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Original Article

Assessment of physicians' proficiency in reading chest radiographs for pneumoconiosis, based on a 60-film examination set with two factors constituting eight indices

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Abstract: Two hundred and thirty-three individuals read chest x-ray images (CXR) in the Asian Intensive Reader of Pneumoconiosis (AIR Pneumo) workshop. Their proficiency in reading CXR for pneumoconiosis was calculated using eight indices (X1–X8), as follows: sensitivity (X1) and specificity (X2) for pneumoconiosis; sensitivity (X3) and specificity (X4) for large opacities; sensitivity (X5) and specificity (X6) for pleural plaques; profusion increment consistency (X7); and consistency for shape differentiation (X8). For these eight indices, one-way analysis of variance (ANOVA) and

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Scheffe's multiple comparison were conducted on six groups, based on the participants' specialty: radiology, respiratory medicine, industrial medicine, public health, general internal medicine, and miscellaneous physicians. Our analysis revealed that radiologists had a significant difference in the mean scores of X3, X5, and X8, compared with those of all groups, excluding radiologists. In the factor analysis, X1, X3, X5, X7, and X8 constituted Factor 1, and X2, X4, and X6 constituted Factor 2. With regard to the factor scores of the six participant groups, the mean scores of Factor 1 of the radiologists were significantly higher than those of all groups, excluding radiologists. The two factors and the eight indices may be used to appropriately assess specialists' proficiency in reading CXR.

Key words: Chest x-ray image, Factor analysis, International Labor Organization Classification, Pneumoconiosis, Sensitivity, Specificity

Introduction

Pneumoconiosis is an important major occupational disease in Asia. The International Labor Organization (ILO; Geneva, Switzerland) and the World Health Organization (Geneva, Switzerland) promote a crusade against pneumoconiosis and occupational exposure, called the Global Program for Elimination of Silicosis[1].

As a part of the crusade program, the use of the ILO Classification with the chest radiograph as a tool of screening and surveillance of pneumoconiosis is recommended[2]. To contribute to this crusade against pneumoconiosis, an international workshop for reading chest x-ray images (CXR) for pneumoconiosis in conformity with the ILO Classification was established as the Asian Intensive Reader of Pneumoconiosis Project (AIR Pneumo)[3].

Profusion 0–3 in the ILO Classification represents the progress of the disease pneumoconiosis. Confirming the dust exposure condition of workers is possible through the appropriate evaluation of profusion by the interpreting doctor. Therefore, the chest radiograph is widely used internationally as an important tool for the secondary prevention of pneumoconiosis. The training of doctors engaged in pneumoconiosis screening will be necessary to suppress the deterioration of pneumoconiosis and to suppress the occurrence of new pneumoconiosis patients.

The AIR Pneumo was held 12 times between 2008 and 2014 in Thailand (four times), Japan (four times), Brazil (three times), and India (one time). Two hundred and thirty-three people attended the AIR Pneumo Training Course. The attendees represented different national origins, which were primarily Asian countries such as Thailand, Japan, China, Hong Kong, and Taiwan; Brazil, Chile, India, Vietnam, Cambodia, Brunei, Indonesia, Philippines, and the Democratic Republic of Congo were also represented. The workshop for reading CXR lasted 3 d (the two-day course plus one-half day for the examination). By using a 60-film examination set on the third day, the attendees' proficiency in reading CXR was assessed using eight indices[3]. The score was calculated using a formula consisting of the eight indices to determine whether an examinee passed or failed before issuing a certificate (Appendix 2).

Factor analysis is conducted using a method that reduces the number of variables, while minimizing a reduction in information[4]. Furthermore, factor analysis is used to analyze an association among many variables to determine underlying factors common among the variables[5–7]. Our previous report[5] suggested that the 60-film examination set of the AIR Pneumo with four factors constituting the eight indices could be used to comprehensively assess an individual's proficiency indicator.

It was possible to compare data based on specialty because the number of participants in the Training Course was substantially increased. Using the eight indices and the common factors obtained from the factor analysis, we assessed whether there was a difference in the reading proficiency, based on specialty. This study used the same methodology as in a previous study[5]. With this analysis, we were able to clarify the indices and factors and with a low score among physicians. The obtained data differed to some extent from the previous report; therefore, we report the results in this study as an original article.

Subjects and Methods

Subjects

The subjects consisted of 233 participants in the AIR Pneumo Training Course. We obtained consent to participate in the current study from all participants. The 1st, 2nd, 3rd, and 4th Training Courses held in Thailand consisted of 29 participants, 22 participants, 17 participants, and 32 participants, respectively. The 1st, 2nd, 3rd, and 4th Training Course held in Japan consisted of 14 participants, 16 participants, 7 participants, and 7 participants, respectively. The 1st, 2nd, and 3rd Training Course held in Brazil consisted of 22 participants, 12 participants, and 7 participants, respectively. The 1st Training Course held in India consisted of 48 participants. The distribution of specialties for each venue is presented in Table 1.

Questionnaire on the attributes of participants in the training course

A self-administered questionnaire was distributed to all participants in the course. They completed it immediately after the examination on Day 3. Responses were obtained from 195 participants (response rate, 83%). Thirty-nine participants did not respond. In the questionnaire, the participants were asked to fill in the fields with their specialty and years of experience as a specialist. For the analysis, the participants were classified into six groups, based on their specialty, as follows: radiology, respiratory medicine, industrial medicine, public health, general internal medicine, and miscellaneous groups.

Program of the 3-day course

The program has been described in a previous study[5]. In brief, the course for reading CXR was held for 2 1/2 d. For 2 d, lectures on the ILO Classification and practical reading training using actual CXR were provided. In this course, a self-practice session involved the participants independently reading 30 films. The correct answers to all 30 films were shown by the lecturer afterwards. After the practical training, an examination was conducted by having the participants independently read films for 180 minutes during the one-half day on Day 3. Sixty films were used in the examination. In this study, the correct answer for each film was matched to the results provided by at least three-fourths of the 12 expert readers (i.e., a total of 12 USA National Institute for Occupational Safety and Health [NIOSH] B readers).

The details of the reading training course, the composition of the examination films, and the details of the eight indices have been provided in a previous study[3], and are provided at the end of this report in Appendix 1. In this report, a formula using the eight indices on a 100-point scale and the allocation of points are provided in Appendix 2. These marks were used for the pass-fail grading, but not for the analysis in this study.

Table 1. The distribution of specialties by venue

	Brazil	India	Japan	Thailand
Radiology	11	2	7	31
Respiratory medicine	20	2	11	13
Industrial medicine	3	11	10	41
Public health	0	1	7	1
General medicine	0	2	4	8
Miscellaneous	0	3	2	3

Eight indices and calculation method

The following eight indices for proficiency in reading x-ray films among the 233 participants were calculated, as presented in Appendix 1.

-Sensitivity (X1) and specificity (X2) for pneumoconiosis

-Sensitivity (X3) and specificity (X4) for large opacities

-Sensitivity (X5) and specificity (X6) for pleural plaques

-Profusion increment consistency (X7)

-Consistency for shape differentiation for small opacities (rounded opacities and irregular opacities) (X8)

Calculation of the sensitivity and the specificity

The correct answers were as follows: films with the mode of profusion 0/0 recorded by at least three-fourths of the experts were considered normal (20 cases), whereas films with a mode of profusion 1/1 or greater recorded by the experts were considered positive for pneumoconiosis (31 cases). Films recorded by these experts as showing large opacity A, B, or C were considered presence of large opacity films (9 cases), whereas films recorded as lacking large opacities A, B, or C were considered absence of large opacity films (41 cases). Films recorded by the experts as showing pleural plaque in profile, face on, diaphragm, or other sites were considered presence of pleural plaque films (9 cases), whereas films recorded as lacking pleural plaque at any site were considered as absence of pleural plaque films (30 cases). The sensitivity and specificity for pneumoconiosis, large opacities, and pleural plaque were calculated using the records of the examinees, as shown in Appendix 1.

Profusion increment consistency

The rate of agreement of profusion was calculated for films with profusion 1/0 or greater that were recorded by at least three-fourths of the experts (30 cases). Of the 30 cases, the percentage of cases in which the read results of each examinee were within the allowance (one minor category below and above) was calculated. The allowances for profusion increment consistency are shown in Appendix 1.

Consistency of shape differentiation for small rounded and irregular opacities

Twenty cases in which the correct answer was "rounded opacity" for the primary and secondary shape recorded by at least three-fourths of the experts and four cases in which the correct answer was "irregular opacity" for the primary and secondary shape recorded by at least three-fourths of the experts were included in this study. Of these 24 cases, the percentage of cases in which the examinees were able to judge whether the primary shape was a rounded or irregular opacity consistent with each correct answer, regardless of the size (i.e., p, q, r or s, t, or u), was calculated.

One-way analysis of variance for the eight indices

A one-way analysis of variance (ANOVA) was conducted to compare the mean of eight indices for six participant groups, based on the specialty. For the multiple comparison, Scheffe's method was conducted to obtain the mean value of the indices for the participant groups.

