Heliyon 9 (2023) e13004

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Evaluation of the clinical utility of temporal subtraction using bone suppression processing in digital chest radiography

Takeshi Takaki [a,*], Seiichi Murakami [b], Natsumi Tani [c], Takatoshi Aoki [c]

[a] Department of Radiology, Hospital of University of Occupational and Environmental Health, Iseigaoka 1-1, Yahatanishi-ku, Kitakyushu-shi, Fukuoka, 807-8555, Japan
[b] Department of Radiological Science, Junshin Gakuen University, 1-1-1 Chikushigaoka, Minami-ku, Fukuoka, 815-8510, Japan
[c] Department of Radiology, University of Occupational and Environmental Health School of Medicine, Iseigaoka 1-1, Yahatanishi-ku, Kitakyushu-shi, Fukuoka, 807-8555, Japan

ARTICLE INFO

Keywords:
Temporal subtraction
Bone suppression processing
Digital chest radiography
Pulmonary lesions

ABSTRACT

Rationale and objectives: To evaluate the usefulness of temporal subtraction using the bone suppression method in digital chest radiography for the detection of pulmonary lesions.
Materials and methods: The images of 31 patients with pulmonary lesions and 19 normal cases were included in the study. Conventional and bone suppression temporal subtraction were performed in the 50 cases selected and used for an observer performance study. Five radiologists participated in the study, and the differences between using conventional and bone suppression temporal subtraction were assessed using jackknife free-response receiver operating characteristic analysis.
Results: The average figure-of-merit values for all radiologists increased significantly using the bone suppression method, from 0.619 (conventional) to 0.696 ($p = 0.032$). The average sensitivity for detecting pulmonary lesions improved from 67.9% to 75.4%, and the average number of false-positive per case decreased from 0.336 to 0.252 using bone suppression temporal subtraction.
Conclusion: Bone suppression temporal subtraction processing can assist with the detection of subtle pulmonary lesions in digital chest radiographs.

1. Introduction

Chest radiography is fundamental for the detection and follow-up of several pulmonary diseases; however, the lung anatomy is complex, and the range of diseases possibly present is extensive. As a result, even experienced radiologists occasionally miss tumors considered detectable [1]. Temporal subtraction (TS) is an image processing technique that subtracts from the current chest radiogram a previous corresponding image from the same patient. This method improves the sensitivity of nodule detection [2,3].

On the other hand, TS requires two images acquired at different times; therefore, accurate alignment of the images is crucial. A certain extent of misalignment usually remains in different parts of the image after rough alignment is obtained, and nonlinear

Abbreviations: BS, bone suppression; CT, computed tomography; FOM, figure-of-merit; FPs, false positives; FROC, free-response receiver operating characteristic; FWHM, full width at half maximum; JAFROC, jackknife free-response receiver operating characteristic; ROC, receiver operating characteristic; TS, temporal subtraction.

* Corresponding author.
E-mail address: takaki-t@clnc.uoeh-u.ac.jp (T. Takaki).

https://doi.org/10.1016/j.heliyon.2023.e13004
Received 20 December 2022; Received in revised form 12 January 2023; Accepted 12 January 2023
Available online 16 January 2023

deformation processing is performed on the previous image to correct any differences in position [4]. However, artifact reduction is also necessary because differences in positioning at the time of imaging can cause bone-related artifacts, possibly resulting in false positive findings [5-7].

Recently, an image-processing technique called bone suppression (BS) processing has been developed and reported to be clinically useful [8-10]. BS attenuates the rib and clavicle signals in chest radiographs, and BS-processed images are similar to soft tissue images obtained using dual-energy subtraction [11]. Therefore, TS images obtained using BS processing are expected to reduce bone-related artifacts and enhance the lesion contrast. This improvement could help detect some lesions that may be missed using conventional TS. However, to the best of our knowledge, no studies have evaluated the clinical usefulness of TS images obtained using the BS technique. Therefore, this study aimed to examine the difference between conventional TS (C-TS) and TS using BS (BS-TS) in the detection of pulmonary lesions using a jackknife free-response receiver operating characteristic (JAFROC) observer experiment. We also evaluated the clinical utility of BS-TS images to identify lesions difficult to detect using conventional TS.

2. Material and methods

2.1. Case selection

Our institutional review board approved this study, and the need for informed consent was waived due to its retrospective nature. All cases were selected by an image inspector, with 17 years of experience, among patients with pulmonary nodules or infiltrating shadows identified on computed tomography (CT) scans at our hospital between April 2017 and March 2021, having normal findings on previous CT scans. Since this study aimed to evaluate the clinical utility of BS-TS for pulmonary lesions and diseases difficult to detect, the cases used in the visual evaluation were selected focusing on such images. The subtlety of the pulmonary lesions in the data used was determined based on the definitions in a publicly available digital image database of chest radiographs [12]. We selected 31 patients with lung diseases (19 with primary lung cancer, eight with lung metastases, and four with pneumonia); they comprised 18 males and 13 females, with ages ranging from 44 to 88 years (mean: 72 years; Table 1). The mean lesion diameter among the 31 cases was 20 mm (range: 10–40 mm). The levels of subtlety for lesion detection were as follows: 3 (10%) of the lesions were obvious, 3 (10%) relatively obvious, 8 (26%) subtle, 6 (19%) very subtle, and 11 (35%) extremely subtle. The current and previous chest radiograms of the normal cases were obtained from 19 patients who underwent CT examinations for various clinical reasons and were found to be negative (Table 2).

