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ORIGINAL PAPER

Left atrial longitudinal strain in dilated cardiomyopathy patients: is there a discrimination threshold for atrial fibrillation?

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Abstract

To determine the left atrial longitudinal strain discrimination threshold of atrial fibrillation (AF) in patients with dilated cardiomyopathy (DCM). A total of 100 DCM patients and LVEF < 25% were included. Of them, 50 had sinus rhythm (SR), and 50 had AF. Patients with significant valvular disease, cardiac pacemakers and prosthetic valves were excluded. Speckle tracking echocardiography was performed to visualize the inferior and lateral walls of the left atrium as well as the interatrial septum. The Q-Analysis software was used to assess left atrial contractile strain (ε_{CT}) during the atrial systole and left atrial conduit strain (ε_{CD}) during the atrial filling. In SR patients analysis was P-wave timed. In AF patients the reference point was at 200 ms before the QRS complex on the surface ECG. The ε_{CD} was significantly higher in SR patients than in those with AF (9.68% vs. 4.7%; $p = 0.0003$). ROC analysis demonstrated that ε_{CD} less than 5.43% (AUC 0.95; 95% CI 0.905–0.995; $p < 0.0001$) together with ε_{CT} below − 1.97% (AUC = 0.97; 95% CI 0.46–1.00; $p < 0.0001$) identified patients with AF. In patients with LVEF < 25% and AF left atrial contractile strain analysis is feasible. In these patients both contractile and conduit strain values are significantly lower than in patients with preserved SR, and ε_{CD} below 5.43% and ε_{CT} less than − 1.97% distinguish SR from AF patients with LVEF < 25%.

Keywords Left atrial strain · Sinus rhythm · Atrial fibrillation · Dilated cardiomyopathy

Introduction

Left atrial function (LA) contributes significantly to the left ventricular filling (LV). Deterioration of LA function during atrial fibrillation (AF) diminishes LV stroke that may result in developing of heart failure (HF) symptoms. In turn, the result of abnormal LV function is increased filling pressure, negatively affecting the parameters of LA function and volume [1]. Degeneration of sinus rhythm (SR) to AF in patients with LV ejection fraction (LVEF) < 25% induces a range of adverse clinical effects that may lead to a sudden deterioration in their clinical condition. Novel echocardiographic techniques such as speckle tracking echocardiography (STE) enable an objective assessment of left atrial wall deformation and provide a better insight into atrial mechanics [2]. The most important parameter assessed by STE is strain which describes the percent change in length of the myocardial walls. In SR patients the mechanical function of the atrial wall is divided into three phases: contractile, reservoir and conduit which refer to wall contraction, filling and passive emptying, respectively [3]. The atrium contracts during the first phase, between the beginning of the P wave and the QRS complex of the ECG. Shortening of the myocardial fibers during systole results in a negative value for strain (the absolute value is taken into account during assessment, whereas the minus sign informs of the fiber shortening). During the second half of the PQ interval strains from the negative values to the zero levels correspond to the phase of relaxation. During the phase from mitral valve closure (MVC) to mitral valve opening (MVO)

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atrial filling and myocardial fiber lengthening occur, and the measured strain is a positive value. The last phase lasts from the MVO to the P wave of the ECG where blood accumulated in the atrium is moved forward followed by passive pulmonary blood flow in the second part of the phase [4]. In patients with AF the typical first (systolic) phase does not occur due to loss of myocardial fibers synchrony, therefore this phase is rarely taken into consideration in routine analysis. Only a few studies have attempted to analyze left atrial systolic strain during AF rhythm [5]. Many investigators have demonstrated the usefulness of strain assessment in numerous clinical conditions (HF with preserved LVEF, arterial hypertension, hypertrophic cardiomyopathy, coronary artery disease) [2, 6–8]. Other studies have shown that LA strain predicts recurrence of AF after electrical cardioversion in patients with AF [2], pulmonary vein isolation [9, 10], medical device implantation [11, 12] or heart surgery [8]. Most of the patients were in sinus rhythm and had a preserved LVEF. In patients with AF rhythm only the strain maximum positive peak was assessed. Taking into account the fact that only the left atrial longitudinal strain (LALS) can be assessed with current technology and the fact that LALS depends both on left ventricular function and type of atrial rhythm, we attempted to determine the value of strain that distinguishes between SR and AF both in the contractile and conduit phase in patients with dilated cardiomyopathy (DCM) and LVEF < 25%.

