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Osaka University
Performance of Various X-ray Film/screen Systems in Demonstrating Small Simulated Low-density Lung Nodules

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X線フィルム/スクリーンシステムの物理特性の違いによる肺野低密度結節影の検出能の検討

丸山雄一郎

肺野の早期腫瘍などの微細な結節影を検出するためには、胸部単純X線像の診断・異常判定を含む低密度肺野域において、肺野内の結節影の検出能にX線フィルム/スクリーンのコントラストや鮮明度、粒状性などが与える影響について検討した。胸部単純撮影用X線フィルムの増感紙システムには以下の6種類（富士メディカル製：HR3, super/HR3, super/HR4, super30/HR3, UR-1, UR-2）を用いた。高さ10mmと5mmで球形、直径1/2および上1/3が球形で観察がりの3種類の体部結節（塩化ビニール製）を撮影し、結節周囲領域の黒化度が0.27, 0.33, 0.4および0.5のフィルムを各20枚、濃度条件は同じであるが結節を置かずに撮影したものを40枚作製し、合計384枚について放射線診断係8名が観察結果の観察方法を5段階の確率度で判定した。判定結果をROC解析しAz値を計算した。検出率が高くなる結節の検出能を高めるためにには、肺野内結節影の検出能を高めることが必要である。すなわち、今回検討したフィルム/スクリーンシステムは良好な検出能を示した（P < 0.05）。X線フィルムの特性曲線において低濃度範囲でコントラストが高いことが望ましい。また低濃度領域で結節の不鮮明な結節影の検出能を高めるためににはシステムの粒状性も重要である。結節影としての結節影は、通常低密度領域に存在する結節影の検出に適する。

Introduction

A high-quality, conventional chest radiograph should be obtained in lung cancer screening programs to efficiently detect the faint, small nodular shadows due to early lung cancer in the lung fields, although it is difficult to image the entire lung field within the linear part of the characteristic curve of the screen-film system owing to the wide variation in tissue density in the thorax, which ranges from the well averted lung superimposed on the intercostals spaces to the lung area superimposed on the hiliar or diaphragm. In the detection of early cancer in the lung fields, it is important to consider the very low density (CT values of nearly -600 HU to -300 HU) commonly exhibited by early adenocarcinomas in the lung. The detectability of such nodules would be greatly influenced by the contrast and noise characteristics of the photographic system, the complexity of anatomical structures around the nodule, the characteristics of the observation system for x-ray films, the interpreter, and so on. The choice of x-ray film/screen system basically determines the efficacy of screening; specifically, the contrast characteristics of x-ray films together with noise level, which varies at different optical densities, affect the detectability of nodular shadows. The present study was carried out to determine the most suitable sersetricomtrial characteristics and to assess the effects of the noise level of the x-ray filmscreen system on the detectability of nodular shadows within the lung fields, particularly in low-density areas.

Materials and Methods

1. Materials

The x-ray equipment and screen/film combinations used in the study are listed below.

X-ray system: HD150B-3C (Shinadzu Corporation, Tokyo)
X-ray tube: P38C (focal spot size, 0.3/0.8 mm)
X-ray film/screen systems: six combinations, including HR-S/HR-3 (HR 3), SUPER HR-S/HR-3 (super/HR-3), SUPER HR-5/HR-3 (super/HR-3)

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Key words: Radiography, Film screen system Observer performance, Lung nodule

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Processing of radiographs: processor KX-500 automatic film processor (Konica Corporation, Tokyo); developer, RD-3; development temperature, 32.5°C. The characteristic curves under the above conditions and the density gamma curves are shown in Figs. 1 and 2, and root mean square (RMS) values are shown in Fig. 3. The characteristic curves, the density gamma curves and RMS values were counted using our sample films. The characteristics of each system are shown in Table 1.