The 50 patients thus selected were divided into two databases: database A, consisting of C-TS images and current and previous chest radiographs, and database B, comprising BS-TS images. The interval between the dates of current and previous chest radiographs ranged from 105 to 1285 days (mean: 527 days).

2.2. Digital radiography and temporal subtraction

All chest radiograms were acquired using the flat-panel detector system AeroDR 1717HQ (Konica Minolta Inc., Tokyo, Japan) and processed using an imaging workstation CS-7 (Konica Minolta Inc.). The imaging parameters were as follows: source-to-image distance: 200 cm; voltage: 100 kV; Cu filtration: 0.1 mm; automatic exposure control: (+); and grid ratio: 12:1. The images were transferred to a TS processing workstation, Senciafinder (Konica Minolta Inc.), for C-TS. BS-TS was performed using an improved version of the TS software with additional BS processing functions. Fig. 1 shows the flowcharts for C-TS and BS-TS. The amount of deformation of the two images in the lung field region is calculated by performing a global matching process for the overall position and a local matching process for regional shapes during the C-TS. These matching processes control the alignment targets by optimizing the size of the region of interest during the template matching process. Warping allows nonlinear image deformation of the previous radiographs based on the amount of deformation calculated from the global and local matching processes. The C-TS is performed by subtracting the deformed previous image from the current one.

The BS-TS adds BS processing to reduce bone-related artifacts in the lung fields. Furthermore, subsequent matching processing using the BS images allows positioning based on the fine soft tissues, reducing artifacts related to these tissues, such as blood vessels.

2.3. Observer performance study

The observer experiment was conducted using an independent rating with a continuous confidence method. Five radiologists, with 5–7 years of experience, were selected as observers. Three of them were assigned to read the images from database A and the other two from database B. Four weeks later, the first three radiologists read the images from database B and the other two from database A to

Table 1
Characteristics of patients with pulmonary diseases.

	Male (18)		Female (13)		Total (31)	
	Range	Mean	Range	Mean	Range	Mean
Age (years)	44–88	71.7	61–83	71.8	44–88	71.7
Height (cm)	149.3–195	167.8	143.7–162.5	152.7	143.7–195	161.5
Weight (kg)	42.5–86.1	64.3	34.8–60.6	48.7	34.8–86.1	57.8

Table 2
Characteristics of patients without pulmonary disease.

	Male (12)		Female (7)		Total (19)	
	Range	Mean	Range	Mean	Range	Mean
Age (years)	30–89	64.2	38–91	67.1	30–91	65.3
Height (cm)	153.6–180.2	167.2	129.7–165	149.7	129.7–180.2	160.8
Weight (kg)	40.1–89.3	65.9	30–65.6	47.9	30–89.3	59.3

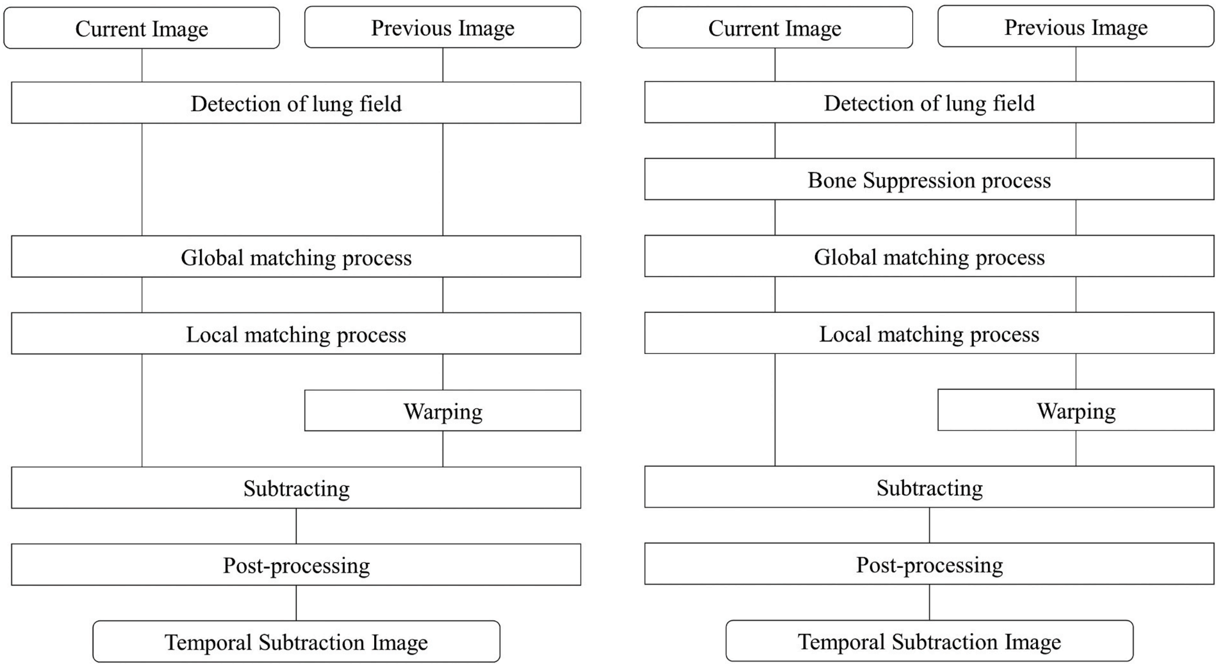

Fig. 1. Flowcharts for conventional temporal subtraction (TS, left) and TS with bone suppression (BS-TS, right). The BS-TS adds BS processing after lung and region detection. In addition, subsequent matching processing is performed using bone attenuation images. This process allows positioning based on fine soft tissues and generates images with reduced artifacts.