Materials and methods

Patients

The study population consisted of clinically stable DCM patients, including 50 subjects with sinus rhythm and LVEF < 25% (SR group) and 50 subjects with atrial fibrillation and LVEF < 25% (AF group). The duration of AF exceeded 3 months. None of the patients in SR group reported previous episodes of AF. Those with organic valvular disease, more than moderate secondary to LV dilatation mitral regurgitation (MR), shunts or prosthetic valves, rhythm other than SR or AF, pulmonary artery hypertension, implanted medical devices, arterial hypertension and atrioventricular conduction disturbances were excluded. Each patient underwent ECG recording to confirm the rhythm. Non-invasive arterial blood pressure measurements were recoded. Body surface area (BSA), body mass index (BMI) and mean arterial pressure were calculated.

Transthoracic echocardiography

Transthoracic echocardiography (TTE) was performed using the General Electric Vivid E9 device (version 112; upgrade BT12) and a sector array M5S (2.5–3.5 MHz) transducer. Images were acquired for the measurement of LA diameter, LA area (LAA), LA volume index (LAVI) and LVEF. LA diameter was measured at the end of LV systole in the parasternal long axis view. LA area and LA volume were measured in the apical four chamber and the apical two chamber views at end systole. LVEF, left ventricular end-diastolic/end-systolic volume (LVEDV, LVESV), stroke volume (SV) were calculated with the biplane Simpson's method using apical four and two chamber views. MR volume was calculated with proximal isovelocity surface area (PISA) method. LA volume, LVEDV, LVESV and MR volume were indexed to BSA. Mitral flow velocities were assessed using pulse-wave Doppler.

Tissue doppler imaging (TDI)

LA images were obtained in the apical four chamber view (with interatrial septum and LA lateral wall visible) and the apical two chamber view (attempting to visualize LA inferior and anterior walls), with stable ECG tracing. LA anterior wall was excluded from analysis due to technical difficulties in acquiring accurate images. The view angle was obtained by positioning the analysis segment of LA wall as much as possible along the direction of the ultrasound wave propagation. TDI was performed at a frame rate of over 100 frames per second (fps). TDI echocardiograms including potential sites for STE analysis within the region of interest during at least three cardiac cycles were recorded. TDI recordings were necessary for future off-line Q-Analysis as required by the STE software.

Post-processing analysis

Off-line analysis of TDI recorded cycles was performed with the Q-Analysis software (General Electric EchoPac workstation, version 112; upgrade BT12). LALS was analyzed inside the following regions of interest (ROI): (1) within interatrial septum (IAS) at its base and close to fossa ovalis (IAS-B), (2) at its superior portion over fossa ovalis (IAS-S), (3) within LA basal lateral wall (LAT-B), (4) mid-portion of lateral wall (LAT-M), (5) LA basal inferior wall (INF-B), and (6) mid-portion of inferior wall (INF-M). In AF patients measurements were taken in cardiac cycles with RR interval exceeding 800–900 ms. In SR patients the P wave was used as the reference point, while in AF patients the analysis starting point was set at 200 ms before the QRS complex. The lowest values recorded in this phase was assumed as the contractile strain (ε_{CT}). It was followed by the positive peak strain, reflecting LA stretching during LA filling – the conduit strain (ε_{CT}) [13, 14]. Averaged measurements from three (sinus rhythm) or five (atrial fibrillation) consecutive heart cycles were taken for further analyses.

