

Comparison of Digital Direct Readout Radiography with Conventional Film-screen Radiography for the Recognition of Pneumoconiosis in Dust-exposed Chinese Workers

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Abstract: Comparison of Digital Direct Readout Radiography with Conventional Film-screen Radiography for the Recognition of Pneumoconiosis in Dust-exposed Chinese Workers: Ling Mao, et al. Department of Pneumoconiosis, Shanghai Pulmonary Hospital, Tongji University School of Medicine, China—Objectives: Pneumoconiosis in China remains a disease with substantial public health significance. Diagnostic standards for the pneumoconioses are based on traditional film-screen radiography (FSR). However, FSR is increasingly being replaced with digital radiographic imaging, which has become the predominant technology available in Chinese clinical practice. To evaluate the applicability of digital direct readout radiography (DR) images in the recognition of pneumoconioses, we compared the profusion of small opacities and large opacities between FSR and DR radiographs. **Methods:** We enrolled 161 pneumoconiosis patients and 31 dust-exposed workers during the course of the study, with FSR and DR images obtained from all participants. Each chest film was interpreted by five readers using the Chinese Diagnostic Criteria classification of radiographs of pneumoconiosis, as were DR images displayed on medical-grade computer monitors. **Results:** No statistically significant differences were observed when the data were analyzed by small opacity profusion subcategory except for 1/1. The overall intermodality agreement of small opacities was good, with a weighted kappa (κ) of 0.77. **Conclusions:** DR images with soft copy display are equivalent with respect to image quality and the

recognition and classification of small parenchymal lung opacities. Additionally, we observed likeness between modalities with respect to the classification of large opacities. Overall, our study findings demonstrate that in a population of Chinese workers with pneumoconiosis, direct readout digital systems are equivalent to traditional film-screen radiography in the recognition and classification of small pneumoconiotic opacities. (J Occup Health 2011; 53: 320–326)

Key words: Chest radiograph, Digital radiography, Physician, Pneumoconiosis, Radiography, Small opacity

Recent reports have highlighted the importance of the adoption of digital imaging techniques in the context of the International Labour Office (ILO) classification of radiographs of pneumoconiosis, as clinical facilities are increasingly abandoning traditional film-screen radiography (FSR)^{1–4}. The diagnosis of pneumoconiosis in China is based primarily upon radiographic findings using the Chinese Diagnostic Criteria of Pneumoconiosis⁵. These criteria, and the accompanying standard radiographic films, are largely analogous to the ILO classification system⁶. Small opacity profusion is identical between the systems (using the 12 subcategory scale) except that small opacity profusion is first independently classified in each of the six lung zones in the Chinese classification system. Valid correspondence between the Chinese and ILO systems has been observed in the past⁷.

Medical screening of workers exposed to hazardous dusts is mandated by Chinese national regulations. These periodic medical examinations, which include physical examination and chest radiography, are intended for the early diagnosis of pneumoconiosis leading to clinical management and removal from further exposure and are

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Table 1. Image technical quality

Quality	Film-screen	Digital
Good	161 (68.5%)	213 (90.6%)
Acceptable, no defects	20 (8.5%)	13 (5.5%)
Acceptable, some defects	14 (6.0%)	4 (1.7%)
Unacceptable	40 (17.0%)	5 (2.1%)

Includes initial 235 study subjects. The 45 unacceptable quality images were from 43 individuals, and all images (both FSR and DR) obtained from those subjects were excluded from subsequent analysis.

made by government-authorized diagnostic panels usually comprised of radiologists, pathologists, pulmonologists and occupational physicians⁸). Radiography remains an essential tool in the identification of pneumoconiosis. However, the diagnostic standards are based upon traditional film-screen technologies.

The move to digital imaging modalities may be even more accelerated in urban China than many parts of the Western world⁹). Pneumoconioses are the most important occupational lung diseases in China, with 10,000–15,000 incident cases reported annually and an estimated lower bound of 520,000 current workers afflicted⁸). In recent years, it has been reported that the pneumoconioses represent 70–80% of the total number of cases of occupational diseases in China¹⁰). The burden of the pneumoconioses in China along with the mandated national screening of dust-exposed workers has necessitated high throughputs. Efficiency in Chinese radiology departments is necessary and highly valued. Digital technologies, particularly direct readout digital systems (DR), are thus considered essential in many urban centers attempting to keep up with the demands of increasing patient populations⁹).