Factor analysis and one-way ANOVA of factor scores

The number of factors was determined using the Kaiser-Guttman "eigenvalue greater than one" criterion in the correlation matrix for the eight indices[8]. In a previous study[5], the more gradual "eigenvalue greater than 0.7" criterion was used because the number of cases was limited. However, the number of cases was increased in this study; therefore, the stricter criterion of 1.0 was used. Varimax rotation was used for the rotation of the factor axes[9]. Based on the results of the factor analysis, the factor scores of each examinee were calculated using a regression method[10].

The mean factor score of each of the aforementioned groups was calculated. One-way ANOVA was conducted to compare the mean of factor scores. For the multiple comparison, Scheffe's method was conducted to obtain the mean of the factor scores of the participant groups.

Statistical analysis

For analysis, we used R version 3.1.2 (2014-10-31; Copyright 2014; R Foundation for Statistical Computing Platform: x86_64-w64-mingw32/x64 [64-bit])[11]. A *p*-value less than 0.05 was statistically significant.

Results

Attributes of the examinees

The details of the specialties of the examinees were as follows: 51 radiologists, 46 respiratory physicians, 65 industrial physicians, nine public health physicians, 14 general physicians, and eight miscellaneous physicians. The mean years of experience as a physician among all participants was 16.4 yr (standard deviation [SD], ± 10.3 yr; median, 14 yr; range, 1–41 yr). The number of CXR that the examinees read for pneumoconiosis after becoming a professional in clinical practice was as follows: 0 films, 30 examinees; 1 or more films but less than 10 films, 55 examinees; 10 films or more but less than 50 films, 37 examinees; 50 films or more but less than 100 films, 23 examinees; and 100 films or more, 48 examinees. Only specialists of all attributes from the questionnaire were analyzed for the association with the eight indices and the factor scores.

Results of one-way ANOVA for the eight indices and the results of multiple comparison

Table 2 shows the results of one-way ANOVA by specialty for the eight indices, and the results of multiple comparison using Scheffe's method. There were statistically significant differences between the means of the six specialty groups (i.e., X3, X5, and X8), as determined by one-way ANOVA.

In the multiple comparison, the indices X3, X5, and X8 in the radiologist group showed a significantly higher mean score, compared with the mean score of the other groups. In the multiple comparison, the mean of X5 was significantly lower in the miscellaneous physicians group than in the other groups. There was no significant difference in any of the eight indices in the respiratory physicians, public health physicians, and general physicians groups.

Results of the factor analysis

Table 3 shows the correlation matrix for the eight indices. The eigenvalues were calculated as 4.071, 1.044, 0.721, 0.625, 0.548, 0.379, 0.320, and 0.294. The Kaiser-Guttman "eigenvalue greater than one" criterion was used; therefore, we decided to conduct a factor analysis with two factors. The results of factor analysis with two factors using orthogonality varimax rotation are shown in Table 4 and Fig. 1.

Among the eight indices, the sensitivity for pneumoconiosis, sensitivity for large opacities, sensitivity for pleural

Table 2. Results of one-way ANOVA for the eight indices and results of Scheffe's multiple comparison among six participant groups

n	Radiology	Respiratory medicine	Industrial medicine	Public health	General medicine	Miscellaneous	All	*p*-value#
	51	46	65	9	14	8	193	
X1	0.956 ± 0.049	0.914 ± 0.103	0.921 ± 0.101	0.913 ± 0.068	0.926 ± 0.098	0.863 ± 0.091	0.912 ± 0.104	0.0807
X2	0.955 ± 0.078	0.957 ± 0.074	0.831 ± 0.231	0.961 ± 0.099	0.879 ± 0.166	0.744 ± 0.346	0.887 ± 0.182	0.00013
X3	0.974 ± 0.072*	0.937 ± 0.114	0.872 ± 0.175	0.938 ± 0.098	0.849 ± 0.229	0.881 ± 0.182	0.881 ± 0.182	0.00238
X4	0.979 ± 0.036	0.969 ± 0.050	0.967 ± 0.073	0.986 ± 0.018	0.969 ± 0.043	0.936 ± 0.076	0.965 ± 0.071	0.573
X5	0.919 ± 0.100*	0.867 ± 0.144	0.791 ± 0.177	0.802 ± 0.165	0.857 ± 0.171	0.597 ± 0.258*	0.804 ± 0.196	0.00001
X6	0.933 ± 0.086	0.943 ± 0.076	0.874 ± 0.168	0.944 ± 0.068	0.812 ± 0.176	0.875 ± 0.133	0.890 ± 0.140	0.00552
X7	0.768 ± 0.124	0.747 ± 0.201	0.646 ± 0.163	0.722 ± 0.237	0.679 ± 0.169	0.650 ± 0.264	0.686 ± 0.183	0.00547
X8	0.911 ± 0.114*	0.879 ± 0.128	0.832 ± 0.152	0.808 ± 0.105	0.838 ± 0.145	0.719 ± 0.196	0.834 ± 0.157	0.00264

