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Clinical application of biological fingerprints extracted from averaged chest radiographs and template-matching technique for preventing left–right flipping mistakes in chest radiography

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Abstract
We aimed to evaluate the identification performance achieved using biological fingerprints extracted from averaged chest radiographs and template-matching techniques for the prevention of left–right flipping mistakes. We produced averaged chest radiographs for each sex by averaging 100 posteroanterior chest radiographs. Further, 400 and 566 chest radiographs were used in consistency and validation tests, respectively, and they were flipped horizontally to produce flipped chest radiographs under the assumption that the left–right flipping mistake occurred. The correlation values obtained with chest radiographs and those obtained with flipped chest radiographs were calculated. When we used correlation indices calculated from the correlation values from four biological fingerprints except for the lung apex, 96.5% (386/400) and 95.8% (542/566) of the left or right sides were identified correctly in the consistency and validation tests, respectively. This result indicates that our proposed method would be promising for the prevention of left–right flipping mistakes.

Keywords Left–right flipping mistake · Chest radiography · Picture archiving and communication system · Biological fingerprints

1 Introduction

Owing to the shift from hard-copy reading to soft-copy reading, picture archiving and communication system (PACS) servers are now used in the management of vast libraries of digital radiographs in many hospitals [1]. The digital radiographs used in soft-copy reading can be processed after acquisition. However, if the left or right sides of the acquired digital radiographs are flipped incorrectly, left–right flipped digital radiographs could be stored in PACS servers. We call this incorrect storage in a PACS server a left–right flipping mistake. According to the 34th quarterly report by the Japan Council for Quality Health Care [2], left–right flipping mistakes occurred when radiological technologists did not change the examination order from posteroanterior (PA) chest radiograph to anteroposterior (AP) chest radiograph for patients who could not hold a standing position. Nine left–right flipping mistakes occurred in the general radiography department of the Kyushu University Hospital within 29 months, between May 2014 and September 2016 (Table 1). Although the frequency of a left–right flipping mistake is very low at 0.0051% (9/176,850), such mistakes should be solved to ensure patient safety. As a measure to prevent the left–right flipping mistake, the image check system called "kenzo system" has been widely used [3]. However, it is difficult for radiological technologists to allocate sufficient time to image checking, particularly in an emergency examination. Therefore, it is desirable to develop an automated image checking system for the prevention of left–right flipping mistakes.

Boone et al. [4] employed an artificial neural network for identifying the orientations of chest radiographs. Although their method demonstrated 99.4% (994/1000) accuracy for the identification and categorization of directional chest

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Table 1 Number of left–right flipping mistakes and total number of examinations in the radiography department

Modality	Number of cases	Total number of examinations
General radiography	5 (0.0041%)	121,089
Bedside radiography	4 (0.0072%)	55,761
Total	9 (0.0051%)	176,850

radiographs, it demonstrated 89.4% (894/1000) accuracy for the identification of the left–right sides from flipped radiographs. The reason for their low performance in the identification of the left–right sides from flipped radiographs was the number of significantly abnormal cases in their database, such as pulmonary edema. To employ it in the clinical environment, it is necessary to improve the identification accuracy. Morishita et al. [5] developed an automated patient recognition and identification method by combining biological fingerprints extracted from chest radiographs with template-matching techniques for preventing filing errors in PACS servers. Although their method indicated promising results for preventing these errors, it required at least one previous chest radiograph of the target patient. Arimura et al. [6] developed a computerized technique for identifying PA and lateral views using averaged chest radiographs.

The left–right flipping mistake may also occur for patients undergoing chest radiography for the first time; hence, it is necessary to develop a method that can prevent the left–right flipping mistake without a previous chest radiograph of the patient. Furthermore, correct identification of the left and right sides is required irrespective of the imaging direction, because AP and PA chest radiographs are acquired in general chest radiography. For the prevention of left–right flipping mistakes, we aimed to evaluate the identification performance achieved using biological fingerprints extracted from averaged chest radiographs and template-matching techniques.

