Effect of Multiscale Processing in Digital Chest Radiography on Automated Detection of Lung Nodule with a Computer Assistance System

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The aim of this study is to evaluate the effect of multiscale processing in digital chest radiography on automated detection of lung nodule with a computer-aided diagnosis (CAD) system. The study involved 58 small-nodule patient cases and 58 normal cases. The 58 patient cases included a total of 64 noncalcified lung nodules up to 15 mm in diameter. Each case underwent an examination with a digital radiography system (Digital Diagnost, Philips Medical Systems), and the acquired image was processed by the following three types of multiscale processing (Unique Image Processing Package, Philips Medical Systems) respectively: (1) standard image from the default processing parameter (structure preference, 0.0), (2) high-pass image with structure preference of 0.4, (3) low-pass image with structure preference of -0.4. The CAD output images were produced with a real-time computer assistance system (IQQA™-Chest, EDDA Technology). Two experienced chest radiologists established the nodule gold standard by consensus reading according to computed tomography results, and analyzed and recorded the detection of lung nodules and false-positive detections of these CAD output images. For the entire cases involved (each case with three types of different processing), a total of 348 observations were evaluated by the receiver operating characteristic (ROC) analysis. The mean area under the ROC curve (A_z) value was 0.700 for the standard images, 0.587 for the high-pass images, and 0.783 for the low-pass images. There were statistically significant A_z values among these three types of processed images ($p < 0.01$). Multiscale processing in digital chest radiography can affect the automated detection of lung nodule by CAD, which is consistent with effects from visual inspection.

KEY WORDS: Digital radiography (DR), computed-aided diagnosis (CAD), image processing, lung nodule, receiver operating characteristic curve (ROC)

INTRODUCTION

Lung cancer is the leading cause of cancer-related deaths in the world. More than 1.3 million people die of lung cancer each year.¹ Although the overall 5-year survival rate is only about 15%, for stage I patients, the rate may go up to 70%.² The early detection and diagnosis of cancerous lung nodules are important for improving chances of survival. Currently, chest radiograph is still the most commonly used imaging modality for lung cancer screening because it is economical and easy to use. However, radiologists may fail to detect some lung cancers that are visible on chest radiographs in retrospect.³ Possible causes of missed lung nodules on chest radiographs include the superimposed anatomical structures and tunnel vision on the obvious abnormality while overlooking other suspicious areas. Radiologists' oversight of abnormal regions is the major cause for failing to detect lung cancers early.⁴⁻⁶

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Several studies have reported that CAD systems with automated detection methods for lung nodules can significantly improve the detection of lung nodules by identifying and indicating suspicious focal opacities on chest radiography.⁷⁻⁹ However, whether and how different post-processing may affect the accuracy of lung nodule detection with CAD is not reported.

The purpose of our study was to evaluate whether different types of multiscale processing in digital chest radiography can affect the detection of nodules with a computer-aided diagnosis system.

MATERIALS AND METHODS

Digital Radiography

Chest radiographs in this study were exposed at 141 kV and were obtained using a digital radiography system (Digital Diagnost, Release 1.3, Philips Medical Systems, Hamburg, Germany). The imaging plate was 43×43 cm in size (matrix size of 3,000×3,000) and records 14 bits in gray level. Each acquisition was then processed with the unified image quality enhancement (UNIQUE) image processing software equipped. Three processed images were obtained for each acquisition using the following three types of multiscale processing: (1) standard image with default pro-

cessing parameters as follows: density 1.0, gamma 2.0, structure boost 2.0, noise compensation 0.0, and structure preference 0.0; (2) high-pass image with processing parameters as follows: density 1.0, gamma 2.0, structure boost 2.0, noise compensation 0.0, structure preference 0.4; (3) low-pass image with processing parameters as follows: density 1.0, gamma 2.0, structure boost 2.0, noise compensation 0.0; and structure preference -0.4. Figure 1 showed example images from the three types of different processing.

