Integration of Temporal Subtraction and Nodule Detection System for Digital Chest Radiographs into Picture Archiving and Communication System (PACS): Four-year Experience

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Since May 2002, temporal subtraction and nodule detection systems for digital chest radiographs have been integrated into our hospital's picture archiving and communication systems (PACS). Image data of digital chest radiographs were stored in PACS with the digital image and communication in medicine (DICOM) protocol. Temporal subtraction and nodule detection images were produced automatically in an exclusive server and delivered with current and previous images to the work stations. The problems that we faced and the solutions that we arrived at were analyzed. We encountered four major problems. The first problem, as a result of the storage of the original images' data with the upside-down, reverse, or lying-down positioning on portable chest radiographs, was solved by postponing the original data storage for 30 min. The second problem, the variable matrix sizes of chest radiographs obtained with flat-panel detectors (FPDs), was solved by improving the computer algorithm to produce consistent temporal subtraction images. The third problem, the production of temporal subtraction images of low quality, could not be solved fundamentally when the original images were obtained with different modalities. The fourth problem, an excessive false-positive rate on the nodule detection system, was solved by adjusting this system to chest radiographs obtained in our hospital. Integration of the temporal subtraction and nodule detection system into our hospital's PACS was customized successfully; this experience may be helpful to other hospitals.

KEY WORDS: Nodule detection system, temporal subtraction, picture archiving and communication systems (PACS), computed radiography (CR) flat-panel detectors (FPDs)

INTRODUCTION

Chest radiography is currently the most frequently used modality for chest diseases

because of the low cost, high throughput, and good performance. In interpreting chest radiographs, radiologists commonly compare a current chest radiograph with a previous one to facilitate the detection of new abnormalities such as pulmonary nodules, interstitial infiltrates, pleural effusions, and cardiomegaly. Chest radiographs are also performed to screen for chest disease in patients who have complaints about a thoracic organ. However, it is often very difficult even for radiologists to detect subtle findings and interval changes, particularly in lesions that involve overlap with anatomic structures such as the thoracic cage, heart, and vessels.^{1,2}

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Some computer-aided diagnosis (CAD) systems have already been manufactured, and in many cases evaluation has been performed at the clinical level.³ Thus, the use of CAD has shifted from laboratory research to clinical practice in radiology departments. The purpose of CAD is to achieve efficiency in diagnostic work by reducing the reading time and improving the reading accuracy. CAD for chest radiographs has the potential to make great progress in the future by linking imaging equipment such as computed radiography (CR) or digital radiography with flat-panel detectors (FPDs) to picture archiving and communication systems (PACS).^{4,5} Temporal subtraction and nodule detection are the most common CAD systems available for chest radiographs^{6,7} (Fig. 1). However, there has been no report as to whether these CAD systems were integrated into a hospital's PACS.

Since May 2002, temporal subtraction and nodule detection systems have been integrated into our hospital's PACS. We use these systems

for the routine interpretation of chest radiographs. Our purpose in this study was to describe our practice of interactive interpretation with the use of temporal subtraction and nodule detection images. Various problems that arose and the methods for overcoming them are described.

MATERIALS AND METHODS

Data Acquisition and Storage of Digital Chest Radiographs

The image data were obtained from CRs (FCR 5501D and FCR 5000, Fuji Film) or from digital radiography with FPDs (CXDI-11, Canon, Tokyo, Japan and THOR AX FD, Siemens, Erlangen, Germany) and stored in a PACS (TOSPACS, Toshiba, Tokyo, Japan) with a digital image and communication in medicine (DICOM) protocol. All radiographs obtained in our hospital were transferred to the PACS server mentioned above

Fig 1. Screen capture of this system. Previous and current chest radiographs are placed on the left display, and temporal subtraction and nodule detection images are placed on the right.

and to an exclusive server to produce a temporal subtraction image and a nodule detection image (CAD image) simultaneously. Previous images for the same patient were selected by means of DICOM header information and automatically loaded with a current image onto the work stations (TWS-2500, Toshiba) with two monochromatic cathode ray tube displays ($2,560 \times 2,048$ pixels, Barco, Kortrijk, Belgium) before interpretation.

