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Clinical utility of dynamic chest radiography as an auxiliary tool for atrial fibrillation detection in heart failure: a pilot study

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Abstract

Background Dynamic chest radiography (DCR) can estimate haemodynamic parameters in patients with heart failure (HF). Atrial fibrillation (AF) often coexists with HF; however, owing to its sometimes paroxysmal nature and minimal or absent symptoms, many patients with AF remain undiagnosed. Additional tools for AF diagnosis may be beneficial; therefore, we evaluated the ability of DCR to distinguish patients with HF in sinus rhythm (SR) from those with AF.

Methods In this small-sample pilot study, 20 patients with HF (median age, 67 years; males, 85%) underwent 12-lead electrocardiography and DCR on the same day. Aortic arch (Ao), right atrial (RA), right and left pulmonary artery (PA), and left ventricular (LV) apex pixel values (PVs) were measured. Seventeen patients were in SR and three demonstrated AF on 12-lead electrocardiography before DCR.

Results The PV and PV change rate waveforms of the Ao, RA, PAs, and LV apex were regular in SR and irregular with AF. The difference between patients in SR and those with AF was particularly clear in the LV apex PV change rate waveforms. In addition, the heart rates (HRs) of patients in SR and with AF could be calculated from the PV change rate waveforms and were similar to those calculated by 12-lead electrocardiography.

Conclusions DCR can detect AF in patients with HF and may be able to infer HR.

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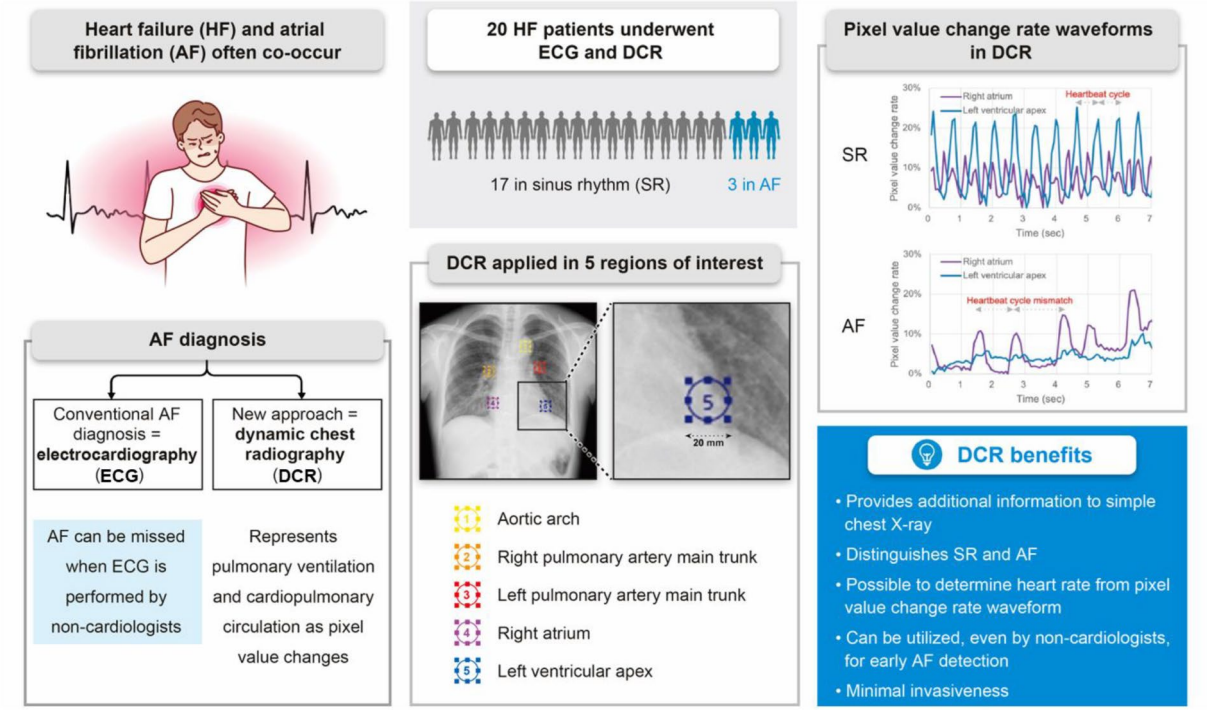
Graphical abstract



Keywords Atrial fibrillation, Dynamic chest radiography, Heart failure, Heart rate, Pixel value, Sinus rhythm

Background

Heart failure (HF) is a leading cause of hospitalisation and death [1]. Atrial fibrillation (AF) is frequent in patients with HF, and their coexistence is associated with substantially increased morbidity and mortality [2, 3]. Moreover, their incidences are associated with each other, suggesting a bidirectional relationship [4]. The Framingham Heart Study revealed that among participants who recently developed AF, 37% had previously diagnosed HF, and 57% who developed HF had AF [2].

AF may be diagnosed by pulse palpation with a sensitivity of 91–100%; however, the specificity of this approach is only 70–77% [5]. AF can also be definitively diagnosed by 12-lead electrocardiography [5], but its diagnosis can be difficult or overlooked when the examination is performed by a non-cardiologist. Furthermore, owing to its sometimes paroxysmal or intermittent nature with minimal or absent symptoms, AF often remains undetected by electrocardiography [6].

Dynamic chest radiography (DCR) is a minimally invasive imaging technique that allows real-time, high-resolution imaging of the thorax. DCR is distinguished by its high spatial and temporal resolution across a large field of view and computer-assisted tracking of moving thoracic structures. DCR allows for the assessment of pulmonary ventilation and circulation readings as quantifiable pixel values (PVs), bypassing the need for contrast media. On DCR, greater X-ray volume emission on the flat-panel detector is indicative of a higher PV, and vice versa. Thus, the change in PV directly reflects the change in moisture content in a region of interest (ROI). Sequential chest radiographs can be obtained during respiration and 15 frames/second heartbeat, and quantified as the change in PV [7, 8].

Flat-panel detector DCR routinely provides information on lung morphology and function or pulmonary ventilation and circulation, as well as diaphragmatic movement and diaphragmatic nerve palsy [7, 8, 9, 10, 11, 12, 13, 14, 15, 16]. Furthermore, DCR is useful for detecting conditions such as acute pulmonary thromboembolism and pulmonary hypertension [17, 18, 19]. Pulmonary function assessment has also been supported by comparing DCR with nuclear medicine ventilation-perfusion imaging [8, 20]. Therefore, DCR is undoubtedly a powerful tool that harnesses dynamic imaging findings to monitor haemodynamic parameters [7, 9, 21]. We recently showed that DCR imaging parameters significantly correlate with the haemodynamic parameters measured during right heart catheterisation in patients with HF [22]. In addition, we demonstrated that DCR

may be useful to identify left ventricular systolic dysfunction based on left ventricular ejection fraction in patients with HF [23]. Furthermore, DCR proved valuable for capturing cardiac contraction not only in the frontal and lateral views but also in the oblique view [24].