2 Materials and methods

2.1 Image database

Our database consisted of 1166 patients who had undergone chest radiography, including 1000 PA chest radiographs in an upright position (500 male and 500 female; mean age 61.9 ± 16.5 years; age range 20–98 years) and 166 AP chest radiographs in a sitting position (59 male and 107 female; mean age 66.8 ± 17.9 years; age range 20–97 years), which were acquired in the Kyushu University Hospital between April 2016 and March 2017. Some chest radiographs in the database included electronic devices, such as pace makers. All the chest radiographs used in our study were not left–right flipped. We performed histogram standardization on all chest radiographs before use. One thousand PA chest radiographs were selected randomly from the PA chest radiographs acquired during the study period. We used all the AP chest radiographs obtained during the study period because the frequency was extremely small compared with that of PA chest radiographs. In our study, chest radiographs of the patients with dextrocardia were not included in our database, and all personal information was anonymized before use. All the chest radiographs were acquired using a flat panel detector system (Fujifilm Corp., Tokyo, Japan) with 42.2 cm × 42.2 cm detectors. In Kyushu University Hospital, radiological technologists trimmed chest radiographs to 35.6 cm × 35.6 cm, or 35.6 cm × 42.2 cm, before storing them in a PACS server. To unify the matrix size of chest radiographs in our database, we further trimmed the chest radiographs of size 35.6 cm × 42.2 cm–35.6 cm × 35.6 cm, after confirming that lung apices and lower lungs were included. Our database thus comprised chest radiographs with a matrix size of 2373 × 2373 (pixel size 0.15 mm) and a 10-bit gray scale. We reduced the matrix size to 64 × 64 using bi-linear interpolation, which reduced the computation time without any loss of performance [7].

Two-hundred PA chest radiographs from 100 male patients and 100 female patients were randomly selected from our database. We subsequently produced averaged chest radiographs for each sex by averaging 100 PA chest radiographs (Fig. 1) [11]. Another 400 PA chest radiographs from 200 male patients and 200 female patients were selected randomly from the remaining 800 PA chest radiographs in our database for the consistency test, and the remaining 566 chest radiographs (400 PA and 166 AP chest radiographs) were used in a validation test. Our image database that was used in the consistency and validation tests included 26.1% (252/966) of abnormal cases, such as pulmonary edema, pneumonia, and cardiac hypertrophy. The chest radiographs used in the consistency and validation tests were deliberately flipped horizontally (left–right) to produce experimentally flipped chest radiographs that simulated mistakenly flipped images (Fig. 2). These chest radiographs are hereafter referred to simply as "flipped chest radiographs".

2.2 Extraction of biological fingerprints from averaged chest radiographs and similarity index

The outline of our proposed method is shown in Fig. 3. We extracted the cardiac shadow (CS), lung apex (LA), superior mediastinum (SM), and right lower lung (RLL) as templates of biological fingerprints from averaged chest radiographs (Fig. 1) [11]. All the image information in a chest radiograph