The image processing parameters of the digital radiography system (Digital Diagnost, Release 1.3) are briefly described below:

1. Density. The density setting adjusts the brightness of a particular part of an image. Value ranges from 0.5 to 2.5.
2. Gamma. The gamma value determines the overall contrast of the image. It has no direct influence on the detail contrast of the structures in the image. Value ranges from 0.5 to 6.0.
3. Structure preference. The structure preference value determines which structure size will be boosted. Value ranges from -2.0 to 2.0. When structure preference value is smaller than zero, general structures such as large fractures are accentuated and boost for fine structures is reduced. When structure preference value is larger than zero, finer structures are emphasized to allow better visualization, and boost for

Fig. 1. a Standard image shows a nodule in the right middle lateral. b High-pass image. Compared with the standard image, the edge of the lung nodule and the noise of the image are enhanced, whereas the contrast between the nodule and the surroundings decreases. c Low-pass image. Compared with the standard image, the nodule is enhanced and the contrast between the nodule and surroundings increases.

coarse structures is reduced. When structure preference value is equal to zero, all bands are structure boosted equally.

4. Structure boost. Applying structure boost allows enhancing the contrast in the structure sizes which have been previously selected in the structure preference setting. Low contrast structures are boosted with this parameter. Value ranges from 0.0 to 8.0.
5. Noise compensation. The lower the dose, the worse the signal-to-noise ratio. Bright low-density areas appear to contain more noise compared to the dark areas. When enhancing the contrast of the dark areas, the noise in the low-dose areas is also enhanced. Increasing the parameter "noise compensation" can reduce structure enhancement in this low-dose area to suppress this effect. Value ranges from 0.0 to 1.0.

CAD System

The IQQA™-Chest CAD is an interactive CAD system (IQQA™-Chest V1.2, EDDA Technology, Inc.). Its processing is a knowledge-based reasoning processing that includes nodule-specific enhancement, nodule segmentation, and local analysis. Nodule-specific enhancement enhances round structures with higher density than surrounding areas. Automated segmentation of candidate lesion structures is performed to further facilitate the examination of local image characteristics including contrast, shape, and spatial relationship to surrounding structures. The fusion of gray-level analysis, contrast analysis, and local regional analysis results in the candidate suspicious areas presented for physicians to reference and to further review before completing the computer-assisted detection of lesions.

CAD Performance Study

One hundred sixteen cases (58 normal and 58 abnormal with lung nodules) were involved for this study from April 2006 to March 2007 in our institution. Our institutional ethics committee approval was obtained before the beginning of this study. The cases were selected on the basis of confirmation on chest computed tomography (CT; interval between chest radiography and CT, 0–14 days; mean, 5.5 days).

The 58 normal radiographs were obtained from 30 women and 28 men whose ages ranged from 29 to 83 years (mean, 57 years). The 58 abnormal radiographs were obtained from 32 women and 26 men whose ages were from 31 to 84 years (mean, 59 years). The 58 nodule cases included 64 noncalcified nodules up to 15 mm in diameter on chest radiographs (nodule sizes ranged from 5 to 15 mm in diameter; mean, 11 mm). The 58 cases included 23 nodules of 5–9 mm and 41 nodules of 10–15 mm. The number of nodules per case ranged from one to three. Fifty-four (93%) of the 58 cases had one nodule, two (3%) had two nodules, two (3%) had three nodules (percentages did not add up to 100% due to rounding). Case selection explicitly excluded cases where nodules were inadequately visible on chest radiographs, although they were identified on CT scans. Cases that included nodules larger than 15 mm in diameter or included more than five nodules were also excluded.

According to Laurence's method,¹⁰ the lungs were divided into 12 zones. Each lung comprised three parts of equal height (upper, middle, and lower), and each part was divided into lateral and medial zones of equal width. The lung nodules were located in all 12 zones as follows: 2 in right upper lateral, 4 in right upper medial, 13 in right middle lateral, 5 in right middle medial, 10 in right lower lateral, 4 in right lower medial, 2 in left upper medial, 3 in left upper lateral, 4 in left middle medial, 9 in left medial lateral, 2 in left lower medial, and 6 in left lower lateral.

The three types of processed digital images were then processed by the real-time interactive CAD system (IQQA™-Chest V1.2, EDDA Technology, Inc.). Two experienced chest radiologists, each with experience of over 15 years, participated as observers. Before the test, ten cases (seven cases with normal findings and three nodule cases), which were not used in the subsequent test, were selected for training so that the radiologists were familiar with the CAD system. Then, these two radiologists established the nodule gold standard by consensus reading according to CT results, and analyzed and recorded the detection of lung nodules and false-positive detections of these CAD output images. The false-positive detections were classified into the following three groups: false-positives because of normal anatomic structures, which were recognized as pulmonary vessel,

rib edge, clavicle, junction of first rib and clavicle, scapula, sternoclavicular joint, calcification of costal cartilage, and nipple; findings outside the lung fields; and findings unrelated to normal anatomic structures. All digital radiographs and CAD processing results were reviewed on a display monitor (E-2320, 2KX2K, Barco, Belgium).