ANOVA: analysis of variance; SD: standard deviation; X1: sensitivity for pneumoconiosis; X2: specificity for pneumoconiosis; X3: sensitivity for large opacities; X4: specificity for large opacities; X5: sensitivity for pleural plaque; X6: specificity for pleural plaque; X7: profusion increment consistency; X8: shape differentiation for small opacities.
The data are expressed as the mean ± SD.
#*p*-value for ANOVA.
*Significant difference from Scheffe's multiple comparison, compared with the other groups ($p<0.05$).

Table 3. The correlation matrix for the eight indices and eigenvalues among all participants

	X1	X2	X3	X4	X5	X6	X7	X8
X1	1	0.233	0.532	0.420	0.426	0.356	0.524	0.640
X2	0.233	1	0.453	0.457	0.379	0.585	0.406	0.420
X3	0.532	0.453	1	0.407	0.488	0.508	0.419	0.581
X4	0.420	0.457	0.407	1	0.282	0.514	0.320	0.436
X5	0.426	0.379	0.488	0.282	1	0.197	0.376	0.497
X6	0.356	0.585	0.508	0.514	0.197	1	0.337	0.461
X7	0.524	0.406	0.419	0.320	0.376	0.337	1	0.538
X8	0.640	0.420	0.581	0.436	0.497	0.461	0.538	1
Eigenvalue	4.071	1.044	0.721	0.625	0.548	0.379	0.320	0.294

X1: sensitivity for pneumoconiosis; X2: specificity for pneumoconiosis; X3: sensitivity for large opacities; X4: specificity for large opacities; X5: sensitivity for pleural plaque; X6: specificity for pleural plaque; X7: profusion increment consistency; X8: shape differentiation for small opacities.

plaque, profusion increment consistency, and consistency for shape differentiation were loaded as Factor 1. This Factor 1 was named the sensitivity (SEN)-related and small parenchymal abnormality (SPA)-related (SEN/SPA) factor. The specificity for pneumoconiosis, specificity for large opacities, and specificity for pleural plaque were loaded as Factor 2. Factor 2 was named the specificity-related (SPEC) factor.

Results of one-way ANOVA of the factor scores and multiple comparison

Based on the results of the factor analysis described in the preceding section, the factor scores of each participant were calculated with a regression method using two factors. Table 5 shows the mean and SD of the factor scores in each of the six participant groups.

For the factor scores of the two factors, one-way ANOVA and multiple comparison using Scheffe's method were conducted in the six participant groups. The results of one-way ANOVA for the two factors were significant. In multiple comparison, the mean factor score for the SEN/SPA factors was significantly higher in the radiologist group than in the other groups.

Discussion

Most participants in this study were respiratory physicians, industrial physicians, and radiologists. The reason for this predominance may be that specialists who often read CXR for pneumoconiosis attended the course. Public

Table 4. The factor-loading matrix with two factors using orthogonal varimax rotation and the contribution rate

	Factor 1	Factor 2
X1	0.835	0.114
X2	0.174	0.847
X3	0.585	0.43
X4	0.394	0.471
X5	0.494	0.297
X6	0.323	0.633
X7	0.558	0.323
X8	0.731	0.35
Sums of squared loading	2.42	1.854
Proportion variance	0.302	0.232
Cumulative variance	0.302	0.534

X1: sensitivity for pneumoconiosis; X2: specificity for pneumoconiosis; X3: sensitivity for large opacities; X4: specificity for large opacities; X5: sensitivity for pleural plaque; X6: specificity for pleural plaque; X7: profusion increment consistency; X8: shape differentiation for small opacities.
Factor 1 includes sensitivity for pneumoconiosis, sensitivity for large opacities, sensitivity for pleural plaque, profusion increment consistency, and consistency for shape differentiation. Factor 2 includes specificity for pneumoconiosis, specificity for large opacities, and specificity for pleural plaque.