To our knowledge, there are no reports of AF detection by DCR in patients with HF. In this pilot study, we investigated changes in the PVs of the aortic arch (Ao), right atrium (RA), right and left pulmonary arteries (PAs), and left ventricular (LV) apex to determine whether they could distinguish patients with HF in sinus rhythm (SR) from those with AF at the time of DCR. PV waveforms were generated from the changes in PVs at these five ROIs. Furthermore, heart rate (HR) was inferred from the PV waveforms.

Methods

Study population

The full study protocol can be accessed on the electronic system of the Bioethics Review Committee of Nagoya University Hospital (https://nagoya.bvits.com/rinri/Common/ Examination No. 2023 – 0103). This was a single-centre, prospective, observational study. Overall, 43 consecutive patients hospitalised for worsening HF who underwent DCR at our institute between July 2023 and December 2023 were recruited. HF was diagnosed by cardiologists in accordance with the modified Framingham criteria [25], including clinical symptoms, physical examinations, conventional plain chest radiography, and echocardiography findings. Patients with HF with reduced ejection fraction (HFrEF) and HF with preserved ejection fraction (HFpEF) were included. All patients underwent treatment for worsening HF with diuretics, vasodilators, mechanical respiratory support, and inotropic agents. Patients undergoing DCR were excluded if breath-hold was difficult ($n = 9$) or if they had difficulty undergoing DCR in the supine position ($n = 14$). Patients with cardiac devices did not undergo DCR. Finally, 20 patients with HF were enrolled (Fig. 1) and underwent electrocardiography and DCR when their HF status had stabilised with treatment.

The study protocol was performed in accordance with the 1964 Declaration of Helsinki and its later amendments and was approved by the ethics review board of our institute. Written informed consent was obtained from all patients.

Dynamic chest radiography

DCR was performed by a radiology technician, and the DCR images were evaluated by a radiology technician, radiologist, and cardiologist. The results of the reference test (electrocardiography) were available to the DCR assessors to avoid bias. Sequential chest radiographs were obtained using a dynamic flat-panel detector imaging system, as previously described [22]. Patients were instructed to hold their breath for at least 7 s to capture the cardiopulmonary perfusion images. The end of breath-hold was determined by the radiographer based on each patient's condition. The exposure dose during breath-hold was approximately 0.8 mGy per dynamic chest X-ray, while the effective dose was 0.16 mSv. The dose per frame was 7.6 μGy. The exposure dose was calculated as 1 pulse dose × 15 frames/second × imaging time. The average imaging time at our institute is 16 s in

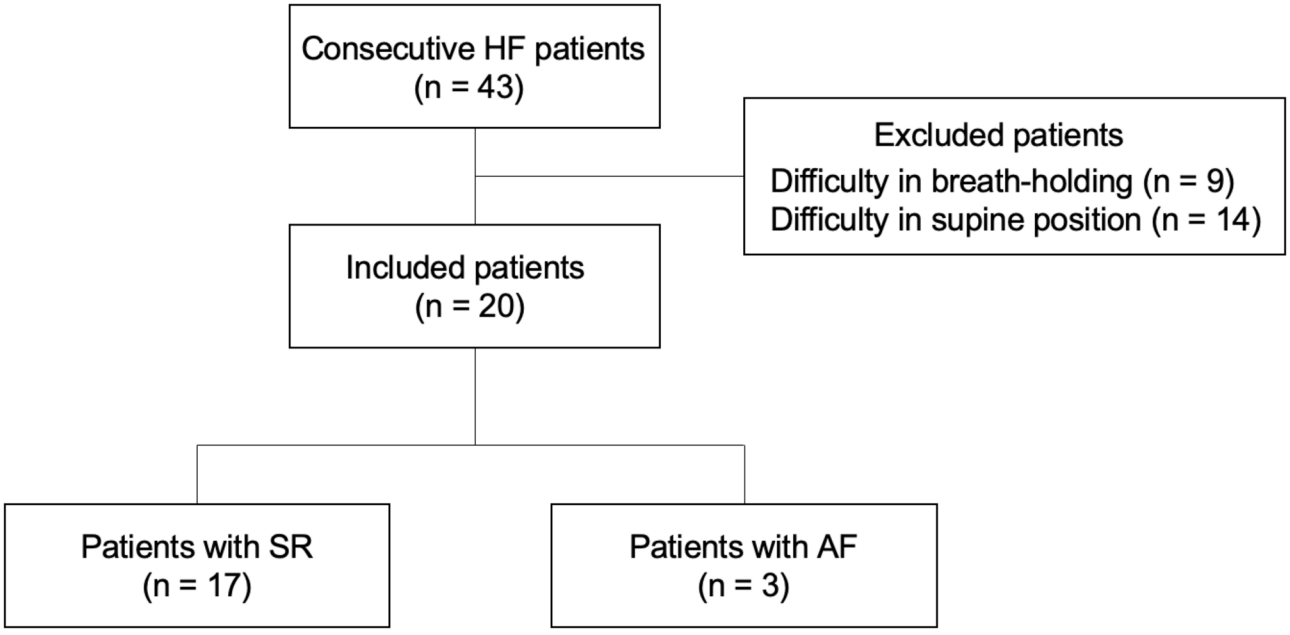


Fig. 1 Flowchart of patient selection

both the standing and supine positions. DCR was performed on all patients in the supine position because 12-lead electrocardiography and echocardiography are also performed in the supine position and we wanted to ensure comparability of the testing conditions. The average exposure dose was 1.8 mGy, which is below the recommended dose of 1.9 mGy for combined frontal and lateral chest radiography, as per the International Atomic Energy Agency's guidance dose. The PV range was 65,536 (16 bits), and the signal intensity was proportional to the incident exposure of the flat-panel detector.

On the basis of the principle that increased blood volume decreases X-ray emission, lower PVs on serial chest radiographs capture temporal changes in radiographic transparency and represent changes in the pulmonary circulation owing to cardiac pumping. The average signal for each ROI (diameter, 20 mm) was measured for all frames. The 3-second frame interval with the lowest maximum and minimum values was selected from the average signal waveform of all frames. The difference between the maximum and minimum values was considered as the maximum amount of change (maximum – minimum), and the rate of change was calculated as (maximum – minimum) ÷ maximum (Fig. 2).