The practical role of digital radiographs in the diagnosis and management of pneumoconiosis in China is clear. However, as with the ILO system, the established method for interpretation of radiographs for pneumoconiosis in China is based upon traditional film-screen radiography. It has been previously noted that the need for equivalence studies is imperative to understand the implications of applying the FSR-based standards to new digital technologies^{1, 3, 11}). Our goal is to address that need and expand the current research to include comparisons in a Chinese patient population. To our knowledge, this is the first study to compare FSR with digital radiography in the recognition of pneumoconiosis using the Chinese classification system (GBZ 70-2002).

Materials and Methods

Subjects

Study subjects were recruited from two sources, the Shanghai Pulmonary Hospital pneumoconioses registry and the dusty work registries. Annual medical examinations

are required of individuals listed in either registry. Between February 2008 and June 2008 all patients with preexisting pneumoconiosis presenting for their annual medical evaluation were invited to participate (n=204). In addition, 31 dust-exposed workers without pneumoconiosis were enrolled. The Shanghai Pulmonary Hospital institutional review board approved the project, and each study participant gave written informed consent. One FSR and one DR image were acquired from each of the 235 study participants within the study period (February 2008 through June 2008). Patients with recognized respiratory comorbidities (e.g., tuberculosis) were excluded from study enrollment. A total of 43 image pairs were excluded from analysis, as at least one image (FSR or DR) in each of the pairs was classified as being of unacceptable quality for the purposes of classification (Table 1).

Image acquisition

FSR and DR images were acquired separately within the range of one day to three months. For each subject, standard posteroanterior FSR and DR images were obtained in the radiology department of the Shanghai Pulmonary Hospital. Protocols for acquiring DR and FSR images for this study were developed to ensure that uniform techniques were employed and to maintain detailed records of the examinations.

The protocol for capturing FSR chest images was as follows. Standard posteroanterior chest FSR was employed: 120–140 kVp, 200–250 mA, photo timer 10–20 msec, 180 cm source-to-image distance, all three photo timer sensors, Kodak medical X-ray film MXB (Eastman Kodak Company) in a Kodak cassette with blue screen. A 10:1 scatter rejection grid with 40 grid lines/cm and a 180 cm focus was employed. Exposed film was developed in an automatic processor using the standard 90-second cycle and Kodak H&D chemistry, and the film was then placed in the patient's film folder. After clinical interpretation, the individual identifiers on the film were covered with opaque tape, and a unique subject identifier number was written on the tape.

The protocol for capturing DR chest images was as follows. Images were captured on the flat-panel amorphous

silicon digital detector of a GE Definium 8000 system (GE Healthcare, Wauwatosa, WI, USA) with the following settings: 120 kVp, 320 mA and a 72" (183 cm) source-to-image distance with left and right (lung field) phototimer sensors. A 13:1 scatter rejection grid with 70 grid lines/cm and a 180 cm focus was employed. The GE Healthcare detector has a pixel size of 200 μm . The image array size is 2,000 \times 2,000 pixels (41 \times 41 cm). The kVp, exposure time, and mAs were recorded on the patient record sheet. The digital image was archived. Subject identifiers were stripped out of the Digital Imaging and Communications in Medicine (DICOM) header of DR image files, a unique subject identifier number was inserted into the header, and the deidentified DICOM file was stored for research purposes. The final digital images were generated using the standard image processing settings for PA chest radiographs on the GE DR system. The GE DR Definium 8000 settings were as follows: anatomy=chest, view=posteroanterior, image type=standard, patient size=small or medium or large, contrast adjust=116%, brightness adjust=164%, tissue contrast=0.02, edge=4; noise reduction=none, area=20% and strength=49% for TE under-penetrated, and area=6% and strength=13% for TE over-penetrated.

Image reading

FSR images were displayed on a standard 3-gang X-ray view box side-by-side with selected standard films. DR images were displayed using high-resolution physician-quality workstations, and the standard films were displayed on the 2-gang view box beside the HR workstations. The physician-quality workstations employed a 2 DOME E5 and EBM server PACS system, and had a resolution of 2,048 \times 2,560 pixels and a maximum luminance of 750 $\text{cd}\cdot\text{m}^{-2}$ (500 $\text{cd}\cdot\text{m}^{-2}$ for a fully white screen). The viewing software included display functions such as window level and width (brightness and contrast) adjustment, continuous zoom, user selectable zoom factor, full resolution and full view image presentation, magnification, and a region-of-interest measurement tool with mean pixel value and standard deviation readings. The brightness and contrast of the monitors were calibrated to satisfy the Digital Imaging and Communications in Medicine (DICOM®) grayscale standard display function. Readers were able to control the displayed brightness and contrast of each individual image via the window level and width settings on the workstation. They also could change the magnification when reading the DR images.