2. Simulated nodules

Six types of simulated nodules were prepared from vinyl chloride in two sizes (5 and 10 mm) and three shapes (spherical, 1/2 flared spherical, and 2/3 flared spherical). The base diameters of the 1/2 and 2/3 flared spherical nodules were identical: 7.5 mm for the 5-mm size and 15 mm for the 10-mm size (Fig. 4). The spherical nodules represented well-defined nodules, and the flared spherical nodules represented poorly defined nodules (Fig. 5).

3. X-ray films for interpretation

Imaging parameters: x-ray tube voltage, 120 kVp; tube current, 130 mA; FFD, 220 cm.

Exposure time: Four exposure times were selected to obtain background optical density (BOD) values for the nodules of 0.27, 0.33, 0.4, and 0.5 for the nodules of 5 mm and 10 mm size. Twenty radiographs were printed on an x-ray film (14" by 14") on which a 4 by 4 square grid (with each frame 6 cm by 6 cm in size) had been predetermined with a simulated nodule placed in it. X-ray exposure was performed with a flat acrylic plate with a thickness of 20 cm placed on the film to adjust the radiographic density.

X-ray films for interpretation were prepared by dividing the x-ray films obtained as described above into separate frames of 2880 grids with all types of simulated nodules generated for interpretation (20 grids for each combination of imaging parameters: 6 screen/film systems, 6 nodule types, and 4 different density conditions). In addition, 360 grids without nodules were generated (40 grids for each combination of imaging parameters: 6 photographic systems and 4 density conditions). A total of 3840 grids were randomly arranged and placed on a view box with a brightness of approximately 6000 lux. During interpretation, areas surrounding the grids were covered to make them dark.

4. Interpretation

Eight diagnostic radiologists with 2 to 32 years of clinical experience evaluated all test grids. Prior to the interpretation of x-ray films, a sample film in which the six types of simulated
nodule had been imaged at BOD 0.5 were shown to the interpreters. They then evaluated all test grids in random sequence and recorded the presence or absence of nodule on each grid. The following five levels of confidence were used: (1) nodule shadow absent, (2) nodular shadow probably absent, (3) nodular shadow possibly absent or present, (4) nodular shadow probably present, (5) nodular shadow present. The time required for evaluation of each film was approximately 5 seconds, and images were observed at a viewing distance of 40 to 50 cm. However these conditions could be adjusted as desired by the interpreter.

5. Statistical analysis

The accuracy values for 144 combinations of the test parameters (consisting of 6 nodule types, 4 optical densities and 5 screen/film systems) were calculated for each of the eight interpreters. Moreover receiver operating characteristic (ROC) analysis\(^5\) was performed by generating ROC curves using the ROCFIT program to calculate the area under the curve (Az). Mean values of 8 observers between the groups were compared using Student's t-test or Welch's t-test. The statistical software package used was SPSS™.

Results

Detection rate of simulated nodules according to the photographic system

Table 2 shows the results of the interpretation experiment. For 10-mm nodules, Az was high for all photographic systems examined. Only at BOD 0.27, was UR-2 superior to other systems, particularly as compared with HR-4 or HR-3.

For 5-mm nodules, UR-2 gave the best results, followed by the HR series. UR-1 was inferior to the others; in particular, the difference was large at BOD 0.27, becoming less as optical density increased. When BCD was 0.40, no statistically significant difference was recognized among systems, excluding UR-1, and at BOD 0.50 the results were identical. In comparison between

![Figure 4: Photographs and dimensions of spherical, 1/2 flared spherical, and 2/3 flared spherical simulated nodules](image)
super/HR-3 and super/HR-4, in which the same x-ray film and different screens were used, the latter was inferior at BOD 0.27.