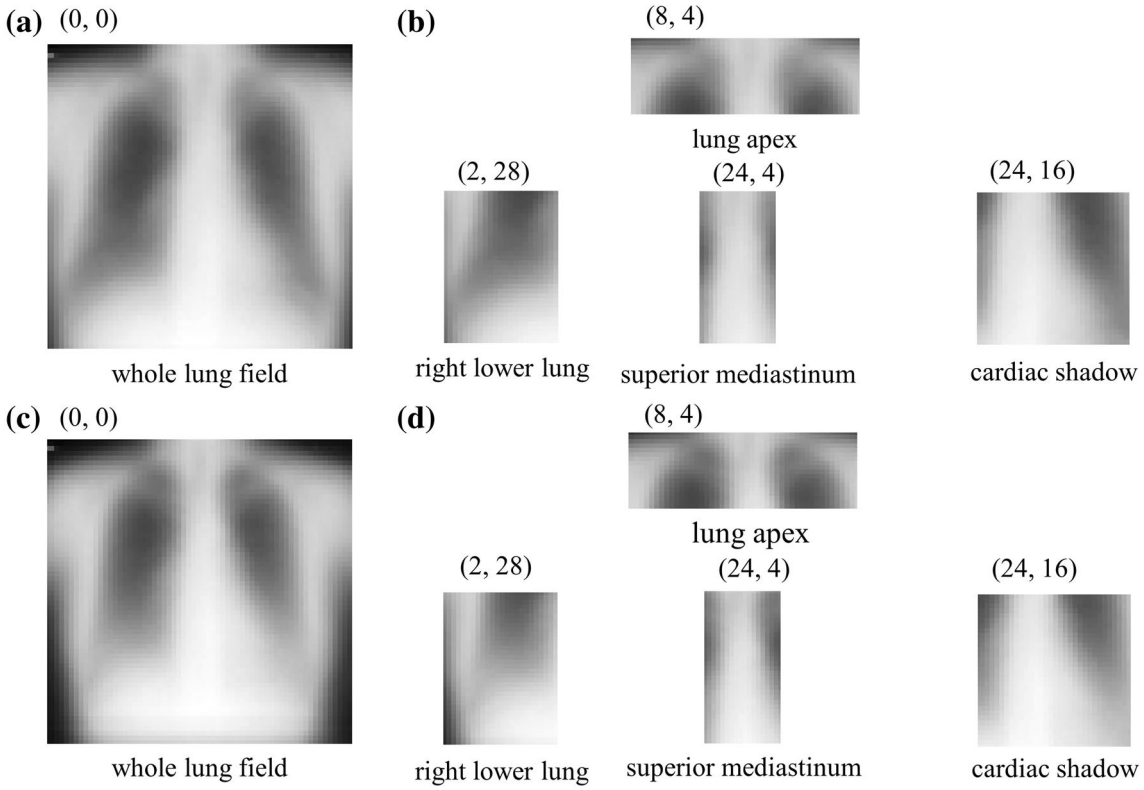

Fig. 1 Averaged chest radiographs from male (**a**) and female patients (**c**), and four templates of biological fingerprints extracted from the averaged chest radiographs from male (**b**) and female patients (**d**). Locations of the top of the biological fingerprints are indicated as number in parentheses

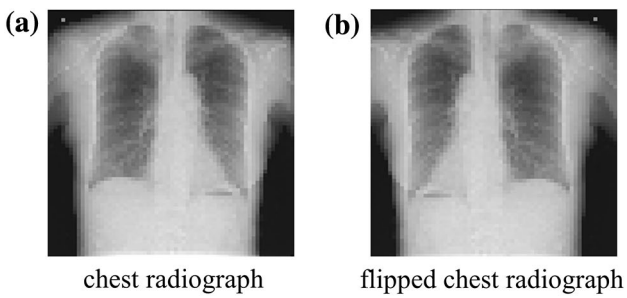

Fig. 2 Example of a chest radiograph (**a**) and the corresponding flipped chest radiograph (**b**)

was used as the whole lung field (WLF). The matrix sizes of WLF, CS, LA, SM, and RLL were 64 × 64, 32 × 32, 48 × 16, 16 × 32, and 24 × 32, respectively [5].

We used normalized cross-correlation value (hereafter referred to as the correlation value) as an index of similarity between biological fingerprints extracted from averaged chest radiographs and chest radiographs with/without flipping. The correlation value ranged from − 1.0 to 1.0, with a higher correlation value indicating greater similarity [5–11]. To determine the best matching position between biological fingerprints and chest radiographs, the biological fingerprints were shifted vertically and horizontally and rotated on the chest radiograph from − 5° to 5°. The size and location of the search area of each biological fingerprint are indicated in Table 2. These parameters were utilized for patient recognition and identification in the previous study [5]. We assumed that these parameters could be used for the identification of the left–right sides of chest radiographs.

2.3 Evaluation of the identification performance of the left or right sides of the chest radiograph

In the consistency test, correlation values obtained with 400 chest radiographs, and those obtained with 400 flipped chest radiographs were calculated. When we calculated the correlation value obtained with the chest radiographs and flipping chest radiographs, we used the averaged chest radiographs from patients of the same sex as the chest radiographs [11]. The identification performance for left or right sides was evaluated by comparing the correlation values obtained with the chest radiographs with those obtained with the flipped chest radiographs. We defined that, when the correlation values obtained with the chest radiographs were higher than those obtained with the flipped chest radiographs, the left or right side was identified correctly. We evaluated the