The five ROIs on DCR, namely the (1) aortic arch, (2) right PA main trunk, (3) left PA main trunk, (4) RA, and (5) LV apex. The diameter of each ROI was 20 mm. The enlarged view of the ROI at the LV apex is shown. From the average signal waveform of all frames, the 3-second frame with the smallest maximum and minimum pixel values was selected. Rate of change was calculated as (maximum – minimum) ÷ maximum. Reproduced from Hiraiwa et al. [22] under CC-BY-NC-ND license. LV, left ventricular; PA, pulmonary artery; RA, right atrium; ROI, region of interest.

The rate of change in PV was used rather than the absolute PV in this study because in our previous study [22], the rate of change in PV was more strongly correlated with haemodynamic parameters than the absolute PV. Moreover, the rate of change in PV allows for normalisation to body size, in case differences in body surface area were to exist between the groups evaluated. We also evaluated PV change rate waveforms in each ROI in addition to the original average PV waveform.

Measurement of image parameters and heart rate by dynamic chest radiography

Density changes on DCR images were measured as changes in PV in five ROIs, namely the aortic arch (Ao), right pulmonary artery (PA) main trunk, left PA main trunk, right atrium (RA), and left ventricular (LV) apex (Fig. 2). The five selected ROIs were chosen to minimise overlap between the structures. The ROIs were manually selected using X-ray images upon breath-hold to eliminate respiratory variability. The RA and LV apex ROIs were positioned above the diaphragm during cardiac systole.

To measure HR, we used the waveform of the PV change rate at the LV apex as shown in the additional figure (Additional File 1). The graph was corrected so that the minimum value was 0% and the maximum was 100%. Frames in which the change from the minimum value exceeded 60% were defined as cardiac systolic frames. The total number of frames from the start frame to the end frame was divided by the number of heartbeats to obtain one cardiac cycle, and the number of beats per minute was calculated. Although a high PV change rate threshold of 80–90% should have been used, the graph fluctuated up and down owing to the influence of unavoidable respiratory variability and body movement; therefore, some of the peaks were not considered peaks at this higher threshold, and the threshold was reduced to 60%.

Laboratory measurements, electrocardiography, and echocardiography

Electrocardiography was performed by an electrocardiography technician, and electrocardiograms were evaluated by an electrocardiography technician and a cardiologist. The results of the index test (DCR) were

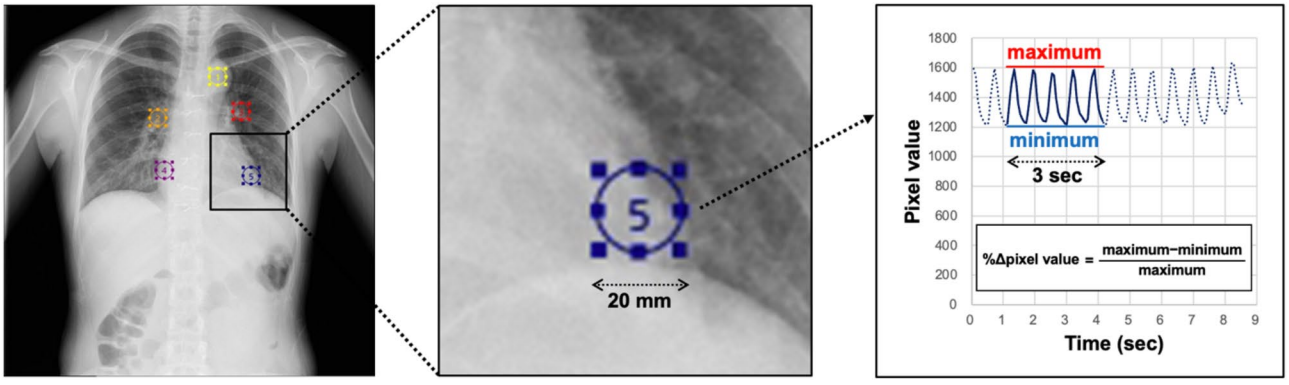


Fig. 2 Five ROIs on DCR

available to the electrocardiography assessors to avoid bias. All patients underwent 12-lead electrocardiography to assess heart rhythm and HR (FCP-8800; Fukuda Denshi Co. Ltd., Tokyo, Japan) immediately before DCR using the Vivid 7 ultrasonography system (GE Healthcare, Milwaukee, WI, US) equipped with a 2.5–3.5-MHz transducer, which included standard M-mode and two-dimensional echocardiography, Doppler blood flow imaging, and tissue Doppler imaging. HR was automatically calculated on the basis of the electrocardiography algorithm in patients in SR and in patients with AF.

Standard M-mode and two-dimensional echocardiography, Doppler blood flow imaging, and tissue Doppler imaging were performed following American Society of Echocardiography guidelines [26]. LV ejection fraction (LVEF) was measured using the Teichholz method and Simpson's method.

Statistical analysis

No sample size calculation was performed because this was a pilot study. All statistical analyses were performed using SPSS Statistics for Windows, version 28.0 (SPSS Inc., Chicago, IL, US) or freely available statistical software (R, version 4.3.0; www.r-project.org). All continuous variables are presented as the median (interquartile range). Parametric variables were compared using the Student's *t*-test, while non-parametric variables were compared using the Mann–Whitney *U* test. Categorical variables are expressed as number (%), and these were compared using Pearson's chi-square test or Fisher's exact test. $P < 0.05$ was considered statistically significant.

Results

Baseline characteristics

The baseline characteristics of all patients are shown in Table 1. Among the 20 patients (Fig. 1) (median age, 67 years), 17 (85%) were male and 3 (15%) were female (Table 1). Of note, the LV apex ROI is unlikely to have been affected by the intense shadow of the breast. Nineteen patients (95%) were classified as New York Heart Association (NYHA) functional class I/II, and one was classified as NYHA functional class III. The median LVEF was 37.6% (25.3–61.0%), and the median plasma brain natriuretic peptide (BNP) and N-terminal proBNP concentrations were 209.9 pg/mL (46.6–396.1 pg/mL) and 1572 pg/mL (521–2355 pg/mL), respectively. The median HR of patients with AF was 70 (45–87) bpm, which indicates that patients with tachycardic or bradycardic AF were not included. Table 1 depicts the laboratory and echocardiographic data. Patients in SR ($n = 17$) were compared with patients with AF ($n = 3$). No significant differences in age, sex, body surface area, NYHA functional classification, or HF aetiology were identified.