Statistical Analysis

Receiver operating characteristic (ROC) analysis was used to compare the detection of lung nodules with the CAD system on the standard images, the high-pass images and the low-pass images. Estimates of the mean area under the ROC curve (A_z) values and SD were computed using the computer program Statistical Package for the Social Sciences 11.5 for Windows. The statistical significance difference of the A_z values of different processed images was estimated using paired z test. Kruskal-Wallis t test was used to compare the patterns of false-positive detection with the CAD system on the three types of processed images. P values less than 0.05 were considered statistically significant difference.

RESULTS

The false-positive detections on three types of processed images for 58 normal cases were shown in Table 1.

For the standard images, there were 138 false-positive detections with an average of 2.38 false-positives per image. Among all false-positives, 88% (120 of 138) were easily recognized as normal anatomic structures, 7% (10 of 138) were findings located outside by the edge of the lung field, and 5% (7 of 138) were unrelated to normal anatomic structures.

For the high-pass images, there were 84 false-positive detections with an average of 1.45 false-positives per image. Among all false-positives, 89% (75 of 84) were recognized as normal anatomic structures, 6% (5/84) were findings located outside by the edge of the lung field, and 5% (4 of 84) were unrelated to normal anatomic structures.

For the low-pass images, there were 185 false-positive detections with an average of 3.19 false-positives per image. Among all the false-positives, 88% (163 of 185) were recognized as normal anatomic structures, 6% (13 of 185) were outside by the edge of the lung field, and 5% (9 of 185) were unrelated to normal anatomic structures.

There were no statistically significant patterns of false-positive detection with the CAD system on three types of images.

The detection rate of lung nodules with the CAD system was 67% (43 of 64), 41% (26 of 64), and 70% (45 of 64) on the standard images, the high-pass images, and the low-pass images, respectively. The A_z value was 0.700 for the standard images, 0.587 for the high-pass images, and 0.783 for the low-pass images (Fig. 2). There were statistically significant A_z values among these three types of processed images ($p < 0.01$).

DISCUSSION

In this study, we evaluated the effect of multiscale processing in digital chest radiography on automated detection of lung nodule with the CAD system. We analyzed the detection of lung nodules and false positives on the three types of multiscale processed images with the CAD system. The nodule detection rate with CAD was 67% (43 of 64), 41% (26 of 64), and 70% (45 of 64) for the standard images, the high-pass images, and the low-pass images, respectively. The A_z value was

Table 1. The Pattern of False Positives on the Three Types of Processed Images with CAD in 58 Normal Cases

Type of Images	Patterns of False-Positives and Frequency (Numbers, Percentages)									Total
	Pulmonary Vessel	Rib Edge	Junction of First Rib and Clavicle	Nipple	SternoClavicular Joint	Scapula	Calcification of Costal Cartilage	Outside of the Lung Field	Unrelated to the Anatomic Structure	
Standard	60 (44%)	34 (24%)	8 (6%)	8 (6%)	2 (1%)	6 (4%)	3 (2%)	10 (7%)	7 (5%)	138 (99% ^a)
High-pass	33 (39%)	21 (25%)	6 (7%)	6 (7%)	3 (4%)	5 (6%)	1 (1%)	4 (5%)	5 (6%)	84 (100)%
Low-pass	77 (42%)	47 (25%)	9 (5%)	10 (5%)	5 (3%)	11 (6%)	4 (2%)	13 (7%)	9 (5%)	185 (98% ^a)

^aPercentages may not add up to 100% because of rounding.

Fig. 2. ROC curves for the three types of processed images. A_z value is 0.700 for the standard images, 0.587 for the high-pass images, and 0.783 for the low-pass images.