2. Detection rate of nodules according to film density

For 10-mm nodules, UR-2 was the best in detecting nodules at BOD 0.27, as shown in Table 2. At BOD values of 0.33, 0.40, and 0.50, detectability was higher than at BOD 0.27, and there was no statistically significant difference between 0.33, 0.40 and 0.50. For 5-mm nodules, UR-2 showed the best detectability at a density of 0.27 followed by the HR series and UR-1. Fig. 6 shows the ROC curves for each imaging system shown with 2/3 spherical nodules. No differences were detected between UR-2 and the HR series at BOD 0.33 or higher. The detectability of UR-1 was frequently lower than that of UR-2 and the HR series. Figs. 7A, and 7B illustrate averaged ROC curves. In the HR series and UR-1, detectability was markedly decreased at BOD 0.27, compared with density values of 0.33 to 0.50 (P < 0.01). For UR-2, on the other hand, almost identical detectability was obtained, compared with the results obtained at density values of 0.27 to 0.50.

3. Detection rate of nodules according to their configuration

Table 3 shows differences in detectability according to the shape of the nodule for 1/2 and 2/3 flared spherical nodules with identical base diameters. For 10-mm nodules, Az values were larger for 1/2 flared spherical nodules than for 2/3 flared spherical nodules, irrespective of the system used, when BCD was 0.27. In particular, statistically significant differences were recognized (P < 0.01) for super/HR-3, super/HR-4, and UR-2. Even for 5-mm nodules, the Az values of 1/2 flared spherical nodules were

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Film/screen system</th>
<th>Spherical</th>
<th>1/2 flared spherical</th>
<th>2/3 flared spherical</th>
</tr>
</thead>
<tbody>
<tr>
<td>10mm</td>
<td></td>
<td>Density</td>
<td>0.27</td>
<td>0.33</td>
</tr>
<tr>
<td>HR-3</td>
<td></td>
<td>0.92</td>
<td>0.97</td>
<td>0.98</td>
</tr>
<tr>
<td>super/HR-3</td>
<td></td>
<td>0.91</td>
<td>0.97</td>
<td>0.98</td>
</tr>
<tr>
<td>super3D/HR-3</td>
<td></td>
<td>0.95</td>
<td>0.98</td>
<td>0.98</td>
</tr>
<tr>
<td>super/HR-4</td>
<td></td>
<td>0.52</td>
<td>0.97</td>
<td>0.98</td>
</tr>
<tr>
<td>UR-1</td>
<td></td>
<td>0.52</td>
<td>0.97</td>
<td>0.98</td>
</tr>
<tr>
<td>UR-2</td>
<td></td>
<td>0.57</td>
<td>0.97</td>
<td>0.98</td>
</tr>
<tr>
<td>5mm</td>
<td></td>
<td>Density</td>
<td>0.27</td>
<td>0.33</td>
</tr>
<tr>
<td>HR-3</td>
<td></td>
<td>0.79</td>
<td>0.93</td>
<td>0.97</td>
</tr>
<tr>
<td>super/HR-3</td>
<td></td>
<td>0.72</td>
<td>0.88</td>
<td>0.97</td>
</tr>
<tr>
<td>super3D/HR-5</td>
<td></td>
<td>0.81</td>
<td>0.93</td>
<td>0.96</td>
</tr>
<tr>
<td>super/HR-4</td>
<td></td>
<td>0.69</td>
<td>0.91</td>
<td>0.96</td>
</tr>
<tr>
<td>UR-1</td>
<td></td>
<td>0.69</td>
<td>0.88</td>
<td>0.96</td>
</tr>
<tr>
<td>UR-2</td>
<td></td>
<td>0.88</td>
<td>0.95</td>
<td>0.96</td>
</tr>
</tbody>
</table>

* statistically significant difference (P < 0.05)

HR-3 = HR-3/HR-3, super/HR-3 = SUPER HR-S/HR-3, super/HR-4 = SUPER HR-S/HR-4, super3D/HR-3 = SUPER HR-S3D/HR-3, UR-1 = UR-1/HG-M, UR-2 = UR-2/HG-M
In low-density areas using super/HR-3 and UR-1, in particular, the differences were the largest. However, no statistically significant differences were recognized.

Analysis of the results shown in Tables 1 and 2, in a comparison of spherical and 2/3 flared spherical nodules, revealed statistically significant differences (p < 0.05) between super/HR-3, super/

HR-4, and UR-2 for 10-mm nodules when BOD was 0.27. In a comparison of spherical and 1/2 flared spherical nodules, no statistically significant differences were recognized between systems, irrespective of the optical density.