Echocardiographic and electrocardiographic findings

According to electrocardiography, the median HR was not significantly different between the two groups. Interestingly, patients with AF demonstrated a lower LVEF of 35.7% compared with 44.7% in patients in SR, according to Simpson's method. The LVEF measured using the Teichholz method and Simpson's method strongly positively correlated with the LV apex PV change rate as shown in the additional figure (Additional File 2). Additionally, patients with AF had a larger left atrial diameter and a higher rate of moderate or severe mitral regurgitation.

Analysis of pixel values and pixel value change rate waveforms in sinus rhythm and atrial fibrillation

During DCR of patients with HF in SR, normal cardiac contraction was observed as shown in the additional video (Additional File 3). PVs were measured in the supine position to ensure comparability of the testing conditions with echocardiography and electrocardiography, which were also performed in the supine position. The PVs of the ROIs in the supine position are shown in Tables 2 and 3 for patients in SR and patients with AF, respectively.

In patients with HF in SR, the PV change rate waveforms were uniform and equally spaced in all five ROIs (Fig. 3a and b). In particular, the PV change rate waveforms in the LV apex were visually clear in patients in SR (Fig. 3b). The HR calculated from the PV change rate waveforms was 92 bpm as shown in the additional figure (Additional File 1), which was almost consistent with the HR of 93 bpm determined by 12-lead electrocardiography as shown in the additional figure (Additional File 4).

In patients with HF with AF, cardiac contraction was irregular, as seen in the moving DCR image (Additional File 5). In patients with AF, the PV change rate waveforms in the Ao, right and left PAs, RA, and LV apex were not uniform, with uneven and scattered spacing (Fig. 3c and d). Comparing the PV change rate waveforms at the LV apex between patients in SR and those with AF, patients in SR had higher PV wave height values and larger wave amplitudes than those with AF (Fig. 3b and d). However, it is possible that this may have been due to patients in SR having better cardiac contractility than patients with AF (Teichholz LVEF: 44.7% in SR vs. 20.8% with AF; Simpson's LVEF: 44.7% in SR vs. 35.7% with AF), rather than indicating the presence or absence of AF. Furthermore, the HR based on the PV change rate waveform over 7 s was measurable in patients with AF (43 bpm) as shown in the additional figure (Additional File 1) and was almost consistent with the HR of 45 bpm measured by 12-lead electrocardiography as shown in another additional figure (Additional File 4).

Table 1 Patients' demographic and clinical characteristics

	All patients (*n* = 20)	Sinus rhythm (*n* = 17)	Atrial fibrillation (*n* = 3)	*P*
Age, years	67 (50–76)	66 (48–74)	79 (70–80)	0.203
Male	17 (85)	14 (82)	3 (100)	0.430
Body surface area, m^2	1.63 (1.49–1.80)	1.58 (1.49–1.79)	1.77 (1.67–1.86)	0.266
NYHA functional class I/II/III	10/9/1	9/7/1	1/2/0	0.666*
Aetiology of HF				
Ischaemic cardiomyopathy	6 (30)	5 (29)	1 (33)	0.891
Dilated cardiomyopathy	2 (10)	2 (12)	0 (0)	0.531
Hypertrophic cardiomyopathy	1 (5)	1 (6)	0 (0)	0.666
Valvular heart disease	3 (15)	2 (12)	1 (33)	0.334
Hypertensive heart disease	3 (15)	2 (12)	1 (33)	0.334
Cardiac amyloidosis	2 (10)	2 (12)	0 (0)	0.531
Cardiac sarcoidosis	1 (5)	1 (6)	0 (0)	0.666
Anthracycline-induced cardiomyopathy	1 (5)	1 (6)	0 (0)	0.666
Post-myocarditis	1 (5)	1 (6)	0 (0)	0.666
Comorbidity				
Hypertension	9 (45)	7 (41)	2 (67)	0.413
Diabetes mellitus	7 (35)	6 (35)	1 (33)	0.947
Dyslipidaemia	11 (55)	9 (53)	2 (67)	0.659
Chronic obstructive pulmonary disease	1 (5)	0 (0)	1 (33)	0.014
Medical therapy				
Angiotensin-converting enzyme inhibitor/angiotensin II receptor blocker	12 (60)	10 (59)	2 (67)	0.798
Angiotensin receptor-neprilysin inhibitor	1 (5)	0 (0)	1 (33)	0.014
Beta-blocker	11 (55)	9 (53)	2 (67)	0.659
Mineralocorticoid receptor antagonist	7 (35)	6 (35)	1 (33)	0.947
Sodium-glucose cotransporter 2 inhibitor	5 (25)	4 (24)	1 (33)	0.717
Loop diuretic	13 (65)	10 (59)	3 (100)	0.168
Laboratory measurement				
Haemoglobin, g/dL	13.0 (10.9–13.7)	12.7 (10.7–13.2)	14.4 (13.8–16.4)	0.063
Sodium, mEq/L	140 (137–141)	140 (137–141)	140 (139–141)	0.871
Albumin, g/dL	4.0 (3.8–4.2)	4.0 (3.7–4.2)	3.8 (3.8–4.0)	0.915
Creatinine, mg/dL	1.05 (0.87–1.29)	0.99 (0.86–1.23)	1.35 (1.32–1.46)	0.026
BNP, pg/mL	209.9 (46.6–396.1)	176.4 (40.8–399.8)	245.4 (226.9–320.1)	0.560
NT-proBNP, pg/mL	1572 (521–2355)	966 (227–2258)	1887 (1779–2444)	0.248
High-sensitivity C-reactive protein, mg/dL	0.08 (0.04–0.53)	0.07 (0.03–0.58)	0.48 (0.26–0.49)	0.779
Electrocardiography				
Sinus rhythm	17 (85)	17 (100)	0 (0)	< 0.001
Atrial fibrillation	3 (15)	0 (0)	3 (100)	< 0.001
Heart rate, bpm	71 (64–82)	71 (64–81)	70 (45–87)	0.697
Echocardiography				
LAD, mm	44.4 (42.1–46.9)	44.0 (40.8–46.8)	45.6 (44.7–58.1)	0.289
LVEDD, mm	55.3 (46.5–65.8)	54.0 (45.4–65.8)	61.5 (56.0–67.6)	0.314
LVEF (Teichholz), %	37.6 (25.3–61.0)	44.7 (28.5–60.7)	20.8 (16.5–30.5)	0.101
LVEF (Simpson), %	38.8 (26.3–62.2)	44.7 (26.4–63.0)	35.7 (22.9–36.8)	0.185
E/e'	17.8 (11.0–21.6)	16.1 (10.7–21.5)	21.6 (18.5–23.9)	0.289
Moderate or severe mitral regurgitation	3 (15)	1 (6)	2 (67)	0.006