eliminate the reading-order effect. ROC Viewer (ver. 2020.7.6.1, JSRT, Kyoto, Japan), a software developed for receiver operating characteristic (ROC) observer experiments, was used for this study [13,14]. The observational experiments were performed using a 3-megapixel 20.8″ monochrome high-resolution LCD monitor (Eizo RadiForce GS-310, Eizo Nanao Corp., Ishikawa, Japan).

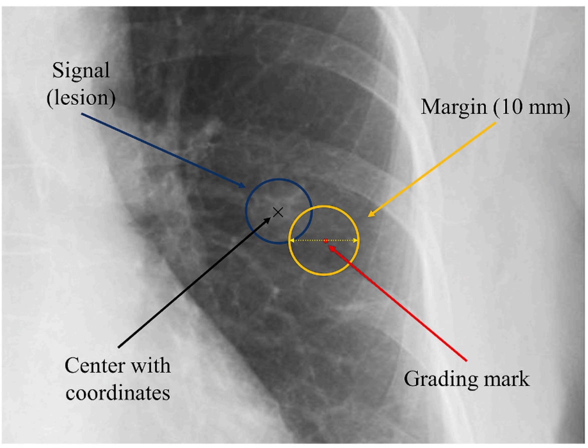

Fig. 2. True positive (TP) determination in free-response receiver-operating characteristic observer experiments. TP was judged when a part of the lesion was included within a pre-defined margin from the location of the grading mark.

The observers clicked the mouse on the current original image in the area suspected to contain a new shadow, referring to the original current and previous chest radiographs and C-TS or BS-TS images, and recorded their confidence level using the rating bar provided. A training was conducted beforehand with cases not previously used in other observational studies. The observers had unlimited image evaluation time and were informed in advance that the databases included images with and without pulmonary lesions; however, they were blinded to their proportions.

2.4. Statistical analysis

The observer-experiment statistical processing was performed using the software ROC Analyzer (ver. 2020.11.15.0; JSRT) [13,14]. A lesion was judged as true positive when at least a portion was included within a predetermined fixed margin from the location of the grading mark. The margin was circular with a diameter of 10 mm (Fig. 2). The gold standard to evaluate the diagnostic performance (i.e., the lesion center X, Y coordinates on a chest radiogram) was determined by the image inspector using the CT images as reference. The diagnostic performance was evaluated using JAFROC analysis; this method has been proposed to estimate when a difference in the detection of lesions, including their location, is statistically significant. This analysis is based on a free-response receiver-operating characteristic (FROC) paradigm and accounts for reader variability [15]. The JAFROC analysis calculated a figure-of-merit (FOM) value equivalent to the area under the ROC curve. The FOM value was calculated with JAFROC using the sensitivity [16] and the number of false positives (FPs) per case, and then the statistical significance of the difference between C-TS and BS-TS was assessed using the Jackknife method [17]. P-values <0.05 were considered statistically significant.

3. Results

3.1. Artifact reduction

Figs. 3 and 4 show cases in which lesions were easily recognized by BS-TS. Fig. 3(a) shows the previous radiograph and Fig. 3(b)

