Radiol Phys Technol (2012) 5:123–128
DOI 10.1007/s12194-012-0145-6

Computerized detection of lung nodules by CT for radiologic technologists in preliminary screening

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Received: 12 December 2011 / Revised: 21 January 2012 / Accepted: 24 January 2012 / Published online: 3 February 2012

Abstract In Japan, radiologists and radiologic technologists are endeavoring to improve the quality of lung CT screening. In particular, preliminary screening by radiologic technologists is expected to decrease radiologists' burden and improve the accuracy of CT screening. We considered that an application of computer-aided detection (CAD) would also be as useful in preliminary screening as in the radiologist's regular reading. Our purpose in this study was to investigate the potential of the application of CAD to preliminary screening. CAD software that we developed was applied to 17 lung CT scans that radiologic technologists had pre-interpreted. A radiologist recognized 29 lung nodules from the CT images, whereas radiologic technologists did not recognize 11 of the 29 nodules at their pre-reading. Our CAD software detected lung nodules at an accuracy of 100% (29/29), with 4.1 false positives per case. The 11 nodules that radiologic technologists did not recognize were included in the CAD-detected nodules. This result suggests that the application of CAD may aid radiologic technologists in their preliminary screening.

Keywords Computer-aided detection (CAD) · Pulmonary nodule · Lung CT screening · Preliminary screening · Radiologic technologist

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1 Introduction

The practical use of CT screening has been discussed in Japan [1–3], and recently, CT screening has been spreading as an optional examination for early detection of lung cancer. However, the accuracy of CT screening may deteriorate because of the spread of this method. For avoiding the deterioration and improving the accuracy in the future, quality control of CT screening is essential. In Japan, the Accreditation Council for Lung Cancer CT Screening was organized in 2009. The council is a non-profit organization that certifies radiologists and radiologic technologists who can maintain the quality of CT screening. Certified radiologic technologists play a role in regular CT scans, reliable control of CT devices, management of patient information, radiation control, and preliminary screening [4]. In particular, it is expected that preliminary screening by radiologic technologists decreases radiologists' burden and improves the efficiency of CT screening. In the preliminary screening, radiologic technologists detect abnormalities in CT images and indicate the detected results to radiologists. However, there are two prerequisites for the practice of preliminary screening. First, preliminary screening by radiologic technologists must be carried out under a certified radiologist's supervision. Second, radiologic technologists must attend a professional training program with regard to anatomy, diseases, and reading of lung images. They need to pass an examination in their training program. If a medical institution had many certified radiologists and their image-interpretation duties were not a heavy burden, it would be unnecessary to carry out preliminary screening by radiologic technologists. However, there are a number of hospitals in Japan that have a shortage of radiologists. If a medical institution does not have sufficient certified radiologists and their image-interpretation duties are too heavy a burden, the institution should consider practicing preliminary screening by radiologic technologists.

We have considered that computer-aided detection (CAD) software can be useful in preliminary screening by radiologic technologists. If they use the CAD software efficiently, it is expected that the accuracy of their preliminary screening would be improved. To our knowledge, there are no reports regarding the application of CAD to preliminary screening by radiologic technologists. Our purpose in this study was to investigate the potential of the application of CAD to preliminary screening. CAD software that we developed was applied to lung CT images that radiologic technologists had pre-interpreted.

2 Materials and methods

2.1 Materials

CT images obtained from 17 patients were used for this investigation. A single CT scan produced 33–51 slice images. The slice thickness and the x–y resolution were 7.5 and 0.68 mm, respectively. A radiologist recognized 29 lung nodules with diameters of 5–25 mm from the CT images produced with 7.5-mm slice thickness and high resolution, whereas two radiologic technologists did not recognize 11 of the 29 nodules at their pre-reading. Figure 1 shows histograms of the nodule diameters.