Data are presented as the median (interquartile range) or n (%)

BNP, brain natriuretic peptide; bpm, beats/minute; E/e', ratio of early transmitral flow velocity to early diastolic mitral annular velocity; HF, heart failure; LAD, left atrial diameter; LVEDD, left ventricular end-diastolic diameter; LVEF, left ventricular ejection fraction; NT-proBNP, N-terminal pro-brain natriuretic peptide; NYHA, New York Heart Association

**P* value was obtained by comparing the number of patients classified as NYHA functional classes I and II with the number classified as NYHA functional class III

Table 2 PVs at ROIs on DCR in patients with SR

Supine position	Pixel values				
ROI	Maximum	Minimum	Mean	Amount of change	Rate of change (%)
(1) Aortic arch	1029.1 (897.3–1154.5)	946.5 (851.6–1095.2)	985.9 (882.2–1124.9)	46.6 (30.0–59.3)	4.8 (2.6–6.8)
(2) Right pulmonary artery main trunk	1861.3 (1514.1–2214.7)	1786.5 (1430.5–2110.9)	1823.9 (1500.9–2167.8)	74.8 (47.8–100.9)	3.6 (3.2–5.1)
(3) Left pulmonary artery main trunk	2054.2 (1954.7–2447.1)	1952.2 (1911.1–2271.5)	2003.2 (1932.9–2359.3)	94.3 (68.0–127.0)	4.2 (2.9–6.9)
(4) Right atrium	1188.0 (985.2–1350.0)	1092.9 (931.7–1202.2)	1140.5 (958.4–1265.4)	76.2 (61.7–105.7)	6.9 (5.4–8.5)
(5) LV apex	1271.3 (1106.5–1535.7)	1096.7 (1015.5–1356.5)	1200.4 (1074.7–1399.1)	135.6 (75.5–157.6)	10.9 (5.7–13.6)

Data are presented as the median (interquartile range)

DCR, dynamic chest radiography; LV, left ventricular; PVs, pixel values; ROI, region of interest; SR, sinus rhythm

Table 3 PVs at ROIs on DCR in patients with AF

Supine position	PVs				
ROI	Maximum	Minimum	Mean	Amount of change	Rate of change (%)
(1) Aortic arch	827.1 (620.3–837.2)	793.3 (591.9–797.6)	814.5 (608.3–817.4)	25.2 (24.1–39.6)	5.5 (4.3–5.9)
(2) Right pulmonary artery main trunk	1531.8 (1200.2–1753.7)	1486.8 (1160.8–1707.9)	1509.3 (1180.5–1730.8)	45.0 (39.3–45.8)	2.9 (2.6–3.4)
(3) Left pulmonary artery main trunk	1538.9 (1391.0–1635.7)	1453.4 (1321.6–1565.0)	1496.1 (1356.3–1600.4)	55.9 (54.6–70.6)	4.2 (3.7–4.9)
(4) Right atrium	1016.2 (804.1–1145.8)	917.5 (725.9–1040.2)	966.8 (765.0–1093.0)	98.6 (78.2–105.5)	9.7 (9.2–9.7)
(5) LV apex	675.4 (623.5–866.2)	655.9 (584.3–809.3)	665.7 (603.9–837.7)	58.8 (39.1–76.5)	8.9 (5.9–9.6)

Data are presented as the median (interquartile range)

AF, atrial fibrillation; DCR, dynamic chest radiography; LV, left ventricular; PVs, pixel values; ROI, region of interest

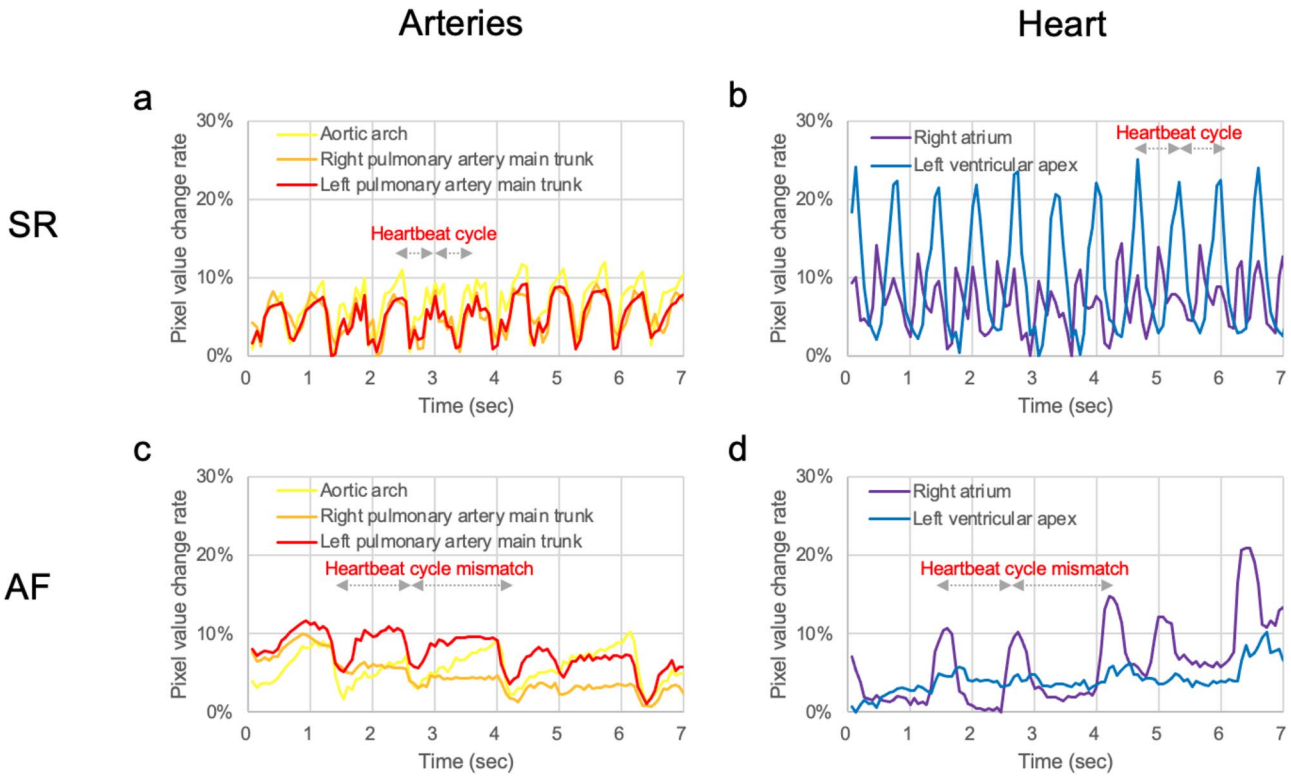


Fig. 3 PV change rate waveforms in sinus rhythm and atrial fibrillation. PV change rate waveforms in a patient with HF in SR (**a**, **b**) and with AF (**c**, **d**) in the five ROIs. AF, atrial fibrillation; HF, heart failure; PV, pixel value; ROIs, regions of interest; SR, sinus rhythm