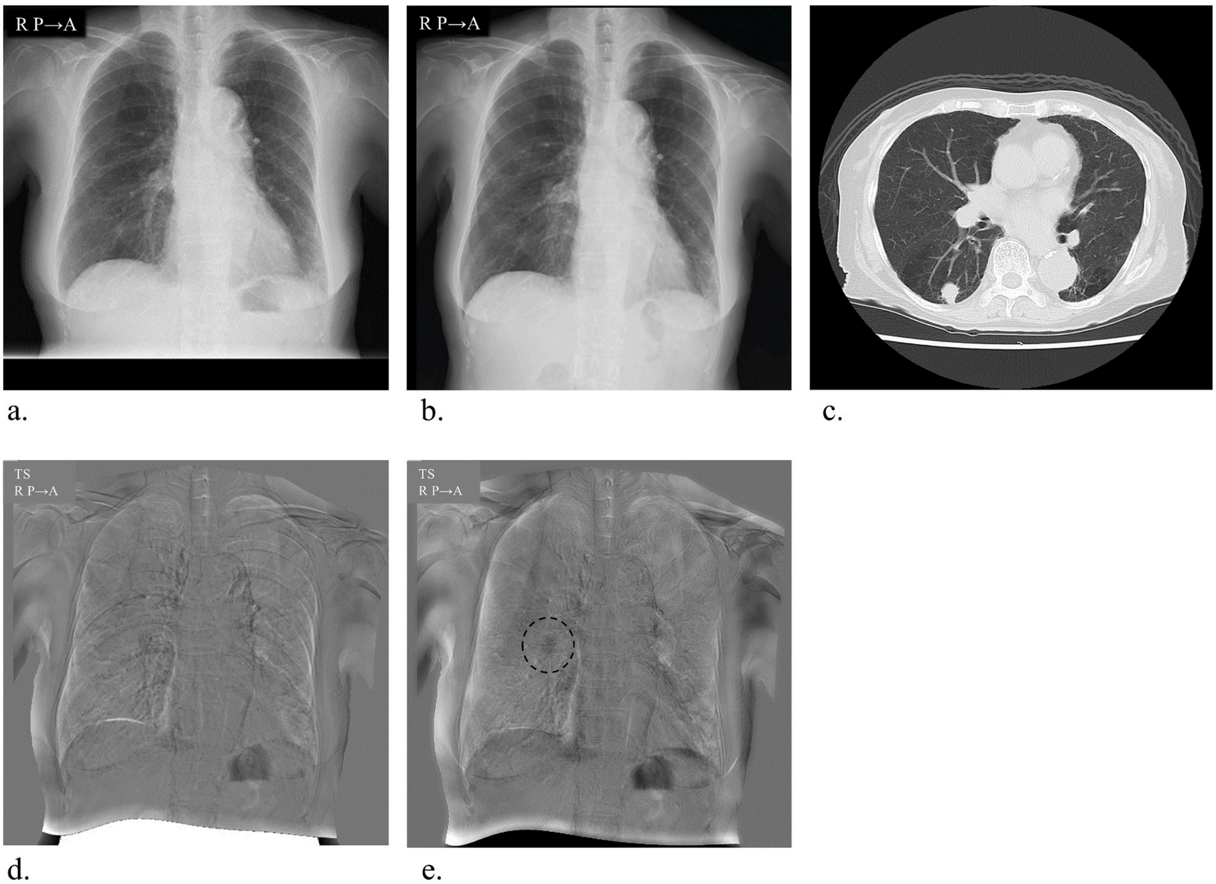

Fig. 3. Images used for temporal subtraction (TS). (a) Previous radiograph. (b) Current radiograph. (c) computed tomography image. (d) Conventional TS image. (e) Improved TS image acquired with bone suppression (BS) processing. The rib artifacts are reduced with BS-TS, and nodule areas are easily recognized.

shows the current radiograph. As seen in Fig. 3(c), despite the relatively large lesion, it was difficult to detect the lesion with C-TS because the position of the rib was different between the previous and current radiograph (Fig. 3(d)). On the other hand, BS-TS could easily detect lesion because it could reduce rib artifacts (Fig. 3(e)). BS-TS was also effective in reducing artifacts at the lung apex. Artifacts were generated in conventional subtraction images due to the different height of the clavicle, the lesion were difficult to detect (Fig. 4(a–c)). On the other hand, the BS-TS reduced clavicle artifacts and improved the visibility of the lesion (Fig. 4(d)). Fig. 5 shows a histogram created from the values of the pixels in the right upper lung field region in BS-TS and C-TS images (same case as Fig. 4). If an ideal temporal subtraction image had been created (i.e., the previous and present images were perfectly aligned), the full width at half maximum (FWHM) of the histogram created from the pixel values would be 1. However, if artifacts are present, the FWHM increases with the number of artifacts [18]. The calculated FWHMs for BS-TS and C-TS were 18 and 25, respectively; therefore, the physical characterization proved that the artifacts were reduced using BS-TS processing.

3.2. *Diagnostic value*

The sensitivity increased for all observers with the use of BS-TS images, from 67.9% with C-TS to 75.4%. The average FPs/case decreased for all observers, except observer C, from 0.336 to 0.252. The mean FOM values were 0.619 and 0.696 for C-TS and BS-TS, respectively, with a statistically significant difference ($p = 0.032$). Tables 3 and 4 show the sensitivity, FPs/case, and FOM of the observer experiments for C-TS and BS-TS. Fig. 6 shows the mean FROC curves for the diagnostic performance using C-TS and BS-TS; this parameter improved with the use of BS-TS images.

Observer C had a slightly increased FPs/case value using BS-TS; the lesion causing this increase was recognized as a rib artifact on the C-TS image, whereas the BS-TS image produced a faint artifact that was interpreted as a positive detection (Fig. 7).