Production and Display of CAD Images

The exclusive server (Truedia/XR, Mitsubishi Space Software, Amagasaki, Japan) produces CAD images by using posteroanterior (PA) or anteroposterior (AP) chest radiographs. This server was designed to automatically produce one nodule detection image for the current image and five temporal subtraction images from the current image and the five previous radiographs. The CAD images, including the nodule detection image and five or fewer temporal subtraction images, are transferred to the same display terminal shortly thereafter. The CAD images are transferred to four of 24 work stations in our hospital, because these four work stations are mainly used for the interpretation of chest radiographs. The daily mean number of chest radiographs that are transferred to the exclusive server to produce CAD images is approximately 60. Therefore, CAD images related to 22,000 chest radiographs are produced per year. Temporal subtraction images are displayed with a 0.5×0.5 K matrix and an 8-bit grayscale. It was determined that a 0.5×0.5 K matrix size for a temporal subtraction image was adequate to maintain usefulness and to reduce CPU time.^{8,9} On the other hand, nodule detection images are displayed with a 2×2 K matrix and a 10- or 12-bit grayscale; this is the same matrix size as that of the original chest radiographs. On the temporal subtraction image, the appearance of a new opacity is shown in black, and the disappearance of an existing opacity is shown in white. The display of temporal subtraction images includes the time and date of the two original images used for the subtraction. On the nodule detection image, candidates for pulmonary nodules are marked by arrowheads on the original chest radiograph.

Process of Interpretation

When chest radiographs are viewed for interpretation on the work station, a list of all previous examinations of the patient is displayed on the lower part of the monitor via communication with the PACS server. Thus, one can know from the list on the monitor whether the image data existed on a local disc. Double-clicking the button on the list can also show one set of CAD images for the current chest radiograph when required during comparative interpretation. Each chest radiologist refers to the CAD images as the occasion demands and does not refer to ones if considered unnecessary.

RESULTS

First Problem

Usually, we can interpret portable chest radiographs with the upside-down, reverse, or lying-down positioning by remounting a chest radiograph on a light box or rotating an image on a work station. However, correct temporal subtraction images are not produced in portable chest radiographs when the original images are stored in PACS with the wrong top and bottom, because the software for temporal subtraction cannot identify whether a chest radiograph was stored with the wrong top and bottom. Previously, when a new chest radiograph was obtained, it was stored immediately in the PACS. Now, it is stored 30 mins after being obtained. A radiology technologist is allowed 30 min to check and correct the top and bottom of the chest radiograph. With this process, all chest radiographs can be stored with the correct top and bottom, and temporal subtraction images are produced properly. Furthermore, radiology technologists can upload the image data of chest radiographs for an emergency patient as soon as they have confirmation of the correct examinations. We cannot use any automatic software for the analysis and correction of image direction, because those software packages cannot recognize a lateral decubitus chest radiograph. We frequently encountered this problem from the beginning and worked to solve it over a period of 8 months.

Second Problem

Because the matrix sizes of chest radiographs obtained from FPDs (CXDI-11 and THORAX FD) vary depending on the collimation size, temporal subtraction images using original images obtained from FPDs showed a lower image quality. On the other hand, the collimation size does not influence the matrix size of the CR image. The temporal subtraction technique for digital chest radiographs was originally designed by the use of CRs and the matrix size of the CRs irrespective of collimation size. The image quality in temporal subtraction was low at first when the matrix sizes of the current and previous chest radiographs differed. The system manufacture has improved the computer algorithm to produce consistent temporal subtraction images using FPD chest radiographs (Fig. 2). The present version of the temporal subtraction system is adequate for chest radiographs obtained from FPDs. Also, we confirmed by consensus evaluation with three chest radiologists that the subjective qualities of 44 temporal subtraction images obtained from FPD chest radiographs were improved after the algorithm improvement. We became aware of this problem 4 months into our use of the new systems and spent 11 months working to solve it.