For this study, the CT images were selected from a hospital in Japan. In the hospital, radiologic technologists pre-read lung CT images as a part of their routine work. Reconstructed CT images with 7.5-mm slice thickness are used in the pre-reading. If the technologists recognize nodule shadows in the pre-reading, they generate and preserve high-resolution CT (HRCT) images corresponding to suspicious shadows. Radiologists interpret all of the images with 7.5-mm slice thickness and the HRCT images that radiologic technologists have generated in their pre-reading. If radiologists recognize any nodules other than the suspicious shadows in HRCT images, they request the radiologic technologists to generate new HRCT images for a more careful survey of the nodules. Therefore, radiologic technologists were additionally requested to generate HRCT images for the 11 undetected nodules in the 17 CT scans used in this study.

2.2 Methods

Figure 2 shows a flowchart of the nodule detection method we developed. The slice thickness in the CT data was linearly interpolated so as to make them isotropic with a voxel size of 0.68 mm. Lung regions were segmented based on a region-growing technique and morphologic dilation/erosion techniques. We applied template matching [5], a dot-enhancement filter [6], and a quoit filter [7] to the CT images, and we generated an integrated image from the three processed images to determine regions containing nodules. In template matching, we used two templates with a three-dimensional Gaussian distribution, 7.48 and 17.68 mm in diameter. The similarity between the reference pattern (template) and the observed pattern was calculated with use of a cross-correlation coefficient.

For the dot-enhancement filter, a dot is defined as a three-dimensional Gaussian function with a distribution of σ. We obtained output values $Z_{dot}(\lambda_1, \lambda_2, \lambda_3)$ with the filter using three Gaussian functions with $\sigma = 1$, 2, and 3 at each voxel. λ_1, λ_2, and λ_3 are eigenvalues calculated from the Hessian matrix of the Gaussian function. In three values of Z_{dot} calculated with $\sigma = 1$, 2, and 3, the maximum value was determined as the final output value of the filter at the voxel.

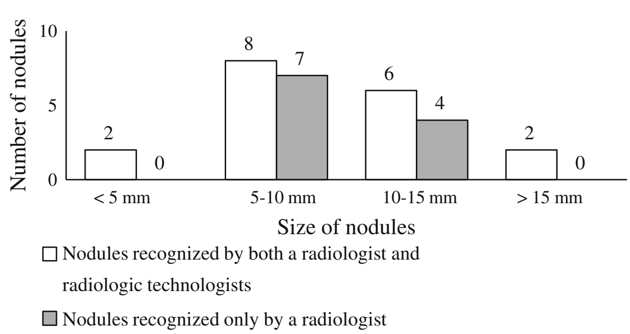

Fig. 1 Histograms of nodule diameters

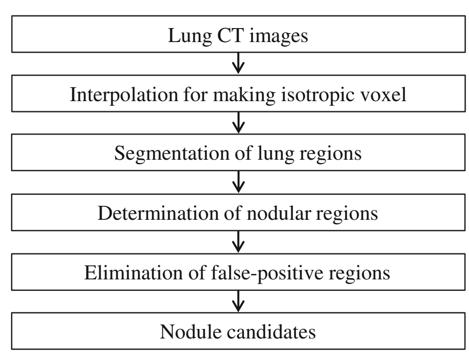

Fig. 2 Flowchart of our nodule detection method

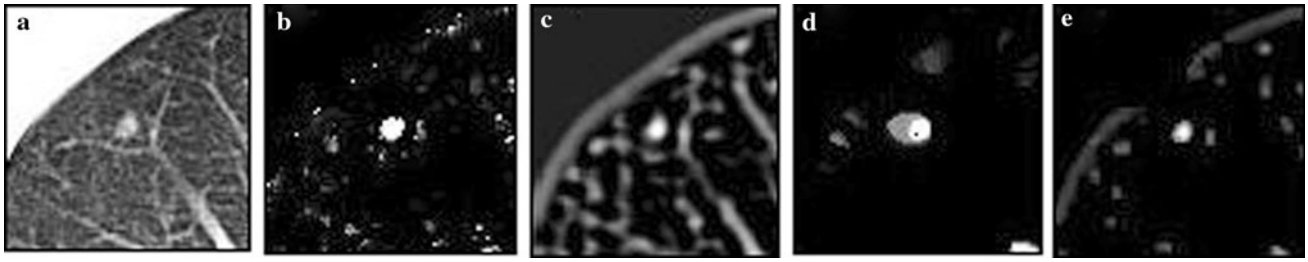

Fig. 3 Illustrations of CT images with determined nodular regions. **a** CT image with a nodule. **b** Image processed by dot-enhancement filter. **c** Image processed by template matching. **d** Image processed by quoit filter. **e** Integrated image of three processed images