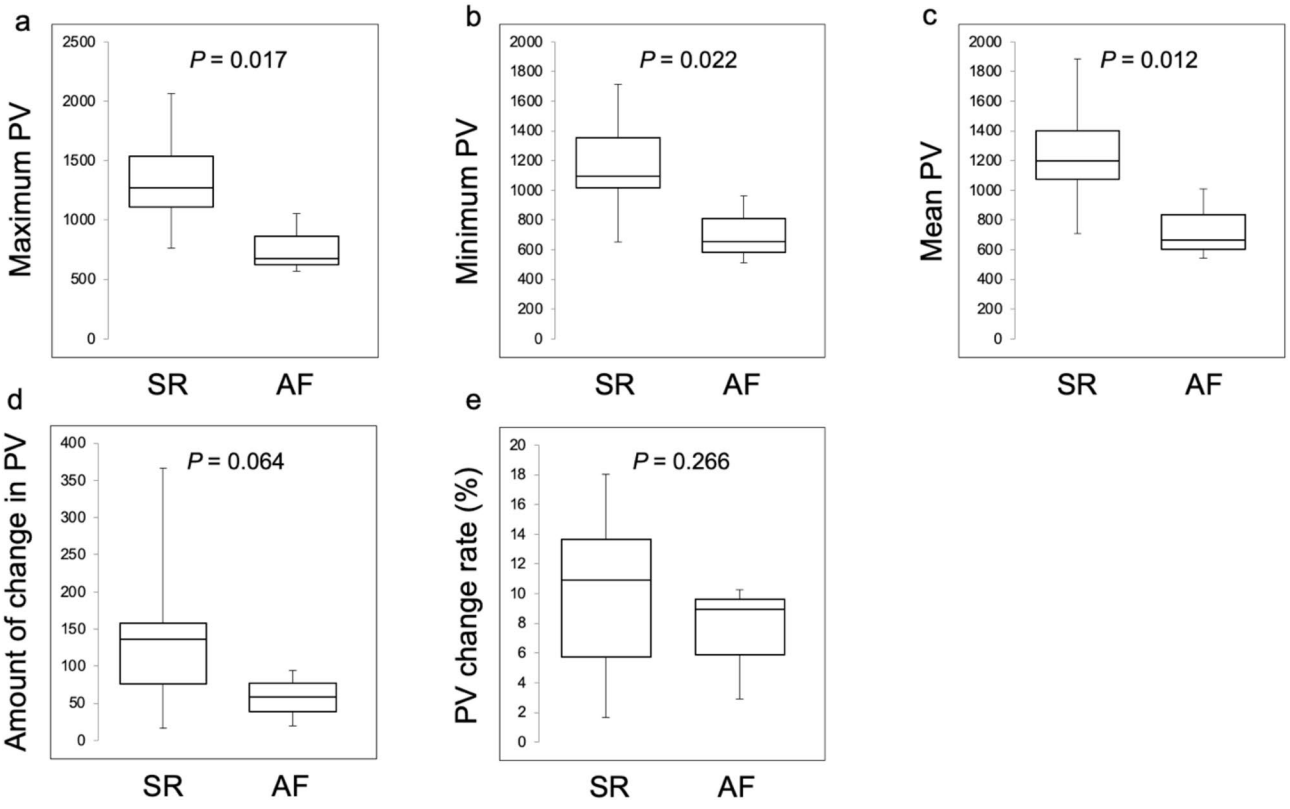


Fig. 4 Comparison of the PVs and PV changes at the LV apex. Comparison between patients in SR and patients with AF in the supine position, including maximum PV (**a**), minimum PV (**b**), mean PV (**c**), PV change (**d**), and PV change rate (**e**). AF, atrial fibrillation; LV, left ventricular; PV, pixel value; SR, sinus rhythm

Differences in the maximum pixel value

Patients in SR ($n = 17$) had a higher maximum PV [1271.3 (1106.5–1535.7) vs. 675.4 (623.5–866.2), $P = 0.017$], minimum PV [1096.7 (1015.5–1356.5) vs. 655.9 (584.3–809.3), $P = 0.022$], mean PV [1200.4 (1074.7–1399.1) vs. 665.7 (603.9–837.7), $P = 0.012$], amount of change in PV [135.6 (75.5–157.6) vs. 58.8 (39.1–76.5), $P = 0.064$], and PV change rate [10.9 (5.7–13.6) vs. 8.9 (5.9–9.6), $P = 0.266$] than patients with AF ($n = 3$) (Fig. 4a and e).

Discussion

The main findings of this pilot study are (1) that DCR has the potential to distinguish AF from SR in patients with HF and (2) that it is feasible to determine HR from the PV change rate waveform on DCR.

Pixel values and pixel value change rate waveforms in sinus rhythm and atrial fibrillation

We observed that the original PV waveforms in patients with AF, although less pronounced than those of patients in SR, exhibited low wave heights and were not visually clear in any of the five ROIs. To address this, we utilised the PV rate of change waveform instead of the original PV waveform to clarify the wave height and waveform, which allowed us to distinguish between patients in SR and those with AF. In patients in SR, the PV rate of change waveform was a series of uniform waveforms with nearly equal intervals, resembling normal electrocardiogram traces. Conversely, in patients with AF, the PV rate of change waveform was not a series of uniform waveforms; instead, the waveform intervals were unequal and scattered. We paid particular attention to the PV rate of change waveform in the LV apex to discriminate between SR and AF.