Third Problem

When two original images, the current and previous chest radiographs, were obtained from different devices, the subjective image quality of the temporal subtraction images was extremely low (Fig. 3). In these circumstances, the poor image quality in temporal subtraction was not caused by misregistration artifacts but by the differences in grayscales of the different devices. Commonly, every device has specific image processing techniques such as graduation, edge enhancement, or dynamic range reduction. This CAD system involves only postprocessing data from chest radiographs because we do not have access to the raw data from PACS. Moreover, the combination of different devices produced variable image quality in temporal subtraction. We encountered this problem from the beginning and have not yet reached a fundamental solution. For each patient, however, we attempt to obtain chest radiographs made with the same device.

Fourth Problem

At first, this nodule detection system showed an acceptable detectability, but had an excessive false-positive rate on each piece of equipment because algorithms for this system had never been adjusted to chest radiographs obtained from equipment in our hospital. Therefore, we adjusted this system to chest radiographs obtained in our hospital by reducing the false-positive rate and maintaining the detectability over 70% (Fig. 4).⁹ In practice, the accuracy of rule-based analysis for each nodule candidate was improved by reducing the false-positive rate. In particular, it was difficult to adjust the CAD algorithm for chest radiographs obtained with FPDs, because this nodule detection system had not been tested with images obtained with any FPD. However, we have never compared the performance of the CAD system before and after the adjustment of the algorithm using the same chest radiographs. Kakeda et al reported on an observer performance study in which they used the old version of the same CAD system, and the detectability of lung cancer and the false positive rate of their study were 73% and 3.15 per case, respectively.¹⁰ In the previously reported study in which the new version of this CAD system was used, the detectability and the false positive rate of the CAD system were 74% and 2.28 per case,¹¹ respectively. We encountered this problem from the beginning and worked for 13 months to solve it.

DISCUSSION

The usefulness of temporal subtraction images in detecting a number of abnormal lesions such as lung nodules and interstitial infiltrates has been reported previously.^{12,13} Furthermore, several previous studies reported the usefulness of nodule detection systems for chest radiographs.^{10,11} On digital chest radiographs, the linkage between the PACS and the CAD system is important in terms of work efficiency.^{4,5} However, there has been no report in which a CAD system for digital chest radiographs was integrated into a hospital's PACS, thus enabling radiologists to interpret chest radiographs routinely with reference to CAD images. We began to use our system for the routine interpretation of chest radiographs in May

Fig 2. Deterioration in the image quality of temporal subtraction due to the different matrix sizes of the original images. In this case, a previous chest radiograph (a) with a 2080X2272 matrix size and the current radiograph (b) with a 2192X2272 matrix size were obtained with CXDI-11. These matrix sizes differed according to the collimation size. The temporal subtraction image produced by use of the original computer algorithm shows prominent misregistration artifacts around the diaphragm (c). The image quality of the temporal subtraction image was improved with the upgraded computer algorithm (d).

2002, and we have arrived at the present system through trial and error. We integrated the exclusive server used for producing the temporal subtraction images and nodule detection images into our hospital's PACS, and the CAD images made by this server were automatically loaded into the display terminal. This image-loading technique can easily be applied to other CAD

systems such as CAD for mammography, gastrointestinal examinations, CT, and others. With regard to cost and work efficiency, our system has only some of the maintenance costs of PACS, and there are no personnel costs for producing CAD images because the system is automatic. Because CAD images are obtained with the original chest radiographs by use of the patient

Fig 3. Deterioration in the image quality of temporal subtraction because the original images were obtained with different devices. In this case, a previous chest radiograph (a) was obtained with FCR5501D and the current radiograph (b) was obtained with CXD-11. The temporal subtraction image produced from these original images does not show a monotonous gray scale, but the gray scale of the mediastinum is dark (c).

code, the examination time, and the date, human errors by the staff in the production and display of CAD images will be reduced.