Image classification

FSR and DR images were interpreted by five readers according to the Chinese Diagnostic Criteria of Pneumoconiosis GBZ 70-2002⁵⁾. The images were reviewed simultaneously by all five readers, though readers independently recorded profusion scores. All five

readers were from the pneumoconiosis department of the Shanghai Pulmonary Hospital. The interval between reading sessions was one to three weeks. For each session, 5 to 30 images were read with the order of images presented randomly, and the readers were blinded to the results of the other readers' interpretations. The FSR and DR images were presented at separate reading sessions. Each reader classified small opacity profusion in each of the six lung fields. A small opacity final determination was rendered for each zone as the median of the five readings. All other factors were recorded in a similar manner including the shape/size of small opacities (recorded as the predominate shape/size for the entire radiograph), the presence of large opacities and pleural involvement. Large opacities were recorded by lung (left and right) in both modalities. For the purposes of this analysis, large opacities were treated dichotomously as the presence of any large opacity versus none. For large opacities, the final determination was comprised of the consensus values for the five readers. All participating readers had passed an examination that is analogous to the NIOSH B Reader Examination in the United States of America and were certified by the National Institute of Occupational Health and Poison Control, Chinese Center for Disease Control and Prevention, as demonstrating proficiency in classifying radiographs of the pneumoconioses.

Statistical analysis

Cicchetti-Allison weighted kappa values were used to examine FSR/DR intermodality agreement¹²⁾. *p*-values presented are 2-sided Mantel-Haenszel chi square unless otherwise noted as Fisher's exact. All analyses were performed using the SAS statistical software package version 9.1 (SAS Institute, Cary, NC, USA).

Results

Image quality

In total, 235 study subjects contributed one FSR and one DR image. Image quality for the 470 radiographs is presented in Table 1 by FSR and DR. In total, 45 radiographs were classified by the panel as being of unacceptable quality for the purposes of classification (40 FSR, 5 DR). Significantly more FSR images were unacceptable for classification purposes than DR images ($p<0.001$). The 45 unacceptable quality images were from 43 individuals (2 subjects had unacceptable FSR and DR images), and all images (both FSR and DR) obtained from those subjects were excluded from subsequent analysis.

Study subjects

Of the 192 study subjects remaining, 183 (95.3%) were male and 161 (83.9%) had a diagnosis of pneumoconiosis prior to enrollment into the study. The mean age of the study participants was 55.7 yr. The subjects without a

prestudy diagnosis of pneumoconiosis were comprised of welders (90.3%) and foundry workers (9.7%). Table 2 lists the dust exposures in the remaining study subjects.

Profusion of small opacities between FSR and DR modalities

Profusion of small opacities was recorded in each of six lung fields for every radiograph. In the present study this yielded 1,152 profusion comparisons. The distribution of small opacities is displayed by modality in Fig. 1. No statistically significant differences were observed when

Table 2. Types of dust exposure in subjects with pneumoconiosis prior to study enrollment

Type of dust exposure	Number (%)
Silica	94 (48.9)
Welding fume	61 (31.8)
Foundry dust	16 (8.3)
Mixed dust	5 (2.6)
Asbestos	4 (2.1)
Carbon black	3 (1.6)
Coal mine dust	3 (1.6)
Talcum powder	2 (1.0)
Mineral wool dust	2 (1.0)
Alumina	2 (1.0)

the data were analyzed by subcategory except for subcategory 1/1. However, the actual difference between modalities in the 1/1 subcategory was statistically borderline ($p=0.04$) and of little practical difference (prevalence ratio=1.2; 95% confidence interval, CI=1.0–1.4). Overall, for the 1,152 profusion comparisons made, the inter-modality agreement was good with a weighted kappa (κ) of 0.77 and 95% CI of 0.75–0.80 (Fig. 1, embedded table).

Small opacity profusion was similarly distributed between the left and right lungs by zone (Fig. 2). Intermodality agreement was highest in the upper zones ($\kappa=0.82$; 95% CI=0.77–0.86), intermediate in the middle zones ($\kappa=0.75$; 95% CI=0.71–0.79), and lowest in the lower zones ($\kappa=0.68$; 95% CI=0.63–0.73). The difference in weighted kappa values by lung zone may be related to differences in the overall distribution of opacities by zone. The upper fields had significantly more 0/0 classifications than the middle and lower zones.