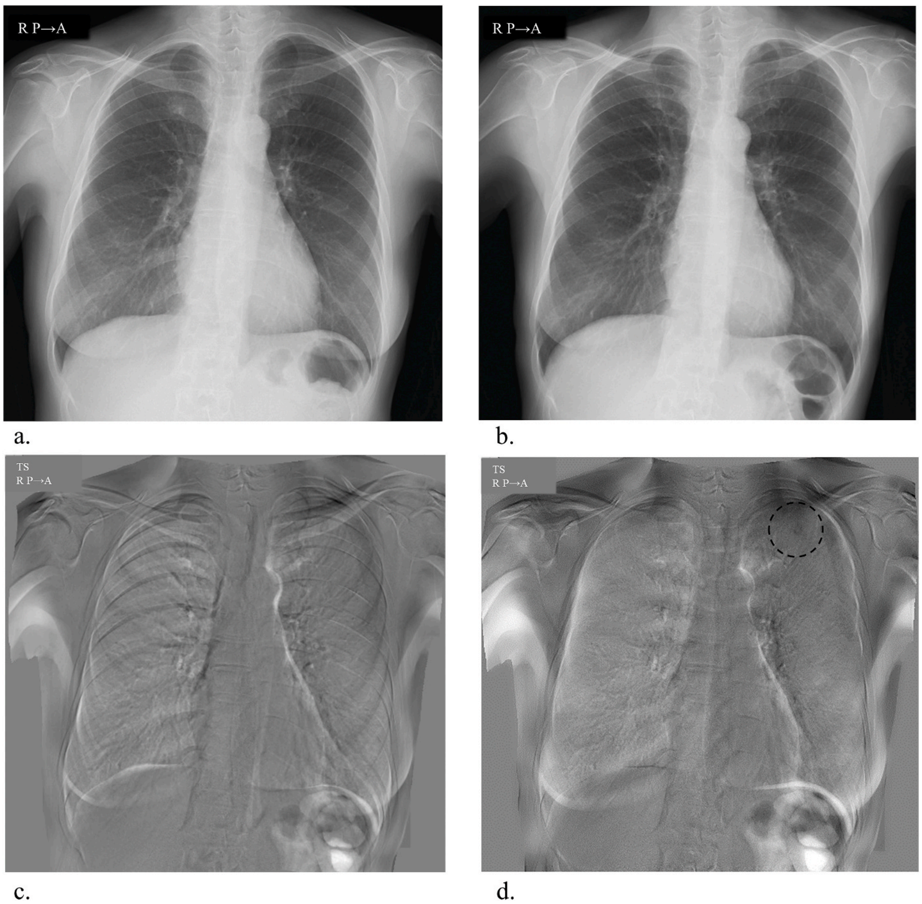

Fig. 4. Images used for temporal subtraction in a patient with a lesion near the clavicle. (a) Previous radiograph. (b) Current radiograph. (c) Conventional temporal subtraction image. (d) Improved temporal subtraction image acquired with bone suppression (BS) processing. The clavicle artifacts were reduced by the BS processing.

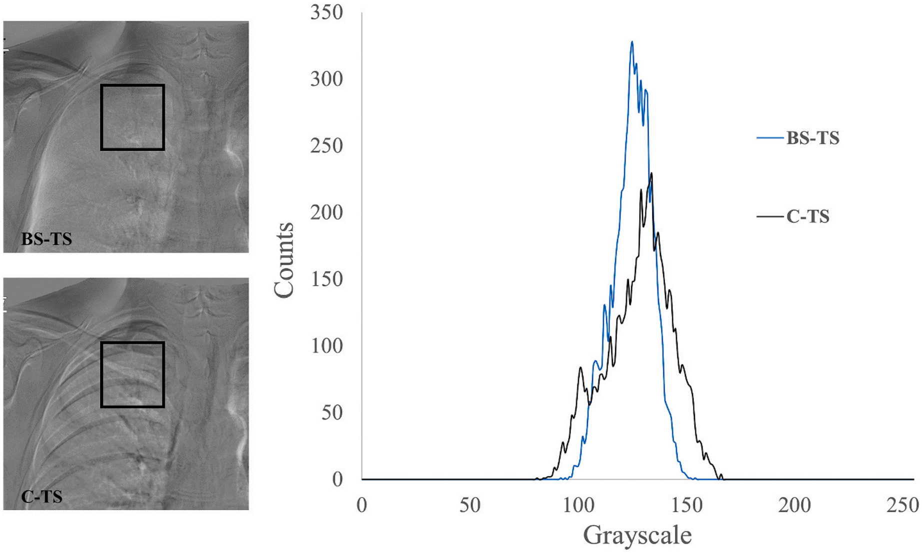

Fig. 5. Histograms of lung field regions in bone suppression (BS-) and conventional (C-) temporal subtraction (TS) images. The full width at half maximum (FWHM) of the histograms was used as a measure of the artifacts; this value increases with the number of artifacts. The calculated FWHMs were 18 and 25 for BS-TS and C-TS, respectively, indicating that BS-TS images are characterized by fewer artifacts than C-TS images.

Table 3
Sensitivity, number of false positives, and FOM for conventional TS.

Observer	Sensitivity (%)	FPs/case	FOM
A	68.8	0.28	0.633
B	66.7	0.16	0.631
C	64.6	0.40	0.608
D	60.4	0.46	0.581
E	79.2	0.38	0.642
Average (SD)	67.9	0.336	0.619 ± 0.02

FOM, figure-of-merit; FPs, false positives; SD, standard deviation; TS, temporal subtraction.

Table 4
Sensitivity, number of false positives, and FOM for TS using bone suppression.

Observer	Sensitivity (%)	FPs/case	FOM
A	75	0.18	0.704
B	77.1	0.12	0.700
C	81.3	0.42	0.712
D	62.5	0.26	0.662
E	81.3	0.28	0.704
Average (SD)	75.4	0.252	0.696 ± 0.02

FOM, figure-of-merit; FPs, false positives; SD, standard deviation; TS, temporal subtraction.

4. Discussion

Our results showed that the average sensitivity to detect subtle pulmonary lesions increased, and the FPs/case decreased with the use of BS-TS. The overall observer's ability to detect new lesions increased significantly with the use of BS-TS; this method allowed the enhancement of changes in the density of faint lesions, providing higher image quality than C-TS.