Our solution to the first problem is applicable to other problems involving the misfiling of image data, such as the entry of the wrong patient's name and the wrong image orientation (posteroanterior or lateral).⁵ It is disastrous for us if image data are uploaded with the wrong header information because the PACS server cannot overwrite image data. In such situations, image data with the wrong header information must be deleted from the PACS server manually. Thus, the

radiology technologist can correct these mistakes within 30 min using chest radiography equipment. During this interval, any misfiling can be recognized. Furthermore, radiology technologists can upload the image data of the chest radiographs for an emergency patient as soon as they receive confirmation of the patient's codes or the parameters of the examinations.

For chest radiographs that are obtained with FPDs, establishing a variable matrix size by the use of different collimation is favorable for the storage of image data in a PACS server because it can save storage capacity. At this time, the saved

Fig 4. Improvement of computer algorithm of nodule detection system. In this case, the nodule detection image with the previous version showed five candidates for pulmonary nodules (a). Among them, one was a true positive for lung cancer (arrow). After the improvement of the computer algorithm, one of two candidates was found to be a true positive (b).

storage capacity in a PACS server with the reversible lossless compression technique corresponds to collimation size. We can select the setting of the FPDs regardless of whether the matrix size is variable or consistent on the chest radiographs. The chest radiography equipment for FPDs is designed to remove pixel data outside the limits of the collimation when a variable matrix size is selected. However, the magnification of a displayed chest radiograph also becomes variable when a DICOM viewer is set up to fit the matrix size of the display terminal. In such a situation, we cannot perform the comparative interpretation of current and previous chest radiographs smoothly because of the difference in magnification between the two chest radiographs. Thus, the magnification of the display must be fixed when a comparative interpretation of chest radiographs obtained with FPDs is made. On the other hand, the area outside the limits of the collimation becomes bright because it is not exposed to x-rays, and radiologists can perceive the glare caused by the collimation when a consistent matrix size is selected.

Each hospital employs different settings for the exposure or subsequent image processing of digital chest radiographs.¹⁴ Therefore, it is usually difficult to apply a CAD system to all chest radiography equipment without any customizing. Thus, each hospital has to customize its CAD systems suitably according to its environment to obtain good performance. In our experience, the nodule detection system on an FPD showed a high false-positive rate at first. After this CAD system is adjusted by reducing the false-positive rate and maintaining high detectability, the performance of this system improved without any fundamental changes in the algorithm. However, we believe that a CAD system that is adaptable to these environmental changes without any adjustment is urgently needed, because a commercially available CAD system may be used by various hospitals.

Recently, World Wide Web technologies have been used in radiology to access information in multimedia-integrated PACS and for teleradiology purposes. Web technology has also been used to access the images stored in a DICOM archive in PACS environments.¹⁵ These DICOM viewers make it possible to download and display image data quickly. However, our hospital's PACS are based on a conventional protocol of DICOM by

use of automatic prefetching. With our downloading method, one can immediately perform a comparative interpretation of current and previous chest radiographs by referring to CAD images because there are current, previous, and CAD images in the local disc of the DICOM viewer upon interpretation. One cannot immediately begin comparative interpretation by referring to CAD images without producing CAD images beforehand, because the CAD server takes time to produce the temporal subtraction images or nodule detection images. Another image-loading style is needed in hospitals with a DICOM viewer of the Web browser type. For example, in one method, CAD images produced by an exclusive server for CAD are sent to the Web browser server before comparative interpretation is done.

In conclusion, we installed an exclusive server to produce temporal subtraction images and nodule detection images in PACS. We encountered four major problems in the use of this system, and three of these problems were solved. The integration of a CAD system into our hospital's PACS was customized successfully on the whole, and our experience may be helpful to other hospitals.

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