Statistical methods

Continuous variables were presented as median and interquartile range or mean and standard deviation according to their distribution. Categorical data were expressed as number and percentage. For quantitative data the differences between groups were analyzed through the Mann–Whitney U test or t-test as appropriate. Proportions were compared with the Chi square test. The receiver operating characteristics (ROC) analysis was performed to assess whether the ε_{CD}, ε_{CT}, LA, LAa, and LAVI (or its combinations; in this case the suitable coefficients were obtained by logistic regression model) can be used to distinguish between AF and SR patients. In this framework, the area under the ROC curve (AUC) with 95% confidence interval (95%CI) was estimated and the optimal cut-off values were determined by maximizing the Youden's index. Subsequently, sensitivity, specificity, positive predictive value, negative predictive value and accuracy for prediction of AF according to each of optimal cut-off point were calculated. All statistical tests were two- sided and P values < 0.05 were considered significant. Computations were performed using STATISTICA data analysis software system, version 12 (StatSoft, Inc. 2014) and R (version 3.1.2; The R Foundation for Statistical Computing, Vienna, Austria).

Results

Baseline characteristics

The study population included patients aged from 24 to 83 years. Both groups did not differ with respect to demographic data, BSA, BMI. Patients with AF had a higher heart rate and lower diastolic blood pressure than their SR counterparts (Table 1).

TTE

In TTE measurements LA, LAa and LAVI were larger, while LVEDVi and SVi were lower in AF patients. However, the LVEF and MR volume were similar in both groups. All MR volume measurements were lower than 30 mL (Table 1).

Table 1 Clinical characteristics and two-dimensional echocardiography results

	Sinus rhythm, n = 50	Atrial fibrillation, n = 50	p value
Age, years	61.5 (56.25; 68)	63 (57; 68)	0.56
Males	42 (84%)	43 (86%)	1.00
BMI, kg/m^2	25.4 (23.73; 28.78)	27.35 (24.05; 32.4)	0.09
BSA, m^2	1.9 (1.8; 2.1)	1.9 (1.83; 2.1)	0.12
HR, min^{-1}	79 (68.5; 87)	87 (81; 94.75)	0.0006
BP systole, mmHg	111.0 (± 14.0)	107.2 (± 12.4)	0.16
BP diastole, mmHg	67 (63; 71)	64 (61; 69)	0.03
BP mean, mmHg	89.53 (± 10.15)	86.31 (± 8.54)	0.09
LA, cm	5.1 (4.8; 5.28)	5.5 (5.1; 5.88)	< 0.0001
LAa, cm^2	28.8 (26.43; 34.18)	36.8 (32.13; 41.28)	< 0.0001
LAVI, mL/m^2	57.3 (51.45; 64.98)	67.65 (58.7; 89.48)	< 0.0001
LVESV, mL	162.5 (138–198)	147.5 (133–171)	0.26
LVESVi, mL/m^2	82.5 (71–108)	77 (68–88)	0.09
LVEDV, mL	198 (168–234)	173 (157–198)	0.07
LVEDVi, mL/m^2	98.5 (85–122)	86.5 (81–107)	0.03
SV, mL	34 (24; 42)	27 (21; 34)	0.049
SVi, mL/m^2	17 (12; 21)	13 (10; 18)	0.026
EF, %	19.15 (15.7; 22.3)	18.15 (12.88; 20.45)	0.17
MR, mL	12 (9–20)	12.5 (9–15)	0.76
MRi, mL/m^2	6 (4–9)	6 (5–7)	0.53

Quantitative data are expressed as mean and standard deviation for normal data or median and interquartile range for non-normal data, qualitative data are expressed as numbers and percentages

SRrEF sinus rhythm reduced ejection fraction, *AFrEF* atrial fibrillation reduced ejection fraction, *BMI* body mass index, *BSA* body surface area, *BP* blood pressure, *HR* heart rate, *LA* left atrium, *LAA* LA area, *LAVI* LA indexed volume index, *LVESV* left ventricle end systolic volume, *LVESVi* left ventricle end systolic volume index, *LVEDV* left ventricle end diastolic volume, *LVEDVi* left ventricle end diastolic volume index, *EF* ejection fraction, *MR* mitral regurgitation, *MRi* mitral regurgitation index

