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Left atrial wall dyskinesia assessed during contractile phase as a predictor of atrial fibrillation recurrence after electrical cardioversion performed due to persistent atrial fibrillation

Paweł Wałek, MD[a,b,*], Elzbieta Ciesla, PhD[a], Iwona Gorczyca, MD, PhD[a,b], Beata Wożakowska-Kapłon, MD, PhD[a,b]

Abstract

Direct current cardioversion (DCCV) is one of the basic methods for restoring sinus rhythm (SR) in patients with atrial fibrillation (AF). Left atrial (LA) strain is one of the parameters used to assess the risk of AF recurrence following DCCV. Assessing the strain also allows for the detection of segmental disorders of LA wall contractility, including dispersion or dyskinesia. In the present study, we determined the predictive value of LA wall dyskinesia in assessing the risk of AF recurrence after DCCV. We performed a comprehensive echocardiography in 89 patients with persistent AF following successful DCCV. We assessed the strain and strain rate in the reservoir (r), conduit, and contractile (ct) phases by using speckle tracking echocardiography. Dyskinesia was diagnosed when the strain rate of any segment of the LA wall displayed positive values during contraction. After 12 months, 47.2% of patients maintained SR. Patients who maintained SR had a significantly lower LA strain (LAS)r assessed in the apical 4-chamber view (4c) (11.38 ± 4.63 vs 14.54 ± 5.11; $P = .004$) and 2-chamber view (2c) (11.05 ± 4.1 vs 14.93 ± 6.82%; $P = .006$), LASct4c (2.51 ± 2.3 vs 5.09 ± 3.29%; $P < .001$), LASct2c (3.6 ± 2.98 vs 5.67 ± 4.23%; $P = .008$), peak strain rate (pLASR) ct4c (0.36 ± 0.24 s vs 0.62 ± 0.4^{-1}; $P < .001$) and pLASRct2c (0.49 ± 0.30 vs 0.79 ± $0.53\,s^{-1}$; $P = .01$). LA dyskinesia was observed less frequently in the 4c view in patients who maintained SR (59.57 vs 17.5%; $P < .001$). Multivariable logistic regression showed that the LASct4c (odds ratio (OR) 0.78; 95%CI 0.63–0.97; $P = .027$) and LA dyskinesia observed in the 4c view (OR 3.53; 95%CI 1.16–10.76; $P = .027$) were significant independent predictors of AF recurrence at 12 months. We conclude that LA dyskinesia observed in the 4c view and LASct4c are independent risk factors for AF recurrence following DCCV.

Abbreviations: 2c = 2-chamber view, 4c = 4-chamber view, AF = atrial fibrillation, AUC = area under the curve, BMI = body mass index, BNP = B-type natriuretic peptide, BSA = body surface area, cd = conduit phase, CI = confidence interval, ct = contractile phase, DCCV = direct current cardioversion, E DT = deceleration time of E wave, EHