Radiological Physics and Technology (2019) 12:40–45
https://doi.org/10.1007/s12194-018-0489-7

Evaluation of the depiction ability of similar subtraction images using digital chest radiographs of different patients

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Received: 8 July 2018 / Revised: 14 November 2018 / Accepted: 15 November 2018 / Published online: 20 November 2018
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Abstract

The temporal subtraction (TS) technique requires the same patient's chest radiographs (CXRs) acquired on different dates, whereas the similar subtraction (SS) technique can be used in patients who have no previous CXR, using similar CXRs from different patients. This study aimed to examine the depiction ability of SS images with simulated nodules in comparison with that of TS images with 2- and 7-year acquisition intervals. One hundred patients were randomly selected from our image database. The most recently acquired images of the patients were used as target images for subtraction. The simulated nodule was superimposed on each target image to examine the usefulness of the SS technique. The most (Top 1) and ten most (Top 10) similar images for each target image were identified in the 24,254-image database using a template-matching technique, and used for the SS technique. SS and TS images were obtained using a previously developed nonlinear image-warping technique. The depiction ability of SS and TS images was evaluated using the contrast-to-noise ratio (CNR). The proportion of Top 1 SS images showing higher CNR than that of the TS images with 2- and 7-year acquisition intervals was 28% (28/100) and 33% (33/100), respectively. Moreover, the proportion of cases that had any of the Top 10 SS images with higher CNRs than those of TS images with 2- and 7-year acquisition intervals was 56% (56/100) and 72% (72/100), respectively. Our study indicates that the SS technique can potentially be used to detect lung nodules on CXRs.

Keywords Digital chest radiograph · Similar subtraction technique · Temporal subtraction technique · Contrast-to-noise ratio

1 Introduction

Digital chest radiographs (CXRs) are still important for detecting respiratory diseases, such as lung cancer, interstitial infiltrates, and pneumothorax. The CXRs are more advantageous than chest computed tomography images because of lower radiation exposure, better throughput, and cost-effectiveness. To improve the sensitivity of detecting abnormalities on CXR, temporal subtraction (TS) techniques were developed [1] and regarded as useful to detect temporal changes in the thoracic field [1]. However, it requires at least two CXRs from the same patient, which are acquired at different time points. Therefore, it is a widely used technology in screening examinations in Japan [2]. However, in clinical situations, the TS technique cannot be used in some cases due to the unavailability of a previous CXR. To resolve this problem, the similar subtraction (SS) technique was developed. The SS technique proposed the use of CXRs from "different patients" with a similar lung shape instead of the same patient's previously taken CXR. Some studies have demonstrated the usefulness of the SS technique [3, 4]. Oda et al. reported that more artifacts were present in SS images than in TS images. However, approximately 70% of SS images were rated as better than the adequate grade

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by three radiologists [3]. Aoki et al. also investigated the diagnostic accuracy of using CXR alone and CXR with SS images based on a subjective evaluation method, the area under the receiver operating characteristic curve (AUC). The AUC of CXR with SS images was higher than that of CXR alone [4]. To the best of our knowledge, some previous studies have been conducted on the basis of subjective evaluation methods, but there are no reports of the superiority of the SS technique verified with an objective evaluation method. To evaluate the potential usefulness of the SS technique in diagnostic radiology, the purpose of this study was to compare the depiction ability of SS and TS images objectively.

Fig. 1 An example of a target image of the right lung with simulated nodule. White dotted circles indicate the location of the simulated nodule. The simulated nodule was superimposed on the right upper lung where it did not overlap with the ribs and/or clavicle

2 Materials and methods

2.1 Digital chest radiographs used in this study

A total of 100 patients who had three CXRs acquired in different years were "randomly" selected from our image database which includes 24,254 anonymized CXR [2]. The most recently acquired CXR for each patient was assigned as the target image to examine the image quality of SS and TS images. Similar CXRs for each target image were also selected from this database using an image-matching technique [5]. CXRs in the database were acquired using a computed radiography system (FUJIFILM Corporation, Tokyo, Japan) with a 10-bit gray scale as part of a lung cancer screening program in Iwate Prefecture, Japan [2]. The original matrix size was 1760×1760 pixels with a pixel size of 0.20 mm. The matrix size of all images was then reduced to 512×512 pixels using a bi-linear interpolation algorithm [5] with a pixel size of 0.69 mm after resizing.