**Discussion**

In frontal chest radiographs, approximately 43% of the lung area and approximately 26% of the lung volume may be obscured by cardiac mediastinal and stbd arophragmatic structures. It is important to achieve high sensitivity to clearly visualize the areas that tend to be obscured. Several methods have been employed to overcome this difficulty, including appropriate selection of the screen/film system and the use of high tube kV settings, compensation filters, and so forth. Several kinds of wide-latitude film for thoracic imaging are now available; wide-latitude film minimizes film darkening in high-exposure areas, and extended-latitude film further provides greater darkening in low-exposure areas, which might lead us to expect a higher contrast in visualizing any abnormality in these regions. However, contrary to this expectation, some extended-latitude films may not improve the recognition of low-density nodules in underexposed areas owing to their low gradient in the low-density range of the characteristic curve.

To clarify these points, more detailed investigations into the effect of the characteristic curve are warranted. In the present

**Fig. 6** ROC curves for the six film/screen systems (5-mm, 2/3 flared spherical nodules at 0.27 density)

**Fig. 7** Averaged ROC curves for eight observers in detecting simulated nodules: (A) UR-1/HR-3-M, (B) UR-2/HG-M
Table 3  Observer performance evaluated by the area under the ROC curve (Az)

<table>
<thead>
<tr>
<th></th>
<th>10mm thickness</th>
<th>5mm thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2/3 flared spherical Az</td>
<td>1/2 flared spherical Az</td>
</tr>
<tr>
<td>HR-3</td>
<td>0.27</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>0.33</td>
<td>0.96</td>
</tr>
</tbody>
</table>
|                  | 0.4            | 0.98          | 0.96          | 0.55          | 0.87          | <
|                  | 0.5            | 0.98          | 0.96          | 0.86          | 0.97          |
| super/HR-3       | 0.27           | 0.80          | 0.92          | 0.89          | 0.83          |
|                  | 0.33           | 0.94          | 0.97          | 0.90          | 0.83          |
|                  | 0.4            | 0.98          | 0.96          | 0.87          | 0.94          | >
|                  | 0.5            | 0.98          | 0.96          | 0.96          | 0.94          |
| super30/HR-3     | 0.27           | 0.90          | 0.94          | 0.88          | 0.77          |
|                  | 0.33           | 0.96          | 0.96          | 0.90          | 0.83          |
|                  | 0.4            | 0.98          | 0.96          | 0.96          | 0.97          |
|                  | 0.5            | 0.98          | 0.96          | 0.97          | 0.97          |
| super/HR-4       | 0.27           | 0.78          | 0.93          | 0.88          | 0.63          |
|                  | 0.33           | 0.92          | 0.97          | 0.90          | 0.84          |
|                  | 0.4            | 0.96          | 0.96          | 0.95          | 0.96          |
|                  | 0.5            | 0.96          | 0.96          | 0.99          | 0.98          |
| UR-1             | 0.27           | 0.86          | 0.89          | 0.87          | 0.75          |
|                  | 0.33           | 0.96          | 0.97          | 0.87          | 0.90          |
|                  | 0.4            | 0.96          | 0.98          | 0.92          | 0.95          |
|                  | 0.5            | 0.97          | 0.98          | 0.95          | 0.96          |
| UR-2             | 0.27           | 0.98          | 0.97          | 2.85          | 0.89          |
|                  | 0.33           | 0.97          | 0.97          | 2.93          | 0.96          |
|                  | 0.4            | 0.98          | 0.97          | 2.97          | 0.97          |
|                  | 0.5            | 0.98          | 0.97          | 2.97          | 0.98          |

"<" and "<<" mean statistically significant difference.
". : P < 0.05, "<<" : P < 0.01.

The table shows performance data for different film/screen systems with various thicknesses and observer evaluations. The data includes Az values for ROC curves, indicating the sensitivity of the system for detecting nodules.