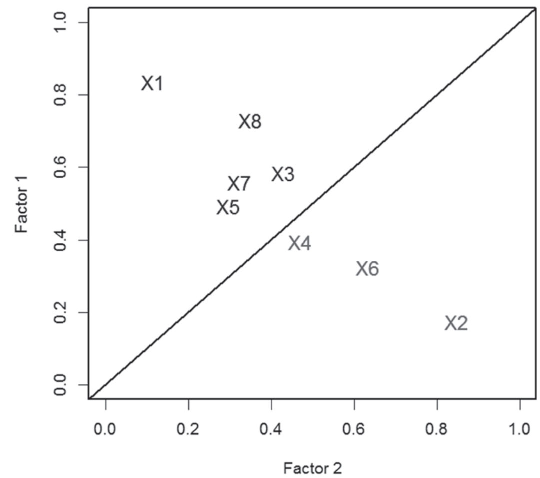

Fig. 1. Factor loading with two factors by using orthogonal varimax rotation.

health physicians and miscellaneous physicians also participated. By pooling the data of all participants and conducting factor analysis, the factors were classified into two categories: the first factor, which was related to the sensitivity for the findings of pneumoconiosis, was the SEN/SPA-related factor; and the second factor, which was related to the specificity in the findings of pneumoconiosis, was the SPEC-related factor. We obtained results consistent with the independent notation scheme (i.e., sensitivity and specificity, which are commonly used for two major indices for screening tests).

In a previous short communication by Zhou *et al.*[5], the data were classified into four factors. However, the results of analysis in the current study were classified into two factors: SEN/SPA-related factors and SPEC-related factors. In the current study, 233 participants were included in the analysis. Of these participants in the current study, we tentatively extracted only 51 radiologists for trial with regard to their specialty and achieved factor analysis using the same method described in the current text. By using this factor analysis method among radiologists, the profusion increment consistency was extracted as the third independent factor. Table 6 shows the comparison with this trial analysis results and those reported by Zhou *et al*[5].

The result of extracting of the third factor (i.e., profusion consistency) and high uniqueness (i.e., pleural plaque) among radiologists was consistent with the findings of the previous study by Zhou *et al*[5]. For radiologists, the independence of this factor may be because of the radiologists' higher skill in reading CXR, compared to the reading skill of other specialists.

In this current study, the eight indices were condensed into two epidemiologically common factors, and each participant's proficiency index was observed comprehensively by calculating the two-factor scores individually. A higher factor score indicated higher proficiency in reading CXR. The results of analysis in this current study suggested that the radiologists' proficiency in reading CXR was superior in Factor 1. It may be that the proficiency in reading CXR is higher among radiologists than among-other specialists. Therefore, a syllabus that can educate other specialists to the skill level of radiologists may be required in the future.

In the actual examination in the AIR Pneumo, using the calculating formula as shown in Appendix 2, pass-fail grading was judged by using a cut-off point of 60 points on a 100-point scale. This calculating formula is available for assessing examinee proficiency in reading CXR on a 100-point scale and is suitable for the consistency of results, even when the number of examinees increase. The weighting of each proficiency index was based on expert opinion. In addition, a weighting that was similar to the weighting of the indices in the test of NIOSH-B[5, 12] was attempted. By contrast, no item of the consistency for shape differentiation exists in the test of NIOSH-B. This is a unique aspect of the examination in the AIR Pneumo.

Table 5. Results of one-way ANOVA for the scores of the two factors and the results of multiple comparison among the participant groups

	Radiology	Respiratory medicine	Industrial medicine	Public health	General medicine	Miscellaneous	All	$p^{\#}$
Factor score for Factor 1	0.4570 ± 0.4397*	0.1141 ± 0.8100	0.0702 ± 0.8839	−0.0612 ± 0.5840	0.0892 ± 0.8033	−0.4665 ± 0.7981	0.000 ± 0.8996	0.0137
Factor score for Factor 2	0.3058 ± 0.4080	0.3799 ± 0.4272	−0.2569 ± 1.1204	0.4153 ± 0.4654	−0.1828 ± 0.8109	−0.5412 ± 1.4397	0.000 ± 0.8811	0.000175

#The *p*-value is based on one-way ANOVA.

*Indicates a significant difference from Scheffe's multiple comparison, compared with the other groups ($p<0.05$).

Factor 1 includes sensitivity for pneumoconiosis, sensitivity for large opacities, sensitivity for pleural plaque, profusion increment consistency, and consistency for shape differentiation. Factor 2 includes specificity for pneumoconiosis, specificity for large opacities, and specificity for pleural plaque.

Table 6. Comparison between the results reported by Zhou, the results of the entire analysis in the current study, and the results of the analysis for radiologists only in the current discussion session

Factor name		The current study (all participants)		Report by Zhou		Radiologists in the current analysis
Sensitivity and abnormal lung parenchyma factor	I	Sensitivity for pneumoconiosis, sensitivity for large opacities, *sensitivity for pleural plaque*, **profusion consistency,** and consistency for shape differentiation	II	Sensitivity for pneumoconiosis and sensitivity for large opacities	I	Sensitivity for pneumoconiosis, specificity for large opacities, and consistency for shape differentiation
Specificity factor	II	Specificity for pneumoconiosis, specificity for large opacities, and specificity for pleural plaque	I	Specificity for pneumoconiosis, specificity for large opacities, and specificity for pleural plaque	II	Specificity for pneumoconiosis and specificity for pleural plaque
			III	**Profusion consistency**	III	**Profusion consistency**
			IV	*Sensitivity for pleural plaque*		
					U	Sensitivity for large opacities and s*ensitivity for pleural plaque*

Roman numbers I–IV indicate the number of the order of factor loading by factor analysis. The letter "U" indicates high uniqueness, which is presented as the result of factor analysis. The differences in each analysis are emphasized using bold and italics.