Actual nodules in the lung varied in size, shape, and contrast. Therefore, we used simulated nodules instead of real nodules to consistently examine CNR in the TS and SS images. The simulated nodule was superimposed in an intercostal space of the right upper lung as shown in Fig. 1. This was to avoid overlapping normal structures such as the ribs and pulmonary markings. We defined the diameter of the round-shaped nodules as two-dimensional Gaussian distribution with a width of $\pm 2.0 \times$ sigma when the peak pixel value of the simulated nodule was 50. This size corresponds to approximately 10 mm in diameter.

2.2 Image searching technique and subtraction methods

The overall scheme of our method is shown in Fig. 2. Similar images for each target image were found in our database based on "biological fingerprints" [5, 6]. Sobel and smoothing filters were used in all images in the database to enhance the edge components of the ribs. A region of interest (ROI) with 128×128 pixels for each target image was then extracted from the right upper lung so that the center of the simulated nodule was similar to that of the ROI. The normalized cross-correlation values were calculated to evaluate the similarity between ROIs of the target image and different patient's image in the database [5]. The most (Top 1) and ten most (Top 10) similar images for each target that were indicated by having the highest and ten highest normalized cross-correlation values [5] were used to obtain the SS images.

TS and SS images were provided by subtracting the target image from previous or similar images, respectively, using a nonlinear image-warping technique [7, 8]. Therefore, each target image had two types of TS image: 2- and 7-year acquisition intervals. Outlines of the TS and SS technique are shown in Figs. 3 and 4. Two TS images with different acquisition intervals and ten SS images were produced from each single target image. Therefore, 100 TS images for the 2- and 7-year acquisition intervals were used for comparison. One hundred Top 1 SS images and 1000 Top 10 SS images were obtained as shown in Figs. 3 and 4. The depiction abilities of the TS image and Top 1 or Top 10 SS images for each target image were compared. The depiction ability of TS and SS images was evaluated using the CNR around the nodule. CNR was calculated using the following equations:

$$\mathrm{CNR} = \frac{\left|\mathrm{Avg_s} - \mathrm{Avg_B}\right|}{\mathrm{RMS_B}},$$

$$\mathrm{RMS_B} = \sqrt{\frac{\sum_{i=1}^{N_\mathrm{B}} (P_i - \mathrm{Avg_B})}{N_\mathrm{B} - 1}},$$