Compared with C-TS, TS obtained using dual-energy subtraction can reduce artifacts; however, these images require dedicated hardware and software, and the radiation dose for patients is high [19-22]. On the other hand, the BS-TS method used in the present study does not require dedicated hardware and software and can produce results similar to those reported in dual-energy subtraction studies [23-26]. Furthermore, BS-TS images are generated from standard chest radiographs without increased radiation doses for the patients.

We focused our analysis on lesions and diseases that were difficult to detect on conventional TS images, aiming to verify whether the TS detection assistance could be improved with BS. More than half of the lesions included in the database were subtle or very subtle. This specific selection may have resulted in the low overall performance (low FOM) of the observer experiment in the present

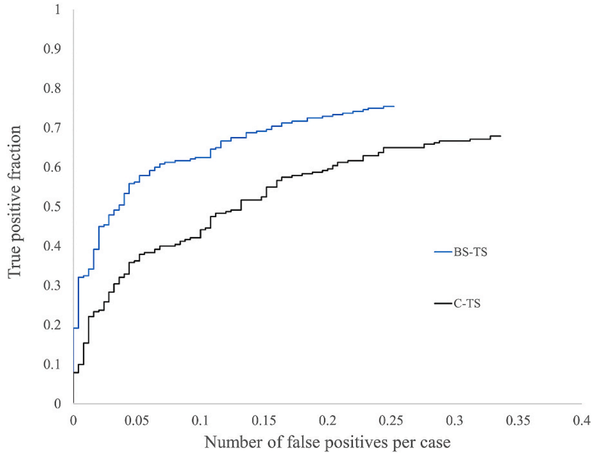

Fig. 6. Comparison of the average free-response receiver operating characteristic curves for the performances of the five radiologists using conventional (C-) and bone suppression temporal subtraction (BS-TS) images. The average sensitivity improved from 67.9% in C-TS to 75.4% with the use of BS-TS.

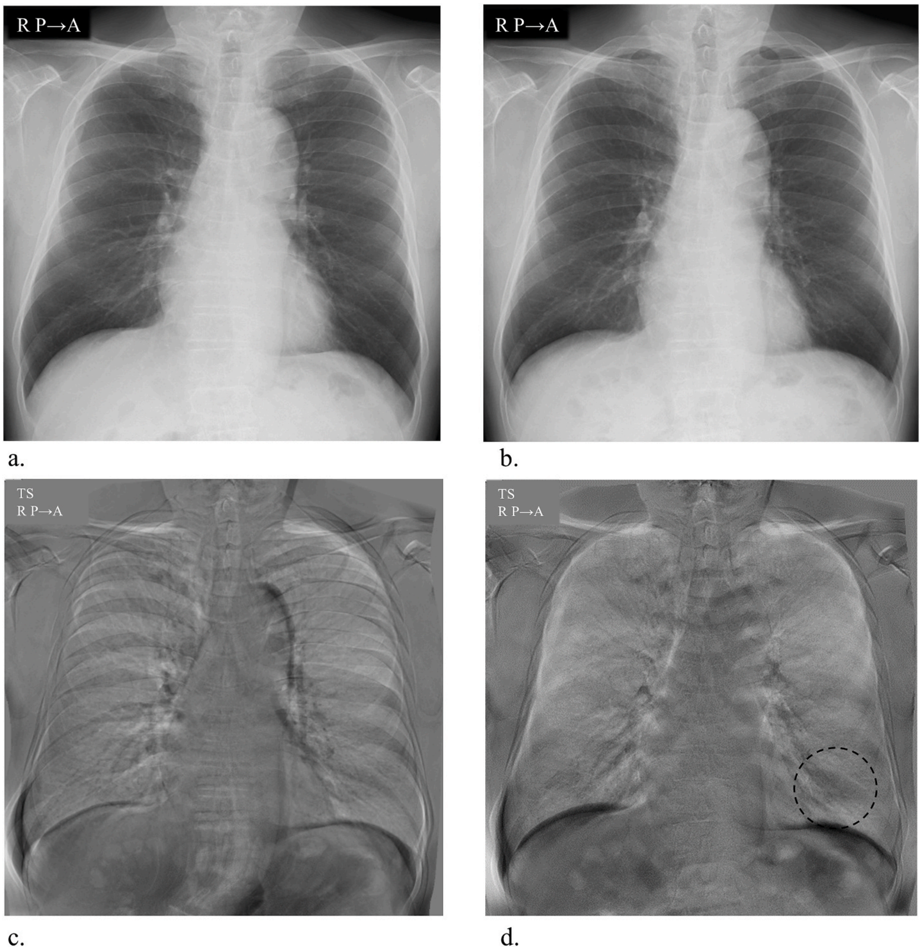

Fig. 7. Original and processed chest radiographs. (a) Previous radiograph. (b) Current radiograph. (c) Conventional temporal subtraction (TS) image. (d) Improved TS image using bone suppression (BS) processing. Faint rib artifacts are shown in the circle, caused by the intensity of BS processing. As with conventional TS images, the observer should be familiar with the pattern of artifacts in BS-TS images.

study. The sensitivity of the BS-TS images using a database with several subtle lesions was 75.4% in the present study. Shiraishi et al. reported a sensitivity of 54.66% with very subtle lesions and 29.6% with extremely subtle ones, though that study did not use TS [12]. We believe that BS-TS is useful for detecting subtle pulmonary lesions. However, our results cannot be directly compared with those obtained in previous studies due to differences in the databases. Therefore, further studies using the same databases will be required to validate the performance of our BS-TS method.