Table 2 Left atrial contractile strain (ε_{CT})

	Sinus rhythm, n = 50	Atrial fibrillation, n = 50	p value
ε_{CT} IAS-B (%)	− 3.90 (− 5.10; − 2.50)	− 1.10 (− 1.50; − 0.83)	< 0.0001
ε_{CT} IAS-S (%)	− 3.10 (− 4.45; − 1.73)	− 1.20 (− 1.78; − 0.80)	< 0.0001
ε_{CT} LAT-B (%)	− 2.50 (− 4.05; − 1.63)	− 1.30 (− 1.88; − 0.90)	< 0.0001
ε_{CT} LAT-M (%)	− 3.30 (− 4.05; − 2.10)	− 1.35 (− 1.90; − 0.90)	< 0.0001
ε_{CT} INF-B (%)	− 3.65 (− 5.50; − 2.70)	− 1.20 (− 1.70; − 0.90)	< 0.0001
ε_{CT} INF-M (%)	− 3.00 (− 4.43; − 1.95)	− 1.15 (− 1.70; − 0.80)	< 0.0001
ε_{CT} mean (%)	− 3.26 (− 3.98; − 2.55)	− 1.31 (− 1.62; − 0.97)	< 0.0001

Data are expressed as median and interquartile range

IAS interatrial septum, *B* basal portion, *S* superior portion, *LAT* lateral wall, *M* medial portion, *INF* inferior wall

Table 3 Left atrial conduit strain (ε_{CD})

	Sinus rhythm, n = 50	Atrial fibrillation, n = 50	p value
ε_{CD} IAS-B (%)	8.75 (6.33; 9.80)	4.80 (4.13; 5.50)	< 0.001
ε_{CD} IAS-S (%)	9.35 (7.80; 11.45)	4.80 (4.10; 5.90)	< 0.001
ε_{CD} LAT-B (%)	8.90 (7.15; 11.05)	4.70 (4.10; 5.40)	< 0.001
ε_{CD} LAT-M (%)	9.10 (6.83; 10.48)	4.55 (3.83; 5.88)	< 0.001
ε_{CD} INF-B (%)	9.20 (7.73; 10.50)	4.65 (4.13; 5.48)	< 0.001
ε_{CD} INF-M (%)	8.95 (7.20; 10.43)	4.25 (3.60; 5.45)	< 0.001
ε_{CD} mean (%)	9.68 (7.19; 10.32)	4.70 (4.21; 5.31)	< 0.001

Data are expressed as median and interquartile range

IAS interatrial septum, *B* basal portion, *S* superior portion, *LAT* lateral wall, *M* medial portion, *INF* inferior wall