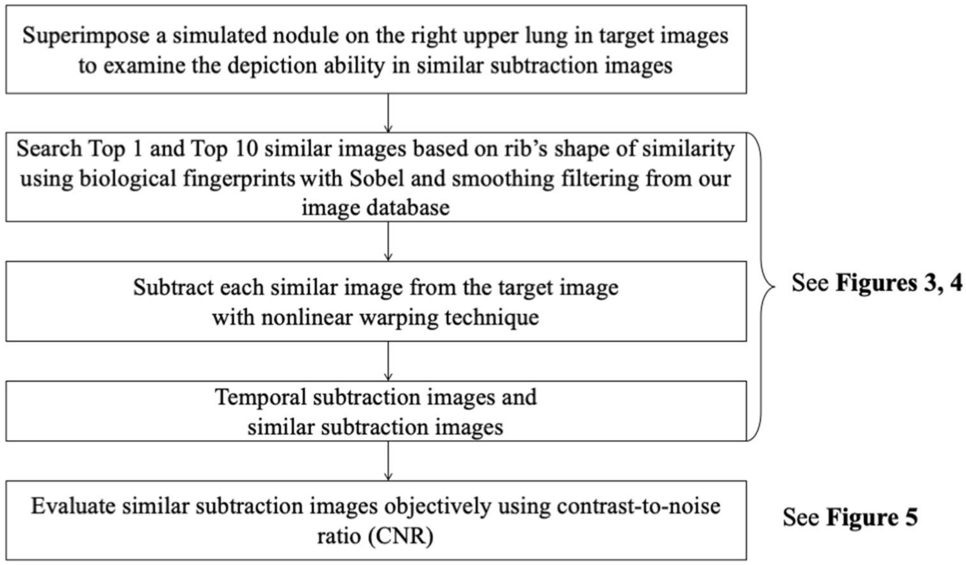

Fig. 2 Overall scheme of our method to compare depiction ability between temporal subtraction (TS) and similar subtraction (SS) images

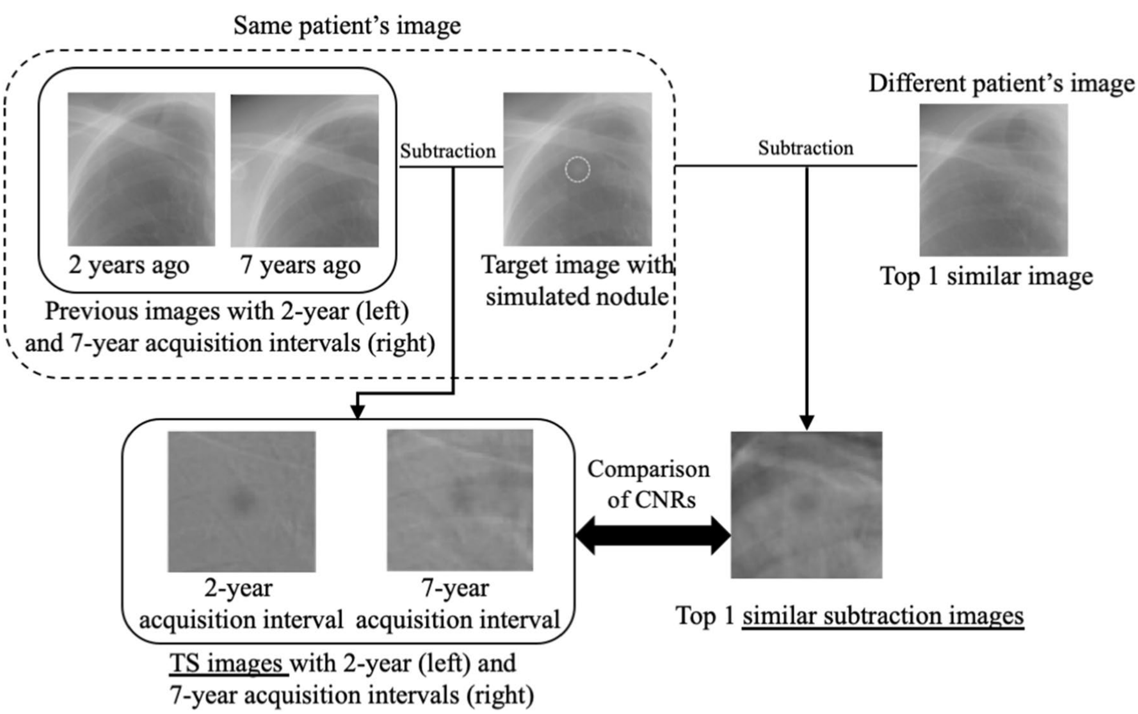

Fig. 3 Illustrations for our test of image quality in terms of comparing contrast-to-noise ratio (CNR) between temporal subtraction (TS) and Top 1 similar subtraction (SS) images. The temporal subtraction image was examined using two different acquisition intervals (2 and 7 years) between the current and previous images for each patient

where Avg_S and Avg_B indicate the average values of the signal and background regions, respectively, and N_B indicates the number of pixels in the background region. Signal and background regions are shown in Fig. 5.