We previously reported the potential of non-invasively assessing haemodynamics by DCR in patients with HF [22]. We found that setting the ROI in the LV apex helped correlate the image parameters of the haemodynamic parameters most closely. Therefore, we also examined changes in the PVs of the LV apex in the present study. The PV change at the LV apex in patients in SR and patients with AF was the most pronounced of the five ROIs, and the PV change waveform at the LV apex was the clearest visually. The largest PV change at the LV apex was considered to reflect the largest change in blood volume in the heart. The PV change rate in the LV apex was strongly positively correlated with LVEF measured by the Teichholz and Simpson's methods, as shown in the additional figure (Additional File 2), suggesting that the LV apex may be the most suitable ROI for capturing

heartbeat and rhythm on DCR. Nevertheless, as AF is a rhythm disorder of the atrium, it would be useful to better understand the changes in the PVs of the atrial area on DCR in the future. However, it is important to consider that it is difficult to identify the exact left atrium on a chest radiograph and set the ROI, while identification of the LV apex is easy. Moreover, we deem it suitable to evaluate the PV waveforms in the LV apex ROI because 12-lead electrocardiography findings in patients with AF do not only evaluate atrial waves; understanding the QRS wave of the ventricle is also useful for HR calculation.

Clinical significance of detecting atrial fibrillation by dynamic chest radiography in patients with heart failure

Twelve-lead electrocardiography is the standard method to detect AF in patients with HF. Conventional electrocardiography is indeed superior to DCR in that the former does not use radiation, and up to now, electrocardiography has been the only available method to detect AF. This study shows that DCR may also have the capability to detect AF; therefore, it may be a potentially useful auxiliary tool to electrocardiography.

With regard to the contexts in which DCR could be useful, in the management of patients with HF, conventional chest radiography is always performed, regardless of whether electrocardiography is performed. DCR provides similar information to conventional chest radiography, as well as providing information similar to electrocardiography (such as heart rhythm, HR, and LVEF). Therefore, DCR may be a useful alternative to conventional chest radiography as the initial assessment method in patients with HF, and if AF is suspected, electrocardiography can then be performed to confirm it. Another scenario in which DCR could be useful is in patients with asymptomatic AF, in whom there may be no official indication for electrocardiography testing; however, if DCR is performed as an alternative to conventional chest radiography during consultation with a non-cardiologist or at a health checkup, it could incidentally detect AF. This could prompt referral for electrocardiography when it may otherwise not have been performed. Therefore, the use of DCR as the initial assessment method in patients with HF could increase the opportunity for AF detection, whether this be by a non-cardiologist, a primary care physician outside of the hospital setting, or at a health screening. We suggest that DCR could be useful for the early initial evaluation, before subsequent referral for electrocardiography confirmation if AF is suspected.

DCR may also be particularly useful as an initial early evaluation in the context of paroxysmal AF, where cardioversion can lead the episode of AF to be missed before an electrocardiogram can be recorded. The main determinants of spontaneous cardioversion include the absence of HF, small atrial size, recent-onset AF, rapid AF rate, and the relationship between a previous AF episode and HR or blood pressure [27]. Negative factors for spontaneous cardioversion include the presence of structural heart disease, low LVEF (< 45%), left atrial enlargement (> 40–45 mm), advanced age, male sex, and history of persistent AF [27]. The population in the present study had HF, which could mean that they would be less likely to cardiovert than patients without HF [27], reducing the likelihood that an AF episode would be missed. However, that is not to say that spontaneous cardioversion would never occur in this population. Similarly, in other cases where spontaneous AF cardioversion does occur, including in patients with and without HF, prognostically important treatment is often delayed and there is no resultant progress in making a diagnosis [28]. Therefore, early or incidental identification by DCR could facilitate the early diagnosis of AF in these cases.

Although the present study was conducted in patients with HF, DCR may also be applicable to patients without HF. For instance, chest radiography may be performed by a non-cardiologist to assist the diagnosis, follow-up, or treatment of patients with conditions other than heart disease, where it is uncommon to perform simultaneous electrocardiography. Therefore, DCR, with its ability to provide similar information to conventional chest radiography, as well as information similar to electrocardiography, may have the ability to incidentally detect AF in these contexts.

We acknowledge that the present study is a pilot study, and future studies would be needed to determine whether and how DCR could fit into the clinical workflow for AF detection. As well as our study, several others have evaluated novel methods to successfully detect paroxysmal AF in patients with HF, using techniques such as wearable devices and artificial intelligence-supported monitoring tools that incorporate photoplethysmography or electrocardiography, allowing HR and rhythm to be detected in the moment without the patient having to wait to attend a clinic for electrocardiography monitoring [29]. Therefore, capturing paroxysmal AF is an important clinical challenge that researchers are actively trying to overcome. As DCR can be performed by non-cardiologists and is easily accessible and portable, it could represent a useful early assessment method that can be performed before patients are subsequently referred for electrocardiography if AF is suspected from the initial results of DCR.

Clinical implications of heart rate measurement using dynamic chest radiography in heart failure

In patients with HF who are in SR, knowing the HR is valuable for understanding HF haemodynamics and the underlying pathophysiology. A high HR may suggest a reduced stroke volume or cardiac output, which may

indicate worsening HF. Conversely, a low HR may signal inadequate cardiac output maintenance. Even in patients with AF, the HR may reflect HF pathophysiology to some extent; for instance, if the patient has tachycardic AF, HF may be exacerbated. Tachycardic AF may also exacerbate HF further, and rate-control therapy to reduce HR in patients with AF may be necessary. Conversely, if the patient has bradycardic AF, the resulting low cardiac output may exacerbate HF. For this reason, methods that measure HR are useful. Currently, electrocardiography and plain pulse examination are used to measure HR in patients with HF. DCR also demonstrates the potential to measure HR, which is another useful feature of this imaging modality. Therefore, as DCR has additional value over conventional chest radiography, it could be a useful adjunct to electrocardiography for identifying AF in patients with HF.

Current clinical applications and benefits and limitations of dynamic chest radiography

At present, DCR has uses in various clinical settings, including the assessment of lung function, particularly ventilation and perfusion; the detection of pulmonary embolism and chronic thromboembolic pulmonary hypertension; and measurement of diaphragm and chest wall motion, as well as other aspects of respiratory mechanics [30]. In the future, it will be necessary to prospectively verify the broader clinical applicability of DCR in heterogeneous patient populations, not only for cardiovascular diseases such as HF, but also for patients with non-cardiovascular diseases. Although further evidence is needed to determine the clinical applicability of DCR for AF detection, DCR provides a plethora of information and has several advantages, including its non-invasive nature (does not require contrast media or radioactive tracers) [22]; portability (allowing for easy bedside use) [31]; use of a low radiation dose (compared with other imaging modalities, such as computed tomography) [30]; rapid image acquisition (making it suitable in emergency settings) [32]; and cost-effectiveness [31]. These benefits make it an attractive option for a wide range of potential clinical applications. It is important to note that DCR uses radiation, which may limit its clinical utility considering that other methods of AF detection, such as pulse palpation, electrocardiography, and echocardiography, do not use radiation. Nevertheless, this study provides valuable information about how DCR expresses the difference in HR between AF and SR, which may aid future research on its use.

