensive to implement and are limited to only a small number of institutions. Despite this fact, with the enhanced image access, storage convenience, and cost savings from decreased repeat and lost studies, PACS seems to be an attractive alternative to current film-based systems. With continued improvement in digital technology, video display, and decreasing costs, digital radiography and video display most likely represent the future of radiographic imaging. Awareness of the limitations of video image interpretation will lead to a more effective use of this new technology.

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