3 Results

Figure 6 compares the number of cases having at least one SS image with a higher CNR than the TS image between the Top 1 SS image and Top 10 SS images for each acquisition interval. The percentage of Top 1 SS images with

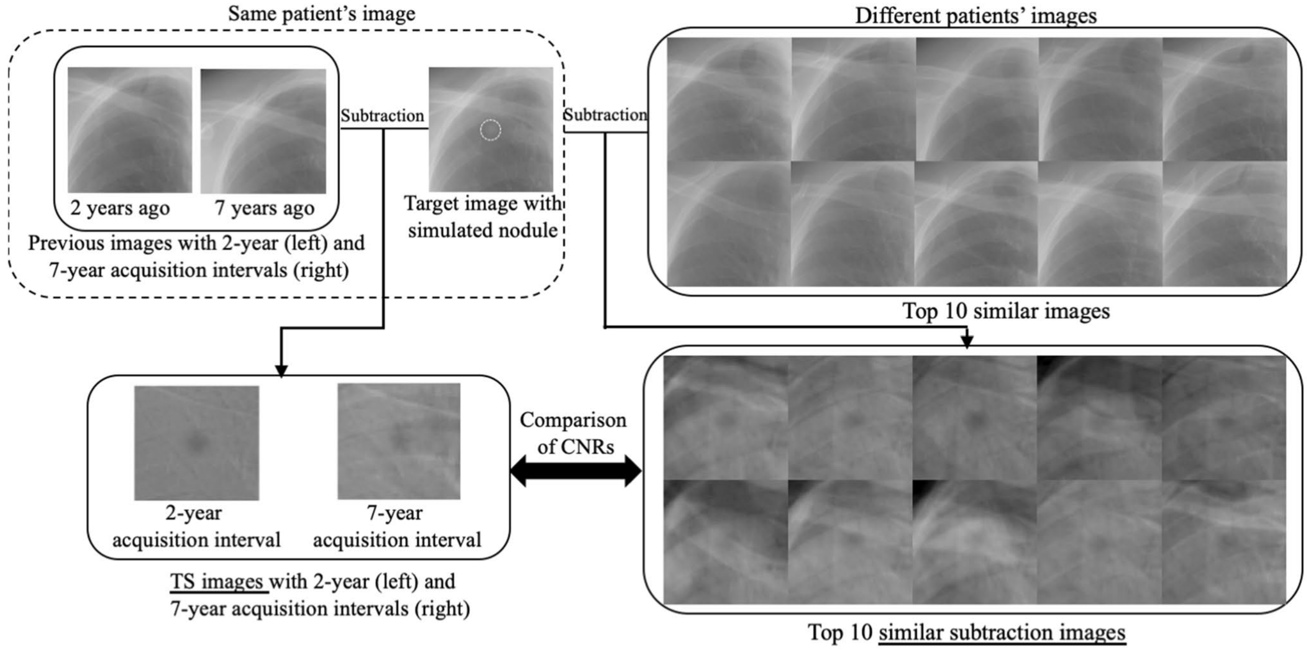

Fig. 4 Illustrations for our test of image quality in terms of comparing contrast-to-noise ratio (CNR) between temporal subtraction (TS) and Top 10 similar subtraction (SS) images. A total of 100 target images and Top 10 similar subtraction images per target image (i.e., 1000 images) were used. The temporal subtraction image was examined using different acquisition intervals (2 and 7 years) between the current and previous images for each patient