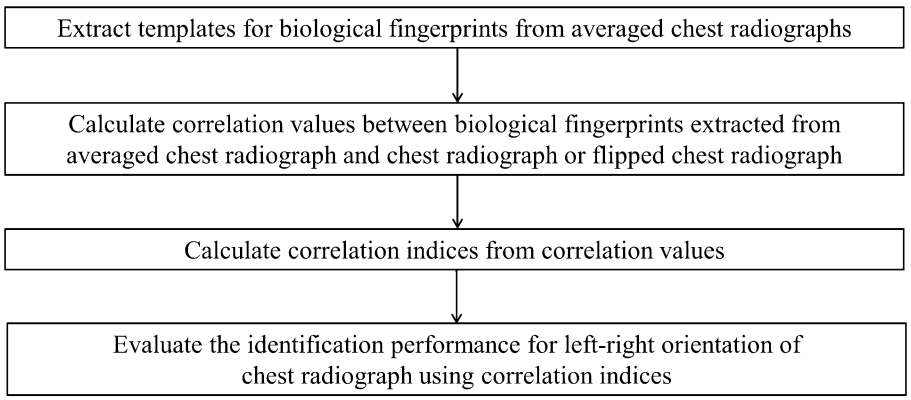

Fig. 3 Outline conducted to develop the identification method for left–right sides of chest radiograph

Table 2 Size and location of search areas in each biological fingerprint for template-matching technique

Biological fingerprints	Search area	
	Size	Location
Whole lung field	64×64	(0, 0)
Cardiac shadow	48×48	(16, 8)
Lung apex	64×28	(0, 0)
Superior mediastinum	32×44	(16, 0)
Right lower lung	40×48	(0, 16)

Locations of the top left of the biological fingerprints are indicated by numbers in parentheses

left–right identification performance using correlation values and a correlation index calculated by summing the correlation values of WLF, CS, SM, and RLL (except for LA). In the validation test, the identification performance for the left or right sides of 566 chest radiographs was also examined using a correlation index.

2.4 Statistical analysis

To verify the usefulness of biological fingerprints for the identification of the left–right sides of chest radiographs, the Wilcoxon signed-rank test was performed in terms of WLF, CS, LA, SM, RLL, and combinations of four biological fingerprints (all except for LA). A p value less than 0.05 was considered statistically significant. Statistical analyses were performed with JMP Pro version 13.0.0 (SAS Institute Inc., Cary, NC, USA).

3 Results

In the consistency test, the correlation values obtained with the chest radiographs were significantly higher than those obtained with the flipped chest radiographs (Fig. 4). The correct identification rates of the left or right side in terms of WLF, CS, LA, SM, and RLL were 89.8% (359/400), 85.8% (343/400), 82.8% (331/400), 87.3% (349/400), and 91.0% (364/400), respectively. The mean and standard deviation of the correlation values obtained with the chest radiographs and with the flipped chest radiographs are shown in Table 3. When we used correlation indices calculated from the correlation values of four biological fingerprints (except for LA), the correct identification rate of the left or right side of the chest radiographs was 96.5% (386/400), which indicated the best performance (Fig. 5). The mean and standard deviation of the correlation indices obtained with the chest radiographs and flipped chest radiographs were 3.593 ± 0.172 and 3.455 ± 0.173, respectively ($p < 0.01$).

In the validation test, the correlation values and correlation indices obtained with the chest radiographs were significantly higher than those obtained with the flipped chest radiographs ($p < 0.01$). Although the correlation values and correlation indices in the AP chest radiographs tended to be lower than those in the PA chest radiographs, the correlation values and correlation indices obtained with the AP chest radiographs were indicated to be higher than those obtained with the flipped AP chest radiographs (Tables 4, 5). When we used correlation indices, the correct identification rate for the chest radiographs was 95.8% (542/566). In other words, the left or right side was identified correctly in 95.8% (383/400) of the PA chest radiographs and 95.8% (159/166) of the AP chest radiographs. Examples of incorrectly identified chest radiographs are shown in Fig. 6: the post-surgery of the right lower lung