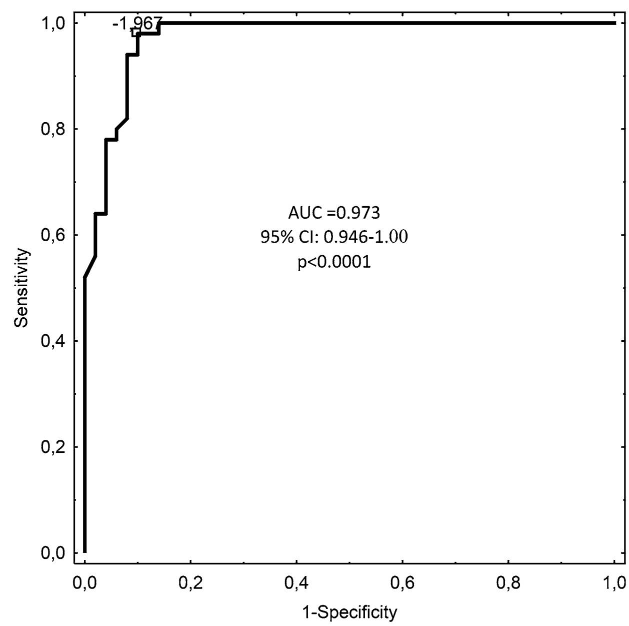

Fig. 1 Receiver operating curves of ε_{CT} for predicting atrial fibrillation

Strain analysis

ε_{CT} values inside each ROI differed significantly between the groups. In SR patients the highest absolute values were encountered in IAS-B and in INF-B, whereas the lowest values were found in LAT-B and INF-M. In contrast, in AF patients ε_{CT} values were similar inside each ROI (Table 2). ε_{CD} values were also significantly different between the groups. In SR group the highest absolute values were found in IAS-S and INF-B, whereas the lowest values were encountered in the IAS-B and LAT-B. In AF group ε_{CD} values were similar inside each ROI (Table 3).

ROC analysis

ROC analyses revealed that all ε_{CT} and ε_{CD} parameters had a good ability to distinguish between SR and AF group. In this context the highest AUC was observed for averaged ε_{CT} (AUC 0.973; 95% CI 0.946–1.00; $p < 0.0001$) and averaged ε_{CD} (AUC 0.95; 95% CI 0.905–0.995; $p < 0.0001$), (Figs. 1, 2). The optimal cut-off value to differentiate between SR and AF group based on averaged ε_{CD} and ε_{CT} was 5.43% and − 1.97%, respectively. When combined, ε_{CT} and ε_{CD} predicted AF better than each of them alone (Fig. 3). Also LA, LAa and LAVI were able to predict AF with high sensitivity, but moderate specificity. Taken together, strain parameters had higher sensitivity and specificity than other parameters obtained from two-dimensional echocardiography. Including LA, LAa, and LAVI to the logistic model did not increase the predictive value of ε_{CT} and ε_{CD} (Table 4).

Discussion

Currently there is no consensus on what atrial strain values should be regarded as normal. The differences between various studies are mainly due to methodological issues. Some investigators point out that analysis using the R wave from the ECG as a reference point tends to overestimate the

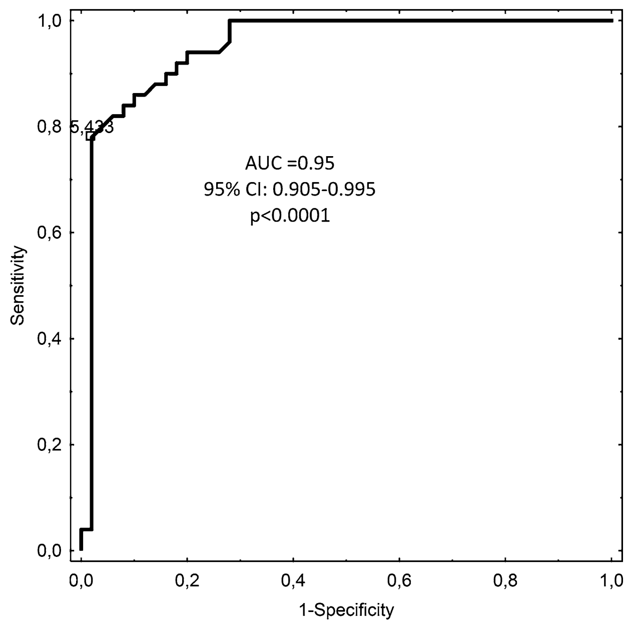

Fig. 2 Receiver operating curves of ε_{CD} for predicting atrial fibrillation

reservoir and conduit function. It seems that using P wave as a landmark for strain analysis provides correct estimations of LA function [6, 7]. Difficulties in comparing studies or results are also due to the lack of standardized terminology regarding phases of left ventricular function [2, 6, 7, 9, 11, 15–18] and the use of 12- (six regions in four chamber view, six regions in two chamber view) or 15-segment (additional three segments in the apical three-chamber view) model for the left atrium by various investigators [7]. In the present study a 6-segment model was used, skipping the roof and anterior wall segments, the most difficult parts of the atrium to visualize on echocardiography. Only a limited number of regions meet the criteria for objective estimation of strain, especially in patients with LA pressure overload, which is encountered in LVEF < 25% leading to LA dilatation and wall distension, thus reducing the availability of suitable regions for analysis.

Cameli et al. found the contractile strain was −6.8 ± 4.4% and the reservoir strain 7.7 ± 5.7% in patients in SR and with LVEF < 35% [6]. In the present study ε_{CT} (corresponding to atrial contraction) was lower in SR group, whereas the ε_{CD} was consistent with data obtained in that research (Tables 2, 3). The contractile phase in patients with AF was rarely estimated, probably because of extremely difficult

Fig. 3 Combined ε_{CT} and ε_{CD} values plot to discriminate atrial fibrillation patients (Δ) from those with sinus rhythm (+). The horizontal dashed line represents the threshold for ε_{CD}, the vertical dashed line represents the threshold for ε_{CT}. The solid line represents the threshold for combined ε_{CD} and ε_{CT}

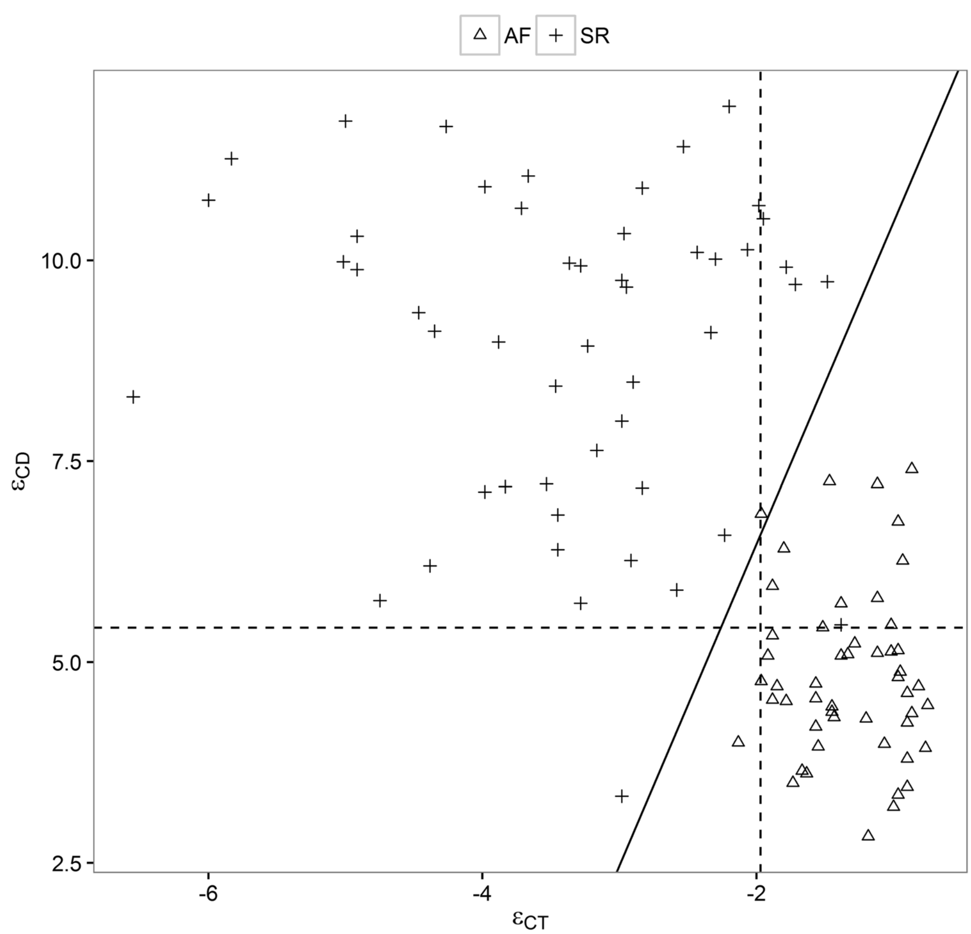

Table 4 Characteristics of the prediction of atrial fibrillation

	AUC (95% CI)	p value	Cut-off value	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
ε_{CT} IAS-B	0.951 (0.907–0.994)	< 0.0001	> − 1.7	84.0	92.0	91.3	85.2	88.0
ε_{CT} IAS-S	0.87 (0.803–0.937)	< 0.0001	> − 2.5	96.0	56.0	68.6	93.3	76.0
ε_{CT} LAT-B	0.798 (0.711–0.885)	< 0.0001	> − 1.9	74.0	70.0	71.2	72.9	72.0
ε_{CT} LAT-M	0.877 (0.807–0.947)	< 0.0001	> − 2.1	80.0	82.0	81.6	80.4	81.0
ε_{CT} INF-B	0.913 (0.854–0.972)	< 0.0001	> − 2.3	96.0	78.0	81.4	95.1	87.0
ε_{CT} INF-M	0.834 (0.748–0.919)	< 0.0001	> − 2.2	92.0	68.0	74.2	89.5	80.0
ε_{CT} mean	0.973 (0.946–1.00)	< 0.0001	> − 1.97	98.0	90.0	90.7	97.8	94.0
ε_{CD} IAS-B	0.891 (0.824–0.957)	< 0.0001	< 6.7	92.0	74.0	78.0	90.2	83.0
ε_{CD} IAS-S	0.938 (0.889–0.987)	< 0.0001	< 6.2	80.0	94.0	93.0	82.5	87.0
ε_{CD} LAT-B	0.887 (0.819–0.954)	< 0.0001	< 7.1	90.0	76.0	78.9	88.4	83.0
ε_{CD} LAT-M	0.904 (0.843–0.965)	< 0.0001	< 6.3	82.0	86.0	85.4	82.7	84.0
ε_{CD} INF-B	0.929 (0.869–0.99)	< 0.0001	< 6.3	88.0	90.0	89.8	88.2	89.0
ε_{CD} INF-M	0.92 (0.862–0.978)	< 0.0001	< 6.3	86.0	86.0	86.0	86.0	86.0
ε_{CD} mean	0.95 (0.905–0.995)	< 0.0001	< 5.43	76.0	98.0	97.4	80.3	87.0
ε_{CT} mean and ε_{CD} mean combined*	0.994 (0.982–1)	< 0.0001	> − 18.67	98.0	98.0	98.0	98.0	98.0
LA	0.786 (0.698–0.874)	< 0.0001	> 5.0	92.0	48.0	63.9	85.7	70.0
LAa	0.804 (0.714–0.894)	< 0.0001	> 30.1	94.0	62.0	71.2	91.2	78.0
LAVI	0.765 (0.674–0.856)	< 0.0001	> 57.8	80.0	54.0	63.5	73.0	67.0
ε_{CT} mean, ε_{CD} mean, LA, LAa, LAVI combined**	0.997 (0.991–1)	< 0.0001	> − 38.19	98.0	98.0	98.0	98.0	98.0

AUC area under the curve, *AF* atrial fibrillation, *IAS* interatrial septum, *B* basal portion, *S* superior portion, *LAT* lateral wall, *M* medial portion, *INF* inferior wall, *PPV* positive predictive value, *NPV* negative predictive value, ε_{CT} contractile strain, ε_{CD} conduit strain

*By 5.076 ε_{CT} mean-1.268 ε_{CD} mean (coefficients were obtained by logistic regression model)