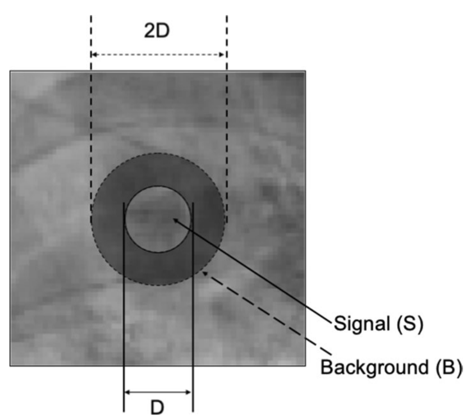

Fig. 5 Illustration for the measurement of the contrast-to-noise ratio (CNR). The signal and background regions are shown. The diameter for the background region was twice that of the nodule

higher CNRs than TS images with 2- and 7-year acquisition intervals was 28% (28/100) and 33% (33/100), respectively. Figure 7 shows the details of the analysis for Top 10 SS images compared to TS images for 100 cases. Figure 7 shows the normalized CNR of the Top 10 SS images compared to that measured in TS images for 2- (Fig. 7a) and 7-year acquisition intervals (Fig. 7b). A total of 1000 plots were found. Plotted normalized CNRs beyond the horizontal lines at 1.0 indicate that the CNRs of SS images were higher than that of the TS images for each case. The total number of cases having at least one SS image with higher CNR than the TS images with 2- and 7-year acquisition interval were 56% (56/100) and 72% (72/100), respectively.

Examples for TS images with different intervals used for subtraction and Top 10 SS images are shown in Fig. 8. The longer interval (7 years) was noted to have decreased image quality in TS images. In other words, the SS technique may have more potential relative to the TS technique with a 7-year acquisition interval rather than 2-year acquisition interval.

4 Discussion

The study described the potential advantage of using the SS images compared to a TS technique by measuring the CNR as a quantitative measure index. For longer acquisition intervals, the percentage of Top 1 and Top 10 SS images with higher CNRs than TS images tended to increase as shown in Fig. 6. These tendencies suggest that the approximately 1/4–1/3 of Top 1 SS images may have a higher depiction ability than TS images with longer acquisition intervals. Moreover, for the Top 10 SS images, the number of cases having at least one SS image with higher CNR than the TS image for each acquisition interval was higher than that for

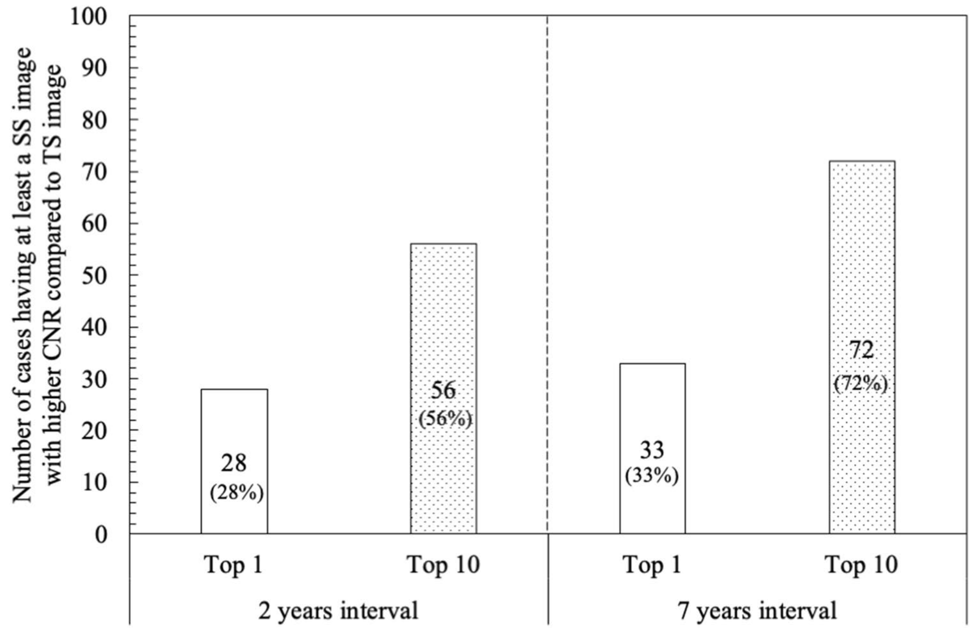

Fig. 6 Comparison of the number of cases having at least one similar subtraction (SS) image with higher CNR than the temporal subtraction (TS) image for each acquisition interval between the Top 1 SS images and Top 10 SS images. As 100 cases were used for analysis, the number of cases and percentages for each graph are the same