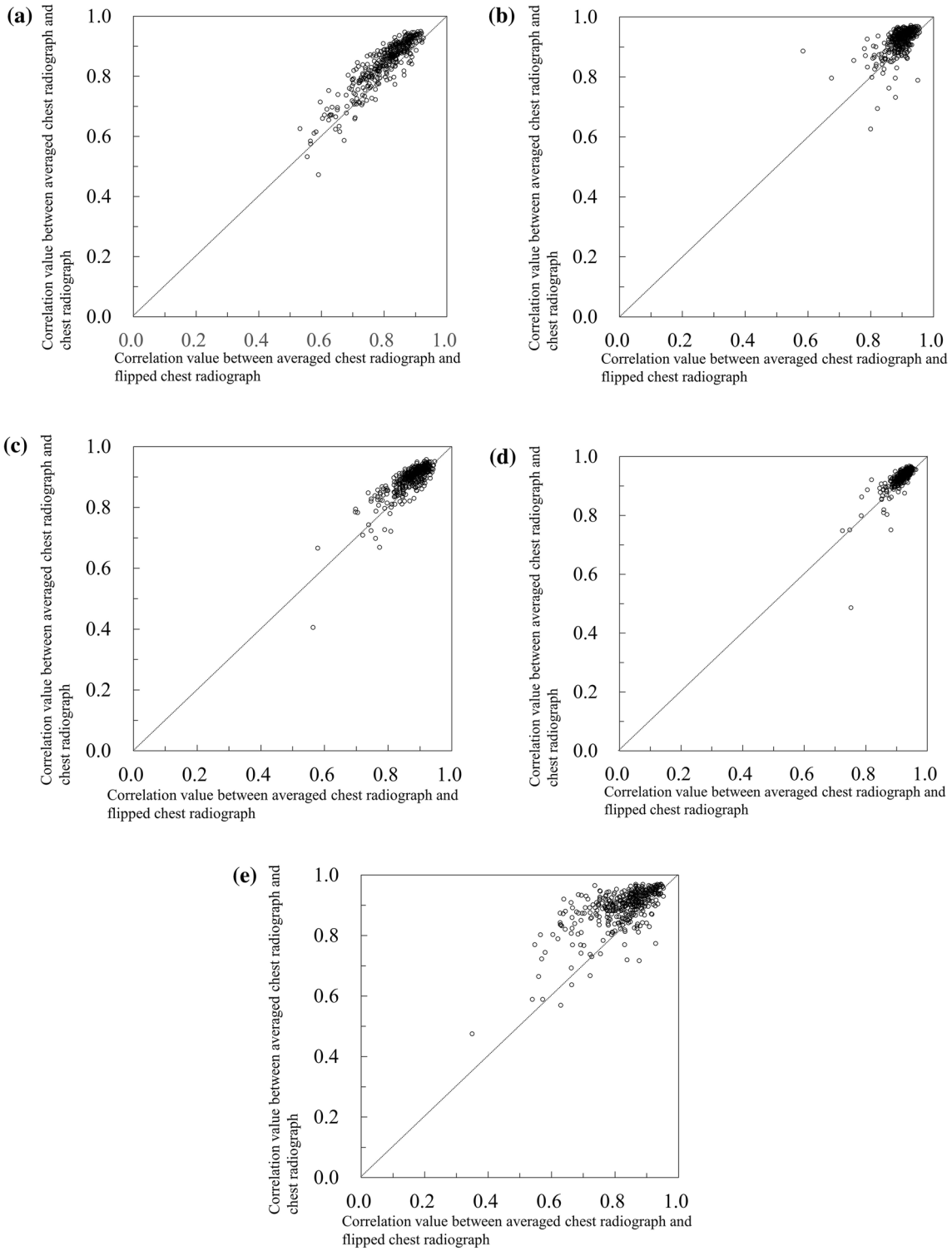

Fig. 4 Correlation values obtained with 400 chest radiographs, and 400 flipped chest radiographs in terms of whole lung fields (**a**), cardiac shadows (**b**), lung apices (**c**), superior mediastinum (**d**), and right lower lungs (**e**)

(Fig. 6a), pleural effusion (Fig. 6b), and abnormal heart shadow (Fig. 6c).

The correct identification rate for the left–right sides of abnormal cases was 84.9% (214/252). Figure 7 indicates examples of correctly identified radiographs despite abnormal cases, such as pulmonary edema, pneumonia, and cardiac hypertrophy.

Table 3 Mean and standard deviation of correlation values obtained with chest radiographs and flipped chest radiographs in the consistency test

Biological fingerprints	Correlation value		
	Chest radiograph	Flipped chest radiograph	*p* value
Whole lung field	0.846 ± 0.080	0.805 ± 0.076	< 0.01
Cardiac shadow	0.922 ± 0.040	0.895 ± 0.037	< 0.01
Lung apex	0.894 ± 0.050	0.872 ± 0.049	< 0.01
Superior mediastinum	0.929 ± 0.036	0.917 ± 0.029	< 0.01
Right lower lung	0.895 ± 0.065	0.827 ± 0.086	< 0.01