The three-dimensional quoit filter consists of a solid spherical filter and a hollow spherical filter. The output value of the quoit filter is the difference between two values obtained using the solid and the hollow spherical filters. The output values were normalized. The parameters of the filters were $r_1 = r_2 = 7.48$ mm, and $r_3 = 6.12$ mm. r_1 and r_2 are the diameters of the solid spherical filter and the hollow spherical filter, respectively. r_3 is the diameter of the hollow region in the hollow spherical filter.

Nodular regions were determined by weighting the output values obtained from the three techniques, as follows:

$$I(x,y,z) = \begin{cases} w_1 T(x,y,z) + w_2 Q(x,y,z) & \text{if } D(x,y,z) > 0 \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where $T(x, y, z)$, $Q(x, y, z)$, and $D(x, y, z)$ are the output values of the template matching, the quoit filter, and the dot-enhancement filter, respectively. $I(x, y, z)$ is the integrated image, and w_1 and w_2 are the weighting factors. We used $w_1 = 0.4$ and $w_2 = 0.6$ in this study. Figure 3 illustrates images obtained by application of the three techniques to a CT image with a nodule. Thirteen features of each determined nodular region were calculated and used for eliminating false-positive (FP) regions. Table 1 is a list of the features. As given in the table, some features, e.g., the mean voxel value, were calculated from both the original CT image and the integrated image. Consequently, twenty-one feature values were obtained for a nodular region. We used a minimum-distance classifier [8, 9] based on the Mahalanobis distance [10] in a twenty-one-feature space to classify true nodules and FPs.

Table 1 List of features for false-positive elimination

Feature	Calculation sources
Volume	Integrated image
Degree of sphericity	Integrated image
Mean voxel value	CT image, integrated image
Standard deviation of voxel values	CT image, integrated image
Coefficient of variation of voxel values	CT image, integrated image
Maximum voxel value	CT image, integrated image
Minimum voxel value	CT image, integrated image
Maximum voxel value/voxel value at the center	CT image
Minimum voxel value/voxel value at the center	CT image
Second moment	CT image, integrated image
Third moment	CT image, integrated image
Fourth moment	CT image, integrated image
Compactness	CT image

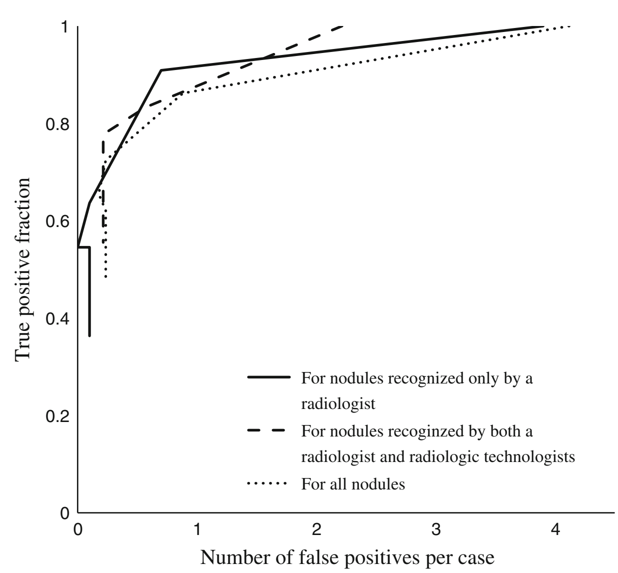

Fig. 4 FROC curves obtained by our nodule detection method

3 Results

Figure 4 shows free-response receiver operating characteristic (FROC) curves obtained by our nodule detection method. In the FROC curve for all nodules, our method detected lung nodules at a true-positive fraction (TPF) of 1.0 (29/29), with 4.1 FPs per case. Figure 5 shows