Conclusion

The two-factor scores and the eight indices obtained from the 60-film examination set could indicate a difference in skills in the participant groups. In addition, it may be that the two factors reflect two aspects of proficiency in comprehensively reading CXR for pneumoconiosis. The scores of the two factors and the eight indices obtained from the 60-film examination may be available for appropriately assessing skills such as proficiency in reading CXR for pneumoconiosis.

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Conflict of Interest

None.

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Appendix

Appendix 1[3]. The course syllabus in the AIR Pneumo Standardized Training Course for reading CXR of pneumoconiosis

The course syllabus that the tutors delivered to the participants included the following topics: introduction to ILO (2000) International Classification of Radiographs of Pneumoconiosis, epidemiology and control of pneumoconiosis in Thailand and Asian countries, quality of radiographs, rounded and irregular parenchymal opacities, large opacities, pleural abnormalities, and additional symbols.

Sixty exam films with the correct answers and the selection criteria

In this context, with the selection described in Table A1 below, the correct answers for each examination film were determined, based on the reading results of 12 NIOSH-B readers. For the profusion in the 12-scale, the mode of profusion among 12 readers is regarded as the correct answer for profusion.

Approximately one-third of the 60 examination films were normal with profusion 0, and two-thirds of the films revealed profusion equal to or more than 1/1. The films with conflicting findings with regard to the presence or absence of large opacities as recorded by the experts were excluded from the indices of sensitivity and specificity for large opacities. The films with conflicting findings with regard to the presence or absence of pleural plaque as recorded by experts were excluded to subject them to calculations of sensitivity and specificity for pleural plaque. The films subjected to the indices of large opacities or pleural plaques were in complete agreement by all 12 NIOSH-B readers only for their presence or absence; however, the size of large opacities recorded by experts may have differed. Nine films were regarded as absolutely with large opacity films and 41 films, as definitely without large opacity films. Nine films with plaque and 30 films without plaque were subjected to the indices of specificity and sensitivity for pleural plaque.

Table A1. Sixty examination films, grouped by criteria and index for correct answer

Criteria	Number of films	Index
Profusion	0/0 (n=20)	Sensitivity and specificity for pneumoconiosis
	Boundary cases (n=4) (profusion mode=0/1)	Not subjected to profusion increment consistency
	Boundary cases (n=4) (profusion median=1/0 or 0/1), mode not determined due to big variations of profusion)	Not subjected to profusion increment consistency
	Profusion 1/0 (n=1)	Profusion increment consistency,
	Profusion 1 (1/1 or 1/2) (n=21)	Sensitivity and specificity for pneumoconiosis
	Profusion ≥2 (n=8)	
	Profusion >1 (n=2), mode was not determined due to big variation of profusion	Not subjected to profusion increment consistency, subjected to pneumoconiosis index
Pneumoconiosis	Yes (n=31), No (n=20)	Sensitivity and specificity for pneumoconiosis
	Boundary cases (n=9)	Not subject to pneumoconiosis criteria
Shape	Purely rounded opacity (R/R*) films (n=20), Purely irregular opacity (IR/IR**) films (n=4)	Shape differentiation for small opacities
Large opacities	Films with large opacities (n=9) (A: n=3, B: n=5, C: n=1);	
Films without large opacities (n=41)	Sensitivity and specificity for large opacities	
Pleural plaque	Films with plaque (n=9); Films without plaque (n=30)	Sensitivity and specificity for pleural plaque

* "R" indicates the rounded shape of small opacities, including p, q, and r.