Small opacity shape/size designations between modalities

The frequencies and percentages of the shape and size designations of small opacities are presented in Table 3. The majority of small opacities were classified as rounded (93.7% FSR and 90% DR), and the distribution of shape did not significantly differ between FSR and DR.

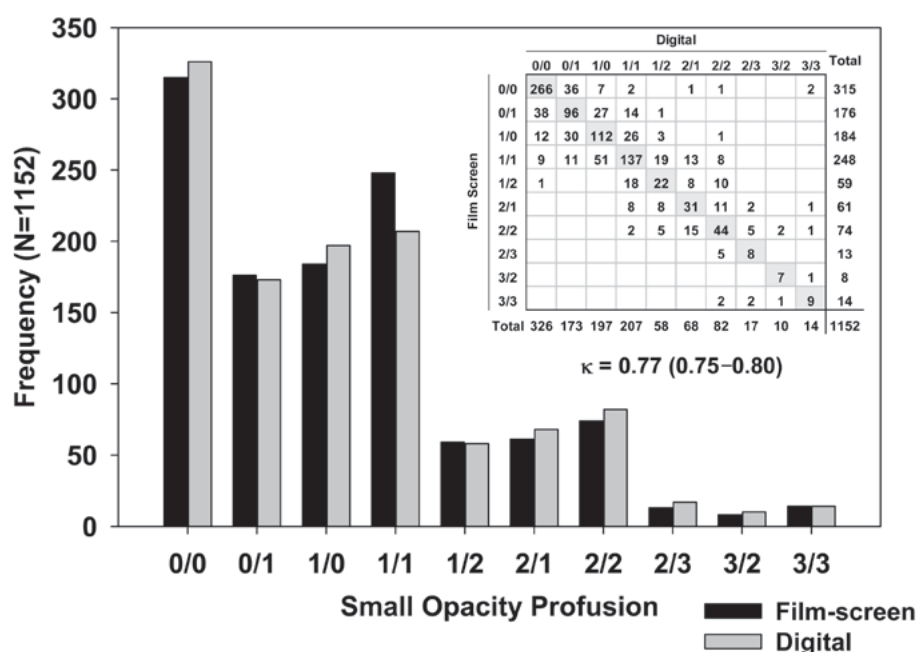


Fig. 1. Profusion of small opacities by lung zone and imaging modality for 192 study subjects. For each radiograph, profusion was recorded in each of the six lung fields for a total of 1,152 classifications each for digital and film-screen. The embedded table represents film-screen and digital agreement pairs. κ : Cicchetti-Allison weighted kappa.