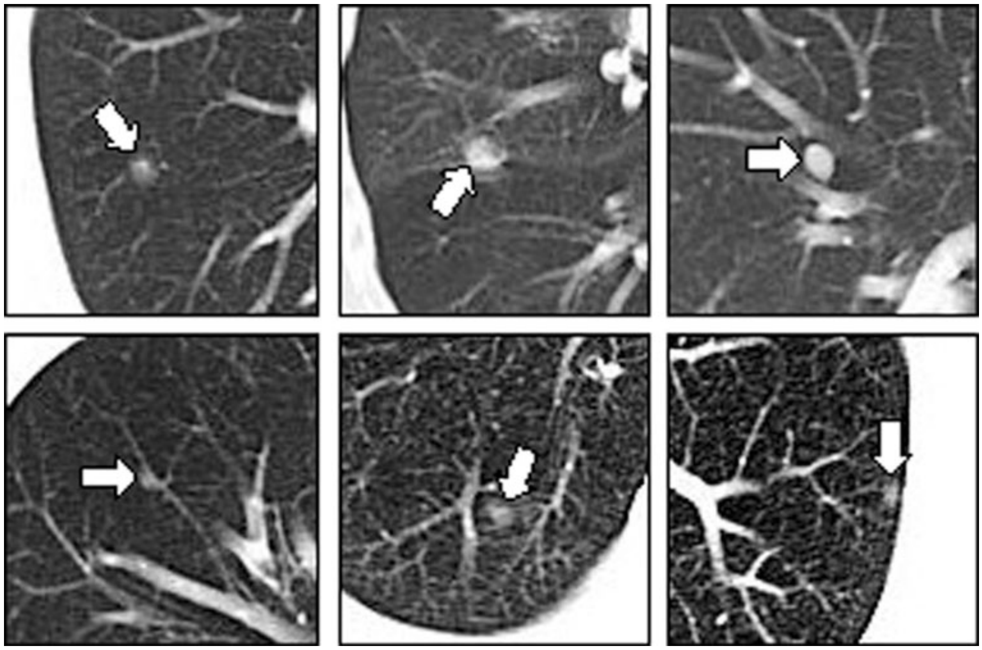

Fig. 5 Illustrations of CT images with nodules detected by our method. *Arrows* indicate nodules. Both a radiologist and radiologic technologists recognized the *upper three nodules*. The *lower three nodules* were recognized only by a radiologist