Study limitations

We acknowledge several limitations of this study. First, the sample size was small; therefore, this is only intended as a pilot study, and not all confounding factors were evaluated. Moreover, many of the experimental aspects, such as the method used to count the waveform peaks to determine HR by DCR, were decided by our group, and alternative approaches should be tested in the future. Furthermore, DCR was not fully compared between patients in SR and those with AF. As such, further large prospective multi-centre studies are required to validate the observations of this small-sample study. Second, the smaller change in PV in those with AF compared with those in SR may indicate more difficulty in accurately capturing PV waveform changes in patients with AF, which could make it difficult to reach a diagnosis. Third, HR measured by electrocardiography in patients with AF may not always accurately reflect the true HR, especially in cases where there are significant variations in QRS complexes over time. According to the HR values measured by electrocardiography, patients with tachycardic or bradycardic AF were not included. Therefore, further studies with larger numbers of patients, including patients with tachycardic and bradycardic AF, are needed to validate the ability of DCR to detect AF. Another important consideration is the fact that differences in thoracic anatomy, overlapping anatomical structures, and variations in body composition may influence PV readings. We did not adjust for body size and tissue density because DCR is a two-dimensional imaging modality that does not consider three-dimensional anatomical information to evaluate how the X-rays pass through the tissues and organs to reach the flat panel, which is one limitation of DCR. Moreover, 12-lead electrocardiography and DCR were not performed simultaneously, so the comparison of HR between the two modalities may not be accurate as HR can vary depending on the patient's condition. In the future, we would like to investigate whether more accurate measurement of HR is possible if DCR and electrocardiography are performed simultaneously. It is possible to attach an electrocardiography monitor to the patient during DCR to measure heart rhythm and rate, which would be useful in future research to evaluate how well DCR reflects the observations made by electrocardiography. Moreover, no formal statistical approach was used to evaluate the concordance between DCR and electrocardiography for HR measurement. In this small-sample study, only a narrative comparison was made. In future work, we will use methods such as Bland–Altman analysis or intraclass correlation coefficient to evaluate the agreement between the two methods. Fourth, the patients were relatively healthy patients with HF (NYHA functional class I or II); it is important to validate whether DCR is useful in patients with more severe HF. Of note, many patients with severe HF and very poor cardiac function have implanted cardiac devices. The DCR imaging system is difficult to use in such patients as these devices can affect X-ray

transmission. As such, further studies on the use of DCR in this population are needed. Finally, arrhythmias other than AF, such as cases where the basic rhythm is SR but SR is mixed with supraventricular extrasystoles or multiple ventricular extrasystoles, were not studied. Therefore, further studies are needed to determine whether cardiac rhythm and HR can be adequately discriminated by DCR in patients with other types of arrhythmia.

Conclusions

Overall, our results suggest that DCR can detect AF in patients with HF and may be able to infer HR. Given that many patients with AF go undiagnosed using existing diagnostic methods, such as electrocardiography, echocardiography, and pulse palpation, we believe that DCR could be a useful adjunct for aiding the diagnosis of AF in patients with HF.

Abbreviations

AF	Atrial fibrillation
Ao	Aortic arch
BNP	Brain natriuretic peptide
DCR	Dynamic chest radiography
HF	Heart failure
HFpEF	Heart failure with preserved ejection fraction
HFrEF	Heart failure with reduced ejection fraction
HR	Heart rate
LV	Left ventricular
LVEF	Left ventricular ejection fraction
NYHA	New York Heart Association
PA	Pulmonary artery
PV	Pixel value
RA	Right atrial
ROI	Region of interest
SR	Sinus rhythm

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12872-025-04820-7.

Additional File 1: Online Resource Figure 1a, 1b. Figure showing HR measured by DCR in patients with HF in SR (a) and with AF (b). DCR was used to obtain a 7-second PV waveform at the LV apex. To measure HR, we used the waveform of the PV change rate at the LV apex. The graph was corrected so that the minimum value was 0% and the maximum was 100%. Frames in which the change from the minimum value exceeded 60% were defined as cardiac systolic frames. The total number of frames from the start frame to the end frame was divided by the number of heart beats to obtain one cardiac cycle, and the number of heart beats per minute was calculated. HR was calculated in the same way for both SR and AF. AF, atrial fibrillation; DCR, dynamic chest radiography; HF, heart failure; HR, heart rate; LV, left ventricular; PV, pixel value; SR, sinus rhythm.

Additional File 2: Online Resource Figure 2a, 2b. Figure showing the correlations between the PV change rate at the LV apex in the supine position and LVEF measured by the Teichholz method (a) and the Simpson's method (b). LV, left ventricular; LVEF, left ventricular ejection fraction; PV, pixel value.

Additional File 3: Online Resource Video 1. DCR video taken in the supine position in a patient with HF in SR. DCR, dynamic chest radiography; HF, heart failure; SR, sinus rhythm.

Additional File 4: Online Resource Figure 3a, 3b. Figure showing 12-lead electrocardiograms of patients with HF in SR (a) and with AF (b). AF, atrial fibrillation; HF, heart failure; SR, sinus rhythm.

Additional File 5: Online Resource Video 2. DCR video taken in the supine position in a patient with HF with AF. AF, atrial fibrillation; DCR, dynamic chest radiography; HF, heart failure.

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Author contributions

H.H.: Conceptualisation, Formal analysis, Funding acquisition, Methodology, Project administration, Supervision, Visualisation, and Writing – Original draft. H.H., S.N., R.I., K.K., S.K., T.K., S.A., K.F., A.T., R.M., T.O., T.M.: Data curation, Investigation, and Resources. H.H., T.M.: Writing – Review & editing. All authors have approved the final version of the manuscript for submission.

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Data availability

The datasets generated and/or analysed during the current study are not publicly available to protect the privacy of the individuals who participated but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Nagoya University Hospital (Date: 30 June 2023/No. 2023/0103). Written informed consent for participation was obtained from all individual participants included in the study.

Consent for publication

Not applicable.

Competing interests

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