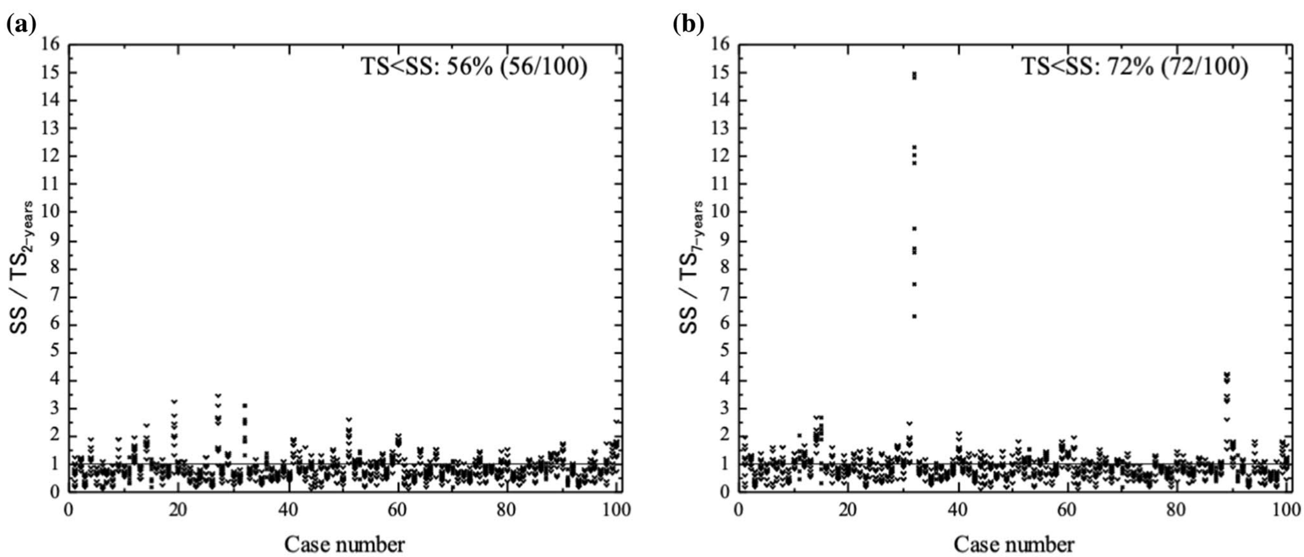

Fig. 7 Comparison between the normalized CNR of similar subtraction (SS) images and corresponding temporal subtraction (TS) images with 2- (**a**) and 7-year (**b**) acquisition intervals. The horizontal axis indicates the case number. The vertical axis indicates the CNRs of SS images normalized by the CNRs of TS images. Therefore, CNRs above 1.0 mean that the CNR of the SS image was higher than that of the TS image

the Top 1 SS images (Fig. 6). Therefore, we believe that if similar images with a similar shape of the lungs and ribs were appropriately selected, the SS technique would be a useful tool to aid in the detection of lung nodules even when using a similar image from a different patient. These results mean that SS images would be useful in detecting suspicious lung nodules on CXR by displaying not only TS images but also Top 10 SS images before deciding further examination such as computed tomography. We believe that SS images should not be used for primary diagnostic purposes only. However, SS images may potentially increase the confidence level of thoracic radiologists and other physicians.

Nevertheless, our study has some limitations. First, different types of nodules and actual nodules were not investigated in this study. Different sizes, contrasts, and locations of nodules should be tested when using similar images. Second, only CNR was used in the quantitative evaluation of image quality for subtraction images.