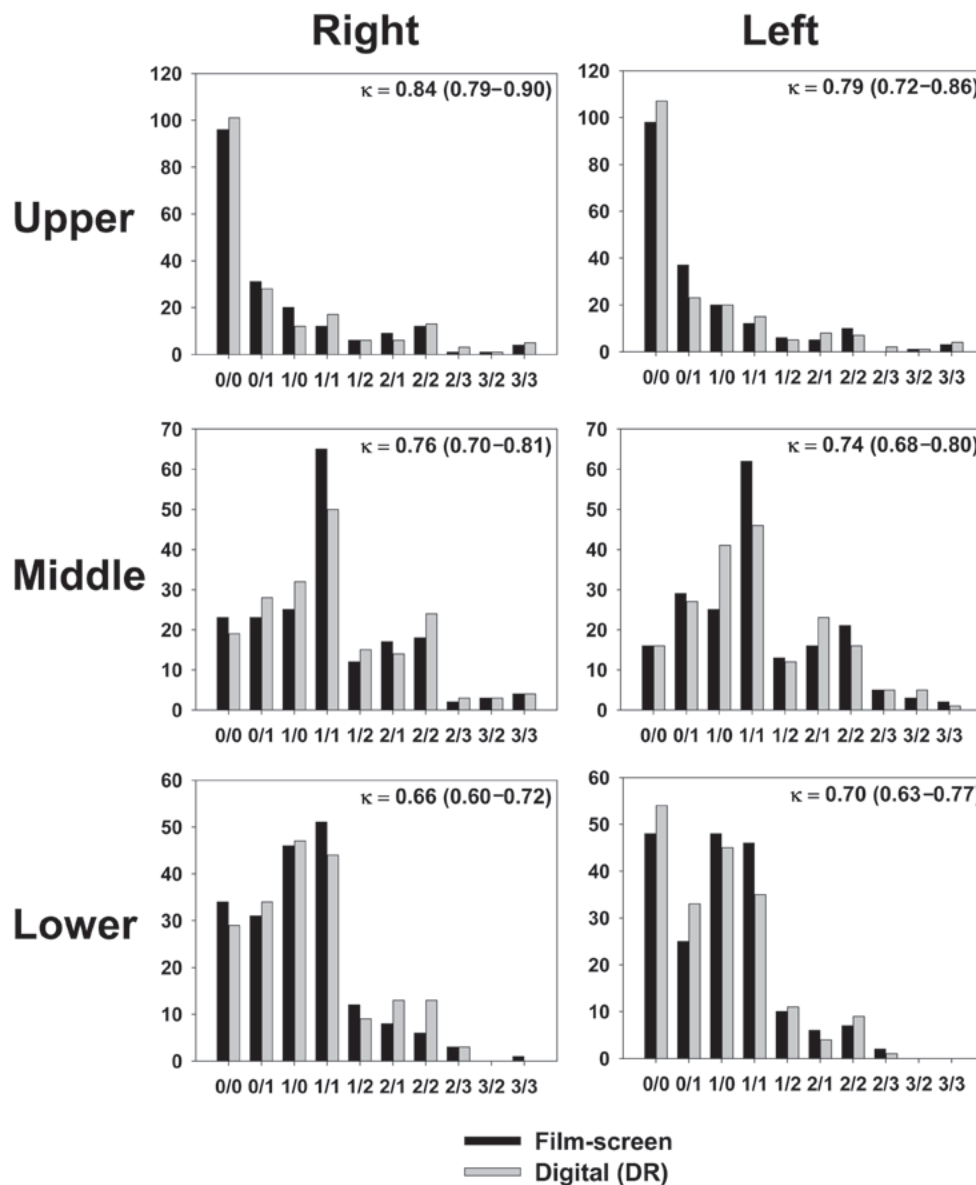


Fig. 2. Profusion of small opacities by lung zone and imaging modality for 192 study subjects. κ : Cicchetti-Allison weighted kappa values.

Large opacities and pleural abnormality

Complete agreement was achieved in the recognition of large opacities between modalities, with 23% (44/192) of radiographs classified as having at least one large opacity with FSR and DR and in the same 44 study subjects. In addition, agreement between modalities was achieved with respect to the location of large opacities. Readers identified 35 large opacities in the left lungs and 42 in the right lungs in both FSR and DR. Pleural abnormalities were observed in two study subjects. One showed calcification of the diaphragmatic dome, and the other showed diffuse pleural thickening with calcification.

These observations were noted in both FSR and DR modalities.

Discussion

Our findings indicate that radiographs obtained using direct readout digital systems with soft copy display are equivalent with respect to image quality and the recognition and classification of small parenchymal lung opacities. Additionally, we observed equivalence between modalities with respect to the classification of large opacities. These findings are consistent with recent studies assessing parenchymal abnormalities comparing FSR and digital

Table 3. Primary shape and size of small opacities for 190 study subjects

Shape/Size	Film-screen	Digital	<i>p</i> -value
p	121 (63.0)	122 (63.5)	0.92
q	48 (25.0)	42 (21.9)	0.47
r	8 (4.2)	7 (3.7)	0.79
s	11 (5.7)	12 (6.3)	0.83
t	2 (1.0)	7 (3.7)	0.17*

Data presented as no. (%). *p*-values presented are 2-sided Mantel-Haenszel chi square and *Fisher exact. Shapes p, q, r represent rounded and s and t irregular opacities.

systems that have been conducted using the ILO classification system^{1, 2, 11}).

It should be noted that this study differs from the studies of Franzblau and Laney in a number of important aspects^{1, 4}). First, our study population was comprised of Chinese workers and included more subjects with small and large opacities than previously studied populations. Based upon our preselection criteria of study participants, we were able to include more radiographs in the 1/0 to 3/3 range and thus a much less skewed distribution of small opacity profusion than has been previously achieved. This is important because the research to date has focused largely upon modality agreement in the 0/1 to 1/0 boundary. Our results indicate that the intermodality agreement remains high and relatively unaffected when assessing radiographs in the higher small profusion categories.