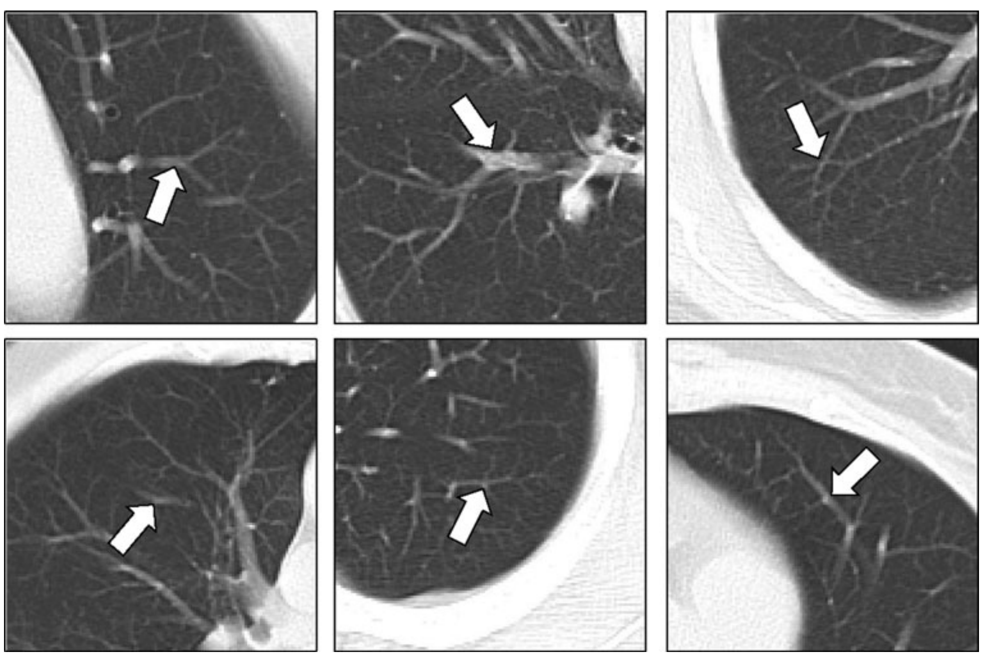

Fig. 6 Illustrations of CT images with false positives indicated by *arrows*

illustrations of CT images with nodules detected by our method. Both a radiologist and two radiologic technologists recognized the upper three nodules in Fig. 5. The lower three nodules in Fig. 5 were recognized only by the radiologist. Figure 6 shows illustrations of CT images with FPs.

4 Discussion

Our CAD software was able to detect all nodules in 17 CT scans. In the step of the determination of the first nodular regions, we set a condition that the output value of the dot-enhancement filter should be greater than zero, as shown in

Table 2 Sensitivities of template matching, quoit filter, dot-enhancement filter, and our method of integrating the three techniques

	For nodules recognized by both a radiologist and two technologists	For nodules recognized only by a radiologist	For all nodules
Template matching	100% (18/18)	82% (9/11)	93% (27/29)
Quoit filter	83% (15/18)	82% (9/11)	83% (24/29)
Dot-enhancement filter	72% (13/18)	82% (9/11)	76% (22/29)
Our method	100% (18/18)	100% (11/11)	100% (29/29)

Eq. 1. According to this condition, it seems that all nodules can be detected with use of only the dot-enhancement filter. However, several nodules were not actually identified because the background region surrounding the nodule also showed output values similar to the output value of the nodular region. Table 2 shows the maximum sensitivities that were obtained with a single use of the template matching, the quoit filter, and the dot-enhancement filter. The sensitivities were calculated when the nodular region could be separated from the background region and could be identified as a solitary region. Our method of integrating the three techniques was able to detect all nodules, whereas the single use of each technique did not detect all nodules.

Our CAD method was applied to interpolated CT images with isotropic voxels. The interpolation may cause some blur in the *z*-direction resolution. However, the interpolation enables us to perform a volumetric analysis in the nodule detection process. When we applied the CAD method to each slice CT image with 7.5-mm thickness, the TPF was 1.0 with 40 FPs per case. The volumetric analysis is considered particularly important for suppressing FPs. It was noted that the false-positive result for the two radiologic technologists was 0.8 per case for the CT images used in this study.

Our CAD application was able to detect the 11 nodules recognized only by a radiologist (these nodules were not recognized by two radiologic technologists). This result suggests that CAD software have the potential to assist radiologic technologists in their preliminary screening. If radiologic technologists use the CAD software efficiently in the preliminary screening, their sensitivity of nodule recognition would be improved. Also, the CAD software will improve the quality of CT screening for lung cancer.

However, FPs may increase with the use of CAD software, instead of yielding an improvement in sensitivity. A large number of FPs may exhaust observers and decrease the quality of CT screening. To overcome this problem, the CAD software would have to be refined further. We believe that our CAD software with a performance of TPF $= 1.0$ with 4.1 FPs per case does not cause too much fatigue for the observers. However, we do not have any evidence for such a claim. Therefore, we should investigate how many FPs should be allowed for the CAD used in preliminary screening by radiologic technologists. An observer performance study such as ROC analysis would be needed in future investigations. In addition, we need more cases of pulmonary nodules for further investigation of our CAD method.

5 Conclusion

We investigated the potential of the application of CAD to preliminary screening conducted by radiologic technologists. Our CAD software was applied to lung CT images that radiologic technologists had pre-interpreted. The CAD application allowed us to detect all nodules that the radiologic technologists could not recognize. This result suggests that the application of CAD may aid radiologic technologists in their preliminary screening.

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