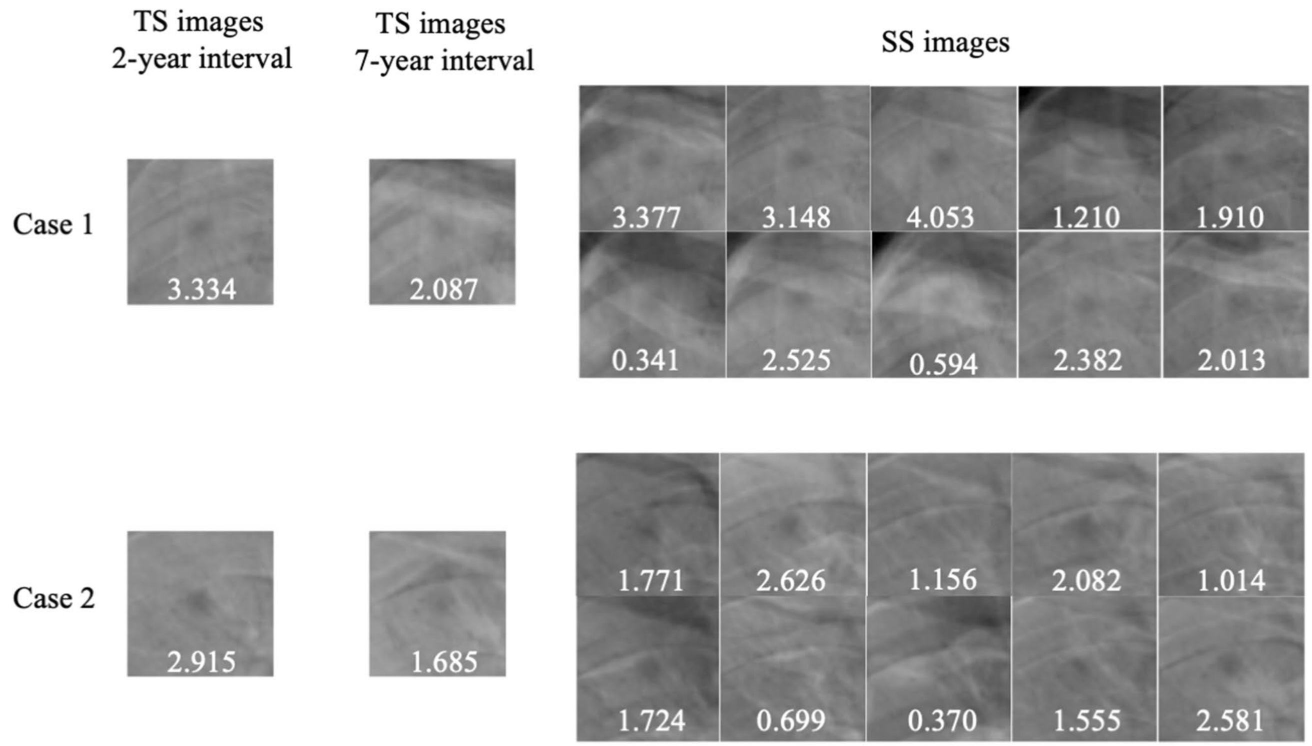

Fig. 8 The examples of Top 10 similar subtraction (SS) images and temporal subtraction (TS) images with 2- and 7-year acquisition intervals for two cases. The numbers on the images indicate CNRs

5 Conclusion

The SS technique using similar chest images from different patients showed comparable or better depiction ability than the TS technique using different images from the same patients.

Compliance with ethical standards

Conflict of interest All authors have no conflicts of interest to disclose.

Statements of human rights All procedures in study involving human participants were performed in accordance with the ethical standards of the Institutional Review Board (IRB) and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Statements of animal rights This article does not contain any studies with animals performed by any of the authors.

Informed consent Informed consent was waived by the IRB for all images included in the database used in study.

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