** "IR" indicates the irregular shape of small opacities, including s, t, and u.

Algorithm for assessing the physicians' proficiency in classifying pneumoconiosis chest x-ray images with the 60-film set

Sensitivity and specificity for pneumoconiosis

1. Definition: Sensitivity for pneumoconiosis was the proportion of true pneumoconiosis cases that was correctly identified as pneumoconiosis by examinees in the test. Specificity for pneumoconiosis was the proportion of truly normal cases that were identified as normal by the examinees.
2. Criteria for the films with pneumoconiosis and normal films
   On the expert's side, a film with the mode of profusion 1/1 or more, as recorded by 12 NIOSH-B experts, was regarded as positive for pneumoconiosis, and a film with the mode of profusion 0/0, as recorded by 12 experts, was regarded as normal. On the examinee side, a film recorded with the mode of profusion 1/0 or more by an examinee was regarded as positive for pneumoconiosis, and a film recorded with the mode of profusion 0/0 or 0/1 was regarded as normal.
3. Equations for calculating the sensitivity and specificity for pneumoconiosis
   Sensitivity for pneumoconiosis
   $$\frac{\text{The number of films classified as positive for pneumoconiosis by an examinee, which were also classified as positive for pneumoconiosis by all 12 NIOSH-B experts}}{\text{The number of films classified as positive for pneumoconiosis by all 12 experts (n=31)}}$$
   Specificity for pneumoconiosis
   $$\frac{\text{The number of films classified as nonpneumoconiosis by an examinee, which were also classified as normal by all 12 NIOSH-B experts}}{\text{Number of films (n=20) classified as normal by all 12 experts}}$$
4. Allowance for correctly recording pneumoconiosis
   For a positive pneumoconiosis film, profusion recorded as 1/0 or more by an examinee was regarded as correct. For a normal film, profusion recorded as 0/0 or 0/1 was regarded as correct.

Sensitivity and specificity for large opacities

1. Definition: Sensitivity for large opacities was the proportion of true large opacities cases that were correctly identified as the presence of large opacities by the examinees in the test. Specificity for large opacities was the proportion of true no large opacities cases that was correctly identified as absence of large opacities by the examinees.
2. Criteria for a film with large opacities or without large opacities
   A film recorded as having large opacity A, B, or C by all 12 NIOSH-B experts was regarded as a true large opacity film. A film recorded as having the absence of large opacity A, B, or C by all 12 NIOSH-B experts was regarded as a true no large opacity film.
3. Equations for calculating the sensitivity and specificity for large opacities
   Sensitivity for large opacities
   $$\frac{\text{The number of films recorded as having the presence of large opacities by an examinee, which were also recorded by all 12 NIOSH-B experts}}{\text{The number of films recorded as having the presence of large opacities by all 12 NIOSH-B experts (n=9)}}$$
   Specificity for large opacities
   $$\frac{\text{The number of films recorded as having the absence of large opacities by an examinee, which were also recorded by all 12 NIOSH-B experts}}{\text{The number of films recorded as having the absence of large opacities by all 12 NIOSH-B experts (n=41)}}$$
4. Allowance for correctly recording large opacities: For true large opacity films, the presence of large opacities A, B, and C recorded by an examinee was regarded as correct. For the true no large opacity film, the absence of large opacities recorded by an examinee was regarded as correct.

Sensitivity and specificity for pleural plaque

1. Definition: Sensitivity for large opacities was the proportion of true pleural plaque cases that were correctly identified as the presence of pleural plaque by the examinees in the test. Specificity for pleural plaque was the proportion of true no pleural plaque cases that was correctly identified as the absence of pleural plaque by the examinees.
2. Criteria for films with or without pleural plaque: A film recorded as having the presence of pleural plaque in profile, face on, diaphragm, or other sites by all 12 NIOSH-B experts was regarded as a true pleural plaque film. A film re-

corded as an absence of pleural plaque film for any site by all 12 NIOSH-B experts was regarded as a true no pleural plaque film.

3. Equations for calculating the sensitivity and specificity for pleural plaque

   Sensitivity for pleural plaque

$$\frac{\text{The number of films recorded as presence of pleural plaque films by an examinee, which were also recorded by all 12 NIOSH-B experts}}{\text{The number of films classified as presence of pleural plaque films by all 12 NIOSH-B experts (n=9)}}$$

   Specificity for pleural plaque

$$\frac{\text{The number of films classified as absence of pleural plaque films by an examinee, which were also recorded by all 12 NIOSH-B experts}}{\text{The number of films recorded as absence of pleural plaque films by all 12 NIOSH-B experts (n=30)}}$$

4. Allowance for correctly recording pleural plaque: For the true pleural plaque film, the presence of pleural plaques in profile, face on, diaphragm or other sites recorded by examinee was regarded as correct. For the true no pleural plaque film, the absence of pleural plaque recorded by an examinee was regarded as correct.