Another distinction between this and previous studies is that we did not use the ILO classification system. However, the relative significance of using the Chinese diagnostic criteria instead of the ILO system is likely minimal. Because the small opacity designations and scales are equivalent between the two classifications systems, our findings should be analogous when compared to the ILO system. One of the strengths of the Chinese classification system in denoting profusion independently by zone is that it provides a greater understanding of the distribution and severity of small parenchymal opacities by zone. This is one of the limitations of the current ILO system and has been recently highlighted in a study conducted assessing the zonal distribution of small opacities in U.S. coal miners with pneumoconiosis¹³).

Our study contained a relatively large number of radiographs with large opacities. We observed complete concordance between modalities with respect to the visualization of large opacities when treated dichotomously (any large opacity versus none). It may be that if large opacities were analyzed on an ordinal scale with multiple categories or continuously by size, we would have identified differences between modalities. Subtle differences in the determination of large opacity size by

modality likely have little clinical importance. However, we did observe that the classification of large opacities in some circumstances did seem to impact the classification of small opacities in certain zones. For example, as presented in the inset table of Fig. 1, there were four instances where high profusion was noted by DR with a 0/0 classification by FSR. In each of these instances, large opacities were noted by FSR, while small opacity profusion was classified as 0/0. A similar finding was reported by Franzblau et al. who found a higher degree of coalescence of small opacities using DR compared with FSR. Their findings demonstrated that in most instances where coalescence was noted by DR, a large opacity was classified using FSR. This provides further evidence that there may be enhanced visualization of the formation of large opacities through the process of coalescing small opacities using DR. We were unable to make inferences regarding pleural abnormality based on these data because the two cases we observed had evident disease that would have likely been identified even on a film of poor quality.

One potential limitation of our study is that the same set of standard FSR images were displayed using backlit view boxes for classification of both FSR and soft copy DR images. In the studies of Franzblau and Laney, the ILO standard films were digitized and presented on soft copy display for the purposes of classification of soft-copy digitally-acquired images. Studies specifically designed to assess the classification of films versus soft-copy digitized FSR images suggested no difference between the two display modes¹⁴). However, it is clear that images based on FSR, whether displayed as hard copy or digitized soft copy are not ideal in the context of classifications of digitally acquired patient radiographs. The ultimate goal should be the development of digitally acquired standard images. In practical terms, the extent to which all of these studies have been impacted by the lack of digitally acquired standard images is likely minimal.

Two other differences that bear mentioning are the concurrent timing of the readings and the use of the median profusion value for the study. Any measure that aggregates

multiple values necessarily reduces the variability. It may be that the use of the median value as our final determination of small opacities could possibly affect any apparent intermodality differences. It has been established for some time that a middling tendency exists in the 12 subcategory classification system¹⁵⁾, though the extent to which using the median value of multiple readings contributes to this phenomena is unclear. This study was designed to assess intermodality differences and was not intended to assess individual reader behaviors. We employed five readers who independently denoted small opacity profusion for each image in this study. It is unlikely that the use of fewer readers would have provided a more accurate reflection of the profusion and zonal distribution of small opacities or that more readers would have substantially shifted the final determination (median profusion score) we report here.

We feel that the equivalence studies of FSR vs. DR in the context of pneumoconiosis have been important, and all of the major studies, including this one, using different methods and patient populations, have come to the same conclusions. However, it is also important to discuss the practical realities of chest imaging as it is actually being conducted in clinical and research settings. Digital radiography has rapidly become the standard, and overall, traditional film-screen systems are no longer being upgraded or supported in many radiology departments. This played a role in our study as is demonstrated by the numbers of unreadable film-screen images that were excluded from analysis, along with their digital pair. The film X-ray machine and automatic processor used for this study were both old and occasionally out of order. In fact, they would have been discarded if not for use in the diagnosis of pneumoconiosis.

Pneumoconiosis in China is a significant problem, and accurate diagnosis moving forward in the face of changing radiographic technologies is important. In this study, we have demonstrated that, in a population of Chinese workers with pneumoconiosis, direct readout digital systems are equivalent to traditional film-screen radiography in the recognition and classification of pneumoconiosis. This study, taken with other recent reports, should provide sufficient evidence to adequately demonstrate the equivalence between digital and film modalities. Further studies that examine a large patient population with coalescing small opacities and utilize computed tomography versus DR and FSR may be warranted. Most importantly, future initiatives should focus upon updating the classification systems of the pneumoconioses to include new digitally acquired standard films.

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