Study, six x-ray film/screen systems with various characteristic curves and noise characteristics were used to investigate the relationship between these photographic characteristics of the system and the detection rate of faint nodules in low-density areas. Additional studies were performed to investigate the relationship between the sharpness of the nodule contour and the detection rate. The ability to detect a nodule depends upon a number of factors, including nodule size and density, sharpness of boundaries, noise in the radiograph, surrounding (anatomical) complexity and viewing conditions. Theoretically, Photographic contrast C is defined as follows:

\[ C = 0.34 \times G \times d \times (\mu_1 - \mu_2) \]

Where C: contrast of the object, G: gradient of the film at the density level of interest, d: thickness of the nodule, and \( \mu_1 \) and \( \mu_2 \): linear attenuation coefficients of the nodule and the surrounding material, respectively. Because the present study focused on the detection of nodules in specific density regions, particularly those with relatively low optical density values of 0.50 or less, corresponding to the lung fields superimposed over the heart, diaphragm, and ribs on chest x-ray films, the value of G was not constant, with lower values in less-exposed regions (Fig.2). Due to the differences in these photographic features of the systems, the detection of nodules was inconsistent among the systems. By using UR-2 with a maximum gradient, the best results were obtained for detecting 10-mm nodules at the lowest density of 0.27. For 10-mm nodules, nodule shadows were detected satisfactorily when the density was high, irrespective of the characteristics of the photographic system. The 5-mm nodules were again detected most satisfactorily using UR-2 at any optical density. UR-1 was inferior, although not significantly different from the HR series. This finding emphasizes the primary importance of film contrast in low-density areas. Next, at a low optical density of 0.27, the noise of the film resulted in low detectability in super/HR-4, which showed the worst value for RMS (Fig.3).
Detectability depends on the sharpness of the nodule's margins. To investigate this factor, 3 types of nodule configuration were used in this study: spherical, 1/2 flared spherical, and 2/3 flared spherical nodules of the same thickness. For 10-mm nodules, detectability was low for 2/3 flared spherical nodules at a low optical density of 0.27, with little difference between spherical and 1/2 flared spherical nodules, which indicates that the sharpness of the margins determines the detectability of the nodule. Detectability was further decreased in the HR-4 system, probably due to the inferior noise characteristics of this system.

No significant difference was observed between spherical and 2/3 flared spherical nodules with a thickness of 5 mm. This was presumably because the detectability of the latter type might be enhanced by the difference in the base area. From these findings, the sharpness of the margins of nodular shadows presumably improves the detectability of the nodule when a system which provides high-contrast images is employed. However, by far the most important factor is contrast. When a low-contrast system is used, the sharpness of the contours might not result in enhanced detectability.

Based on the findings of the present study, we conclude that diagnosis should be performed using a high-contrast x-ray image with sufficient noise to characterize detect nodular lesions in low-density areas where the lung fields are superimposed over the ribs, the mediastinum, or other structures. The results of this study also indicate that photographic systems equivalent to UR-2 which can provide high-contrast images with superior noise characteristics are most suitable for the detection of nodules in low-density areas within the lung fields. Portions of the lung fields superimposed over the ribs, mediastinum, and diaphragm tend to become low-density areas when such a system is used. To overcome this problem, it is desirable to use other methods such as high-voltage imaging, compensating intensifying screens, compensating x-ray filters, and so on.

**Conclusion**

1. In order to improve the detectability of low-density nodules in areas of low optical density, a photographic system that maintains high contrast in low-density areas should be employed. Therefore, it is desirable that the characteristic curve of the x-ray film selected exhibit high contrast even in low-density areas.

2. In order to improve the detectability of nodular shadows with unsharp margins in low-density areas, the noise characteristics of the system should also be carefully considered.

3. The use of a chest x-ray system with high contrast and improved noise level, such as the UR-2 system, is appropriate for the detection of peripheral early lung cancers in low-density areas within the lung.

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**References**