Profusion increment consistency

1. Definition: Profusion increment consistency is the consistency between the profusion on film recorded by the experts and the profusion recorded by an examinee.
2. Criteria for the film subjected to profusion increment consistency: films with profusion 1/0 or more were included.
3. Equation for calculating profusion increment consistency

$$\frac{\text{The number of films with profusion correctly classified by an examinee within one minor category allowance among the films subjected to profusion increment consistency}}{\text{The number of films subjected to profusion increment consistency (n=30)}}$$

4. Allowance for correctly classifying profusion: for each film, the profusion recorded by an examinee was compared with the mode of profusion recorded by the experts. The profusion within one minor category difference below or above was regarded as the allowance for the correct classification, as shown in Table A2.

Shape differentiation for small opacities

The primary/secondary shape and size of small opacities recorded by 12 NIOSH-B certified experts were summarized and categorized into four shape patterns—R/R, R/IR, IR/R, and IR/IR—in which “R” represents a rounded shape (i.e., p, q and r) and “IR” represents an irregular shape (i.e., s, t and u).

1. Definition: Shape differentiation for small opacities was the consistency between the shape of small opacities recorded by examinee and that recorded by 12 NIOSH-B experts, based on the four shape patterns.
2. Criteria for films subjected to shape differentiation: for each film, the number of experts among 12 experts who recorded a category as R/R, R/IR, IR/R, or IR/IR were counted. If 10 or more experts among 12 experts recorded the shape pattern as R/R and only two or fewer experts recorded the shape as R/IR, IR/R, or IR/IR, then the film was regarded as a purely rounded opacity film. However, if 10 or more experts recorded the shape pattern as IR/IR, and only two or fewer experts recorded the shape as IR/R, R/IR, or R/R, then the film was considered a purely irregular opacity film. There were 24 films subjected to the index of shape differentiation, which included 20 films with purely rounded opacities and four films with purely irregular opacities.
3. Equation for calculating shape differentiation for small opacities

$$\frac{\text{The number of films correctly classified for shape by an examinee among the films subjected to shape differentiation}}{\text{The number of films subjected to shape differentiation (n=24)}}$$

Allowance for the correctly recorded shape pattern: For a film with a purely rounded shape R/R, with the shape of R/R or R/IR as recorded by an examinee were regarded as an allowed shape pattern that agreed with the shape pattern recorded by the experts. For a film with a purely irregular shape IR/IR, the shapes IR/IR and IR/R recorded by examinee were regarded as an allowed shape that agreed with the shape pattern recorded by the experts. The crude agreement for shape differentiation between the experts and the examinees are shown in Table A3.

Table A2. Allowances for profusion increment consistency of each film

Expert's correct answer	Examinees' answer allowed		
1/0	0/1	1/0	1/1
1/1	1/0	1/1	1/2
1/2	1/1	1/2	2/1
2/1	1/2	2/1	2/2
2/2	2/1	2/2	2/3
2/3	2/2	2/3	3/2
3/2	2/3	3/2	3/3
3/3	3/2	3/3	3/+
3/+	3/3	3/+	

Table A3. Allowed agreement for shape differentiation for small opacities

		Examinees' answer			
		R*/R	R/IR**	IR/R	IR/IR
Experts' answer	R/R	Y	Y	N	N
	IR/IR	N	N	Y	Y

* "R" indicates the rounded shape of small opacities, including p, q, and r.
** "IR" indicates the irregular shape of small opacities, including s, t, and u.

Appendix 2. The agreement by the AIR Pneumo Committee scoring scheme and the criteria for the examination

i) Accurate detection of small opacities, large opacities, and pleural plaques

– Small opacities: 30 × (sensitivity + specificity −1) = small opacity accuracy marking ……………..…(1)
(0/1 and 1/0 cases were not subjected to this sensitivity and specificity calculation)
The total cases subjected to accurate detection of small opacities were designated as the Appendix 1 Table A1 algorithm

– Large opacity: 15 × (sensitivity + specificity −1) = large opacity accuracy marking………………… (2)
The total cases subjected to large opacity were designated as the Appendix 1 Table A1 algorithm

– Pleural plaque: 15 × (sensitivity + specificity −1) = pleural plaque accuracy marking…..……………..(3)
The total cases subjected to pleural plaque were designated as the Appendix 1 Table A1 algorithm.

ii) Consistency of reading results is marked for profusion and shape of small opacities. Crude agreement of profusion and crude agreement of shape were determined by using the following marking matrices:

– Profusion: 25 × crude agreement = profusion consistency marking……..……………..(4)
Cases of profusion 1/0 or higher were subjected to the marking for consistency. One minor category difference was allowed for any cases (Table A2).

– Shape: 15 × crude agreement = shape consistency marking……………..……………(5)

* Sixty points or more of 100 points were needed to pass the AIR Pneumo Certification test.
Total points = (1) + (2) + (3) + (4) + (5)>60 or <60 (i.e., 60 points was the cut-off mark)