0.700 for the standard images, 0.587 for the high-pass images, and 0.783 for the low-pass images. The A_z value of the low-pass images was significantly superior to that of the standard images and the high-pass images ($p < 0.01$), and the A_z value of the high-pass images was significantly inferior to that of the standard images ($p < 0.01$). The false-positive rate was an average of 2.34 (136 of 58) false positives per image of normal cases for the standard images, 1.45 (84 of 58) for the high-pass images, and 3.19 (185 of 58) for the low-pass images. Among the three types of images, the false-positive rate was the highest for the low-pass images and lowest for the high-pass images. Our results indicated that multiscale processing in digital chest radiography can affect the detection of lung nodules of this CAD system.

We explore this result by the following discussion of explanation. The spatial frequency composition of a digital radiography image (also for the input of CAD processing) depends on the characteristics of digital system, including digital detector and digital image processing models. For digital radiography system, the final diagnostic images displayed on monitors for physicians' review are processed images by equipped digital processing methods. The initial images obtained with digital system have wide dynamic range and,

when unprocessed, are not suitable directly for human vision of fine image details. Appropriate digital image processing can compensate for this aspect.^{11,12} Spatial frequency processing is accomplished by some modalities. Unsharp masking and multiscale processing are the most common processing techniques. Unsharp mask filtering is a simple image processing technique that can change the spatial frequency composition of an image. The technique splits an image into high and low spatial frequency components by using filtering and by subtracting the low-pass image from the original. The effects of unsharp mask filtering are dependent on the kernel size. Unsharp masking with small kernel size enhances high frequency, and medium mask size enhances medium frequency. Low frequency is enhanced with large kernel size, and local contrast is enhanced. Multiscale processing is another frequency processing technique, which is developed based on hierarchically repeated unsharp masking. It is more effective and flexible than unsharp masking. With Unlike unsharp masking, the image is split into two sub-images, and with multiscale processing, image is decomposed into several frequency bands. Each band contains information only from a particular structural size and different levels of contrast. The decomposition step can be implemented by repeatedly splitting the image into a high-pass component and a low-pass component. This process starts with the highest frequency band. The resulting low-pass component is then taken as input to the next stage until eight or more separate frequency bands have been created. For filtering, each of these sub-bands can be processed independently. By enhancing individual frequency bands or groups of frequency bands, size-specific processing is possible.¹³⁻¹⁶ In our study, different sub-bands were enhanced by different structure preference values for the three types of processing. As a result, the spatial frequency compositions of the three types of processed images were different.

In our study, each case was exposed once, and three types of processing (using different parameters of the UNIQUE software, in particular, using different structure preference values) were applied to achieve three types of images for display and review. Among the three types of images reviewed, the low-pass images processed with a structure preference value of -0.4 appear to improve the accuracy of lung nodule detection with the CAD

Fig. 3. a Scan of a 39-year-old man with standard processing. CAD output image indicates two suspicious areas (*circles*). These areas contain false-positive findings because of normal anatomic structures. The true nodule is missed (*arrow*). b Scan of the same 39-year-old man with high-pass processing. CAD output image indicates two suspicious areas (*circles*). These areas contain typical false-positive findings because of normal anatomic. The true nodule is missed (*arrow*). c Scan of the same 39-year-old man with low-pass processing. CAD output image indicates five suspicious areas (*circles*). One area contains the true nodule overlapping scapula (*arrow*), and others contain typical false-positive findings because of normal anatomic structures. d CT scan of the same 39-year-old man. CT scan confirms the presence of the nodule.

system, whereas the false-positive rate is highest among the three types of the post-processed images (Fig. 3). In our opinion and also from visual inspection, the possible reason may be that when the structure preference value was set to -0.4 , the lower spatial frequencies of images were enhanced. That is, the pulmonary nodule was enhanced and the contrast between a pulmonary nodule and its surroundings increased.¹¹ At the same time, normal anatomic structures within the lungs such as pulmonary vessels were enhanced. The accuracy

of lung nodule detection with the CAD system for the high-pass images was inferior to others, and the false-positive rate is the lowest. In our opinion and also from visual inspection, this was mainly because of the fact that higher spatial frequencies of images were enhanced when the structure preference value was set to 0.4 . That is, the edge of the lung nodule and noise of the image was enhanced, and the contrast between a pulmonary nodule and its surroundings decreased.¹¹ The normal anatomic structures within the lungs such

as pulmonary vessels are under the same influence. The standard images obtained with structure preference value set to 0.0; the high spatial frequencies and low spatial frequencies were enhanced in a relatively more balanced way. The accuracy of lung nodule detection and the false-positive rate on standard images with CAD system were higher than that of high-pass images and lower than that of low-pass images. The result indicated that the different spatial frequency among the three types of CAD input images can affect the automated detection of lung nodules with the CAD system.