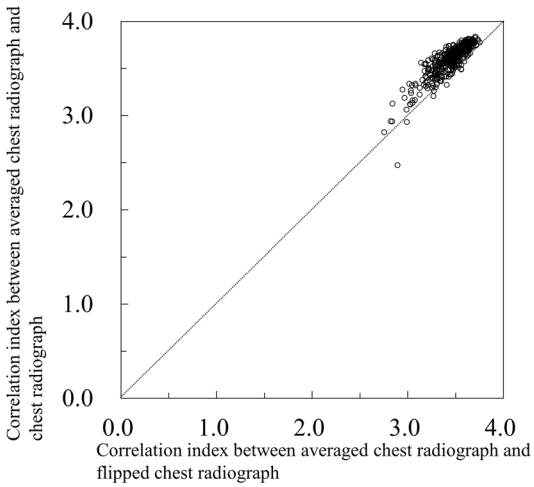

Fig. 5 Correlation index obtained with 400 chest radiographs and 400 flipped chest radiographs

4 Discussion

We proposed a method for identifying the left or right side of chest radiographs using biological fingerprints extracted from averaged chest radiographs and template-matching techniques to prevent left–right flipping mistakes. We used normal and abnormal cases without distinction to demonstrate the potential usefulness of this method for the identification of left–right sides of chest radiographs acquired in a clinical environment. The correlation values and correlation indices obtained with the chest radiographs were indicated to be significantly higher than those obtained with the flipped chest radiographs (Table 3). When we used correlation indices calculated from the correlation values of four biological fingerprints (except for LA), the correct identification rates of the left or right side of the chest radiographs were 96.5% (386/400) and 95.8% (542/566) in the consistency and validation tests, respectively. These results indicated that our method provided a comparable performance to the method proposed in a previous study [4]. When we used the correlation values of WLF, CS, SM, and RLL, our method

Table 4 Mean and standard deviation of correlation values obtained with chest radiographs and flipped chest radiographs in the validation test

Biological fingerprints	Correlation value			
	Chest radiograph		Flipped chest radiograph	
	PA chest radiograph (N = 400)	AP chest radiograph (N = 166)	PA chest radiograph (N = 400)	AP chest radiograph (N = 166)
Whole lung field	0.855 ± 0.066	0.814 ± 0.079	0.817 ± 0.066	0.785 ± 0.077
Cardiac shadow	0.919 ± 0.045	0.905 ± 0.044	0.891 ± 0.039	0.875 ± 0.046
Lung apex	0.887 ± 0.057	0.839 ± 0.070	0.870 ± 0.061	0.837 ± 0.066
Superior mediastinum	0.924 ± 0.034	0.907 ± 0.051	0.914 ± 0.034	0.897 ± 0.042
Right lower lung	0.899 ± 0.053	0.885 ± 0.055	0.836 ± 0.072	0.820 ± 0.075

Table 5 Mean and standard deviation of correlation index obtained with chest radiographs and flipped chest radiographs in the validation test

	Chest radiograph		Flipped chest radiograph	
	PA chest radiograph (*N* = 400)	AP chest radiograph (*N* = 166)	PA chest radiograph (*N* = 400)	AP chest radiograph (*N* = 166)
Correlation index	3.597 ± 0.149	3.514 ± 0.183	3.457 ± 0.153	3.377 ± 0.176

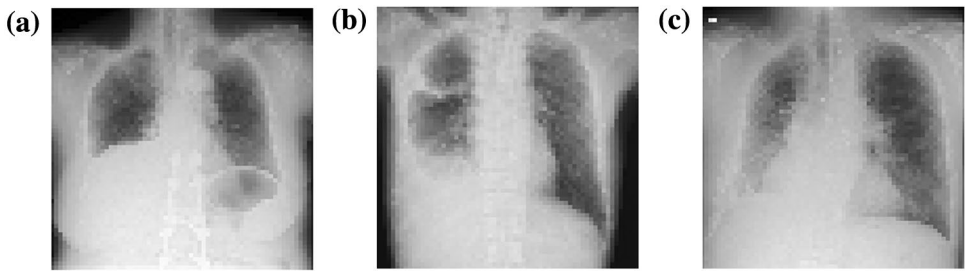

Fig. 6 Examples of incorrectly identified left or right sides of chest radiograph owing to the post-surgery of the right lower lung (**a**), the pleural effusion (**b**), and the abnormal heart shadow (**c**)