In regard to the artifact in the BS-TS image misinterpreted by observer C, there are two possible causes: the first is that the rib attenuation process was not applied properly to the previous and present images, resulting in residual bone signal in the BS-TS images; the BS processing shows a tendency to be less effective on the rib ends [11], possibly due to anterior rib remnants. The second possible reason is that bone remnants may have been present in the previous or present image, caused by residual signals in the posterior part of the ribs. Therefore, the observer must be familiar with the typical artifact patterns when reading BS-TS and C-TS images.

In addition, several observers commented on artifacts near the diaphragm in BS-TS images. BS-TS emphasizes density changes in faint lesions; therefore, the contrast is enhanced during post-processing compared with C-TS. As a result, artifacts near the diaphragm caused by different respiration phases are emphasized, and undetectable areas are thought to be more pronounced. TS images can improve the detection rate of nodules near the diaphragm [3], and a future challenge is to reduce artifacts in this area by developing a method to reduce differences caused by respiration.

This study had some limitations. First, most of the reference standards for the presence of pulmonary lesions were pathologically proven; however, some were established only by a consensus panel. This limitation is common in CAD evaluation studies. Second, the radiographic interpretation time was not considered, and the performance of radiologists is based on both diagnostic accuracy and interpretation time [27]. Third, this is a retrospective study; further prospective studies with a greater number of cases are likely necessary to confirm the clinical usefulness of BS-TS. Fourth, this was a preliminary study with a small number of cases. Fourth, this was a preliminary study with a small number of cases. The sample sizes were considered based on previous TS observer performance study papers [28-30], however, it is also affected by statistical differences between the systems under evaluation. Fifth, this study did not examine whether the effect of temporal subtraction images on observer ability depends on clinical experience. Further observer performance studies including experienced radiologists with a larger number of cases are likely necessary to confirm the clinical usefulness of this computerized method.

5. Conclusion

This study demonstrated that BS-TS processing can reduce rib and clavicle artifacts, and this method can assist in the detection of subtle pulmonary lesions in digital chest radiography.

Author contribution statement

Takeshi Takaki: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Takatoshi Aoki: Conceived and designed the experiments; Wrote the paper.

Natsumi Hirano: Performed the experiments.

Seiichi Murakami: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

The authors do not have permission to share data.

Declaration of interest's statement

The authors declare no competing interests.

Additional information

No additional information is available for this paper.

References

[1] L. Monnier-Cholley, F. Carrat, B.P. Cholley, et al., Detection of lung cancer on radiographs: receiver operating characteristic analyses of radiologists', pulmonologists', and anesthesiologists' performance, Radiology 233 (2004) 799–805, https://doi.org/10.1148/radiol.2333031478.
[2] H. MacMahon, S.G. Armato 3rd, Temporal subtraction chest radiography, Eur. J. Radiol. 72 (2009) 238–243, https://doi.org/10.1016/j.ejrad.2009.05.059.
[3] S. Kakeda, K. Nakamura, K. Kamada, et al., Improved detection of lung nodules by using a temporal subtraction technique, Radiology 224 (2002) 145–151, https://doi.org/10.1148/radiol.2241010719.