One limitation of our study design was that we evaluated the effect of the multiscale processing with three different structure preference values on automatic lung nodule detection but have not extended to study to evaluate whether different values of other processing parameters set affect the lung nodule detection with the CAD system.

Another limitation was that the CAD system provides features of interactive intelligent qualitative and quantitative analysis to help radiologists in reviewing digital chest images. In this study, we only evaluated the effect of multiscale processing on the automatic lung nodule detection of the system, without assessing whether this effect is carried over to the combined performance of physicians together with CAD.

In conclusion, our results indicate that multiscale processing in digital chest radiography can affect the detection of lung nodules with the CAD system similar to the effects on human vision, and appropriate image processing may improve the accuracy of lung nodule detection with the CAD system. The topics of which image processing parameters are most appropriate for the CAD system and for the combined detection performance of physician with CAD need to be further studied.

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REFERENCES

1. Ezzati M, Lopez AD: Estimates of global mortality attributable to smoking in 2000. *Lancet* 362:847–852, 2003
2. Smith IE: Screening for lung cancer: time to think positive. *Lancet* 354:86–87, 1999
3. Quekel LG, Kessels AG, Goei R, Engelsloven JM: Miss rate of lung cancer on the chest radiograph in clinical practice. *Chest* 115:720–724, 1999
4. Kundel HL, Nodine CF, Carmody D: Visual scanning, pattern recognition and decision-making in pulmonary nodule detection. *Invest Radiol* 13:175–181, 1978
5. Shah PK, Austin JH, White CS, Patel P, Haramati LB, Pearson GD, Shiau MC, Berkmen YM: Missed non-small cell lung cancer: radiographic findings of potentially resectable lesions evident only in retrospect. *Radiology* 226:235–241, 2003
6. Austin JH, Romney BM, Goldsmith LS: Missed bronchogenic carcinoma: radiographic findings in 27 patients with a potentially resectable lesion evident in retrospect. *Radiology* 182:115–122, 1992
7. Abe H, MacMahon H, Engelmann R, Li Q, Shiraishi J, Katsuragawa S, Aoyama M, Ishida T, Ashizawa K, Metz CE, Doi K: Computer-aided diagnosis in chest radiography: results of large-scale observer tests at the 1996–2001 RSNA scientific assemblies. *Radiographics* 23:255–265, 2003
8. Kakeda S, Moriya J, Sato H, Aoki T, Watanabe H, Nakata H, Oda N, Katsuragawa S, Yamamoto K, Doi K: Improved detection of lung nodules on chest radiographs using a commercial computer-aided diagnosis system. *AJR* 182:505–510, 2004
9. Sakai S, Soeda H, Takahashi N, Okafuji T, Yoshitake T, Yabuuchi H, Yoshino I, Yamamoto K, Honda H, Doi K: Computer-aided nodule detection on digital chest radiography: validation test on consecutive T1 cases of resectable lung cancer. *J Digit Imaging* 14:575–580, 2006
10. Monnier CL, Carrat F, Cholley BP, Tubiana JM, Arrive L: Detection of lung cancer on radiographs: receiver operating characteristic analyses of radiologists', pulmonologists', and anesthesiologists' performance. *Radiology* 233:799–805, 2004
11. Prokop M, Schaefer-Prokop CM: Digital image processing. *Eur Radiol* 7(Suppl 3):S73–S82, 1997
12. Prokop M, Schaefer C, Oestmann JW, Galanski M: Improved parameters for unsharp mask filtering of digital chest radiographs. *Radiology* 187:521–526, 1993
13. Stahl M, Aach T, Dippel S: Digital radiography enhancement by nonlinear multiscale processing. *Med Phys* 27:56–65, 2000
14. Vuylsteke P, Schoeters E: Multiscale image contrast amplification (MUSICA). *Proc SPIE Med Imaging* 2167:551–560, 1994
15. Höppner S, Maack I, Neitzel U, Stahl M: Equalized contrast display processing for digital radiography. *Proc SPIE* 4681:1–9, 2002
16. Prokop M, Neitzel U, Schaefer PC: Principles of image processing in digital chest radiography. *J Thorac Imaging* 18:148–164, 2003