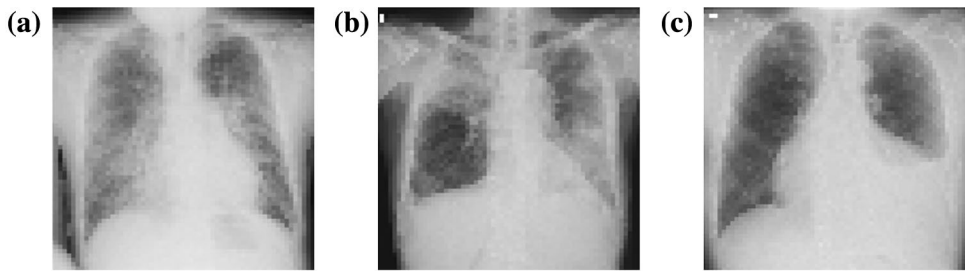

Fig. 7 Examples of correctly identified left or right sides of chest radiograph despite the abnormal cases such as pulmonary edema (**a**), pneumonia (**b**), and cardiac hypertrophy (**c**)

showed the best performance. This was because anatomical structures such as the cardiac shadow in the template of CS, descending thoracic aorta included in SM, and right costophrenic angle included in RLL were suitable as landmarks for identifying the left or right side. However, LA was not suitable for improving the identification performance, because the left and right sides of LA were bilaterally symmetrical.

Although the correlation values obtained with the AP chest radiographs were indicated to be lower than those obtained with the PA chest radiographs, our method identified 95.8% (158/166) of the left or right side of the AP chest radiographs. The correlation values obtained with the AP chest radiographs were indicated to be lower than those obtained with the PA chest radiographs because the cardiac shadows and mediastinum in the AP chest radiographs are wider than those in the PA chest radiographs. However, owing to left–right flipping in addition to widening, the correlation values obtained with the flipped AP chest radiographs were indicated to be lower than those obtained with the AP chest radiographs. Therefore, our method could be applied to AP chest radiographs as well.

The left–right sides of 84.9% (214/252) of abnormal cases shown as in Fig. 7 were identified correctly, which indicated that our method could identify the left–right sides of mild to moderately abnormal cases. However, 3.5% (14/400) and 4.2% (24/566) of the left or right sides were identified incorrectly in the consistency and validation tests, respectively. We considered that biological fingerprints in these cases, as indicated as Fig. 6, lost landmarks for the identification of the left or right side because they had abnormal shadows on biological fingerprints such as CS, SM, and/or RLL. Toge et al. [9] reported that an apparent large difference in breathing and the difference in positioning between two chest radiographs in the same patient prevented patient recognition and identification. We considered that the large difference between averaged chest radiographs and chest radiographs with abnormal shadows on biological fingerprints caused incorrect identification in the cases shown in Fig. 6. Arimura et al. [6] developed a method for identifying the PA and lateral views by producing several averaged chest radiographs depending on patient body size. In our study, we expected that the identification performance of the left or right side would be improved by producing several averaged chest radiographs based on abnormal cases such as post-surgery of the right lower lung, pleural effusion, or an abnormal heart shadow. In future work, we will collect many chest radiographs based on abnormal cases to improve the identification performance. To further improve the identification performance, a deep learning approach may be useful. However, we did not utilize the approach in this study because it requires many chest radiographs for training.

Our study has two limitations. First, bedside chest radiographs were not included in our database. As bedside chest radiographs are acquired frequently, we should develop a left–right identification method for them. Second, the chest radiographs of the patients with dextrocardia were not included in our database. Our method is not suitable for patients with dextrocardia owing to the lack of a cardiac shadow in the template of CS. However, we believe that our method will identify the left or right side without using a previous chest radiograph of the target patient. It may also be useful as an image checking system to assist the radiological technologists in the "kenzo system".

5 Conclusion

When we used the correlation index calculated from correlation values of four biological fingerprints (except for LA), 96.5% (386/400) and 95.8% (542/566) of the left or right sides of the chest radiographs were identified correctly in the consistency and validation tests, respectively. This result indicates that our proposed method would be promising for the prevention of left–right flipping mistakes.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with animals performed by any of the authors. All procedures performed in studies involving human participants were in accordance with the ethical standards of the Institutional Review Board (IRB) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The IRB was obtained without patients' informed consent.

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