**By 8.930 ε_{CT} mean-1.661 ε_{CD} mean- 4.835 LA + 0.164 LAa + 0.137 LAVI (coefficients were obtained by logistic regression model)

analysis. Limantoro et al. assessed the AF cycle length and wall motion velocity in the basal segment of the LA lateral wall, which was found to range from 1 to 3 cm/s in most patients [5]. In the current study ε_{CT} in AF group was − 1.31% (− 1.62%; − 0.97%), which corresponded to tissue velocity of about 1.4 cm/s. To the best of our knowledge this is the first study to consider ε_{CT} and ε_{CD} in patients with reduced EF in subgroups with SR and AF. We demonstrated ε_{CT} and ε_{CD} in SR patients were higher than in patients with AF. Simultaneously, those measurements were lower when compared with other patients with preserved EF [4, 16–18]. These findings indicate that LA mechanics is related both to the severity of LV damage and type of atrial rhythm. In SR patients with reduced EF the mitral inflow A wave is smaller than in patients with LVEF > 55% [4, 11, 12, 16], indicating high LV filling pressure, at which the contractile function of markedly enlarged LA (median LAVI 57.3 mL/m^2) is depressed. For this reason LA contraction contributes to a lesser extent to mechanical LV filling in these patients. In our study SR patients had low ε_{CD} when compared to other studies with preserved LVEF [4, 18], and AF had ε_{CD} twice lower than SR patients (4.7% vs. 9.68; p < 0.001, Table 3). In AF patients LAVI was higher than in SR patients (57.3 vs. 67.6 mL/m^2; p < 0.0001, Table 1), therefore we suppose that LA enlargement also contributes to very low ε_{CD}. The LA wall in AF is distended to such a degree that LV filling depends mainly on the conduit phase which is directly related to heart rate. When SR patients develop atrial fibrillation the time from MVC to MVO shortens leading to lower ε_{CD}. Simultaneously, decreased ε_{CT} and ε_{CD} as a result of further deterioration of left atrial mechanical function may explain further clinical status aggravation.

An ability of LA strain measurements to predict AF is a separate issue. Motoki et al. [9] in a group of 256 patients with preserved LVEF and after ablation due to AF, demonstrated that the total strain < 23.2% was an independent risk factor for arrhythmia recurrence. Schneider et al. [10] in a group of 118 patients undergoing ablation due to AF found out that LALS in the reservoir phase > 19.5% assessed in the inferior atrial wall was the best single predictor of SR preservation. Kosmala et al. [11] in a group of 146 patients with preserved LVEF without previous history of AF requiring permanent cardiac pacing observed that LALS in the contractile phase less than 8.6% (absolute values) was associated with risk for developing AF, especially in the concomitant presence of elevated LAVI > 62 mL/m^2. Decreased

LALS during the reservoir function was an independent predictor of postsurgical AF in 90 patients with preserved LVEF, without heart valve disease and previous history of AF undergoing coronary artery bypass grafting [8]. Also in patients with LVEF < 35%, decreased strain values were associated with higher risk for developing AF [12]. In the current study, we demonstrated that ε_{CD} less than 5.43% and ε_{CT} less than − 1.97% distinguished SR from AF patients. Therefore, we propose atrial strain measurements as a stratification method in heart failure patients to select those at risk of imminent AF development. Although the combination of ε_{CT} and ε_{CD} had the best accuracy in the AF prediction, its application in clinical practice may be limited due to technical difficulties in ε_{CT} measurements in AF patients.

Our study has several limitations. The lack of standardization in the left atrial strain measurement together with differences in software between manufactures make our results difficult to compare with others. Moreover, there is no dedicated software for atrial strain and all calculations were performed in the application initially invented for the left ventricle. In addition, all measurement are obtained in the post-processing analysis. Finally, receiver operating characteristics of strain values as a predictor of atrial fibrillation are estimations only and were not confirmed in any observational study. All of these warrant a cautious approach to our results.

Conclusions

In patients with LVEF < 25% and atrial fibrillation the left atrial contractile strain analysis is feasible. In these patients both contractile and conduit strain values are significantly lower than in patients with preserved sinus rhythm, and ε_{CD} below 5.43% and ε_{CT} less than − 1.97% distinguish AF from SR patients.

Compliance with ethical standards

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

Ethical approval All procedures performed were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments.

Informed consent Informed consent was obtained from all individual participants included in the study.

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