[4] A. Kano, K. Doi, H. MacMahon, et al., Digital image subtraction of temporally sequential chest images for detection of interval change, Med. Phys. 21 (1994) 453–461, https://doi.org/10.1118/1.597308.
[5] C. Schaefer-Prokop, U. Neitzel, H.W. Venema, et al., Digital chest radiography: an update on modern technology, dose containment and control of image quality, Eur. Radiol. 18 (2008) 1818–1830, https://doi.org/10.1007/s00330-008-0948-3.
[6] M. Tsubamoto, T. Johkoh, T. Kozuka, et al., Temporal subtraction for the detection of hazy pulmonary opacities on chest radiography, AJR Am. J. Roentgenol. 179 (2002) 467–471, https://doi.org/10.2214/ajr.179.2.1790467.
[7] H. Okazaki, K. Nakamura, H. Watanabe, et al., Improved detection of lung cancer arising in diffuse lung diseases on chest radiographs using temporal subtraction, Acad. Radiol. 11 (2004) 498–505, https://doi.org/10.1016/S1076-6332(03)00820-1.
[8] S. Takagi, T. Yaegashi, M. Ishikawa, Dose reduction and image quality improvement of chest radiography by using bone-suppression technique and low tube voltage: a phantom study, Eur. Radiol. 30 (2020) 571–580, https://doi.org/10.1007/s00330-019-06375-6.
[9] G.S. Hong, K.H. Do, A.Y. Son, et al., Value of bone suppression software in chest radiographs for improving image quality and reducing radiation dose, Eur. Radiol. 31 (2021) 5160–5171, https://doi.org/10.1007/s00330-020-07596-w.
[10] S. Schalekamp, B. van Ginneken, L. Meiss, et al., Bone suppressed images improve radiologists' detection performance for pulmonary nodules in chest radiographs, Eur. J. Radiol. 82 (2013) 2399–2405, https://doi.org/10.1016/j.ejrad.2013.09.016.
[11] F. Li, R. Engelmann, L.L. Pesce, et al., Small lung cancers: improved detection by use of bone suppression imaging—comparison with dual-energy subtraction chest radiography, Radiology 261 (2011) 937–949, https://doi.org/10.1148/radiol.11110192.
[12] J. Shiraishi, S. Katsuragawa, J. Ikezoe, et al., Development of a digital image database for chest radiographs with and without a lung nodule: receiver operating characteristic analysis of radiologists' detection of pulmonary nodules, AJR Am. J. Roentgenol. 174 (2000) 71–74, https://doi.org/10.2214/ajr.174.1.1740071.
[13] J. Shiraishi, D. Fukuoka, T. Hara, et al., Basic concepts and development of an all-purpose computer interface for ROC/FROC observer study, Radiol. Phys. Technol 6 (2013) 35–41, https://doi.org/10.1007/s12194-012-0166-1.
[14] J. Shiraishi, D. Fukuoka, R. Iha, et al., Verification of modified receiver-operating characteristic software using simulated rating data, Radiol. Phys. Technol 11 (2018) 406–414, https://doi.org/10.1007/s12194-018-0479-9.
[15] D.P. Chakraborty, L.H. Winter, Free-response methodology: alternate analysis and a new observer-performance experiment, Radiology 174 (1990) 873–881, https://doi.org/10.1148/radiology.174.3.2305073.
[16] K. Sugimoto, J. Shiraishi, F. Moriyasu, et al., Improved detection of hepatic metastases with contrast-enhanced low mechanical-index pulse inversion ultrasonography during the liver-specific phase of sonazoid: observer performance study with JAFROC analysis, Acad. Radiol. 16 (2009) 798–809, https://doi.org/10.1016/j.acra.2008.12.025.
[17] D.P. Chakraborty, K.S. Berbaum, Observer studies involving detection and localization: modeling, analysis, and validation, Med. Phys. 31 (2004) 2313–2330, https://doi.org/10.1118/1.1769352.
[18] A. Sugimoto, S. Katsuragawa, Y. Uchiyama, et al., [Development of temporal subtraction method for chest radiographs by using pixel matching technique], [Article in Japanese], Nippon. Hoshasen Gijutsu Gakkai Zasshi 69 (2013) 855–863, https://doi.org/10.6009/jjrt.2013_jsrt_69.8.855.
[19] S.G. Armato 3rd, D.J. Doshi, R. Engelmann, et al., Temporal subtraction of dual-energy chest radiographs, Med. Phys. 33 (2006) 1911–1919, https://doi.org/10.1118/1.2163387.
[20] H. MacMahon, F. Li, R. Engelmann, et al., Dual energy subtraction and temporal subtraction chest radiography, J. Thorac. Imag. 23 (2008) 77–85, https://doi.org/10.1097/RTI.0b013e318173dd38.
[21] P. Vock, Z. Szucs-Farkas, Dual energy subtraction: principles and clinical applications, Eur. J. Radiol. 72 (2009) 231–237, https://doi.org/10.1016/j.ejrad.2009.03.046.
[22] Z. Szucs-Farkas, K. Lautenschlager, P.M. Flach, et al., Bone images from dual-energy subtraction chest radiography in the detection of rib fractures, Eur. J. Radiol. 79 (2011) E28–E32, https://doi.org/10.1016/j.ejrad.2010.01.016.
[23] F. Li, R. Engelmann, K. Doi, et al., Improved detection of small lung cancers with dual-energy subtraction chest radiography, AJR Am. J. Roentgenol. 190 (2008) 886–891, https://doi.org/10.2214/AJR.07.2875.
[24] J. Ricke, F. Fischbach, T. Freund, et al., Clinical results of CsI-detector-based dual-exposure dual energy in chest radiography, Eur. Radiol. 13 (2003) 2577–2582, https://doi.org/10.1007/s00330-003-1913-9.
[25] Z. Szucs-Farkas, M.A. Patak, S. Yuksel-Hatz, et al., Single-exposure dual-energy subtraction chest radiography: detection of pulmonary nodules and masses in clinical practice, Eur. Radiol. 18 (2008) 24–31, https://doi.org/10.1007/s00330-007-0758-z.
[26] H. Kashani, C.A. Varon, N.S. Paul, et al., Diagnostic performance of a prototype dual-energy chest imaging system: ROC analysis, Acad. Radiol. 17 (2010) 298–308, https://doi.org/10.1016/j.acra.2009.10.012.
[27] T. Aoki, O. Oda, Y. Yamashita, et al., Usefulness of computerized method for lung nodule detection in digital chest radiographs using temporal subtraction images, Acad. Radiol. 18 (2011) 1000–1005, https://doi.org/10.1016/j.acra.2011.04.008.
[28] T. Aoki, S. Murakami, H. Kim, et al., Temporal subtraction method for lung nodule detection on successive thoracic CT soft-copy images, Radiology 271 (2014) 255–261, https://doi.org/10.1148/radiol.13130460.
[29] M. Ueno, T. Aoki, S. Murakami, et al., CT temporal subtraction method for detection of sclerotic bone metastasis in the thoracolumbar spine, Eur. J. Radiol. 107 (2018) 54–59, https://doi.org/10.1016/j.ejrad.2018.07.017.
[30] T. Terasawa, T. Aoki, S. Murakami, et al., Detection of lung carcinoma with predominant ground-glass opacity on CT using temporal subtraction method, Eur. Radiol. 28 (2018) 1594–1599, https://doi.org/10.1007/s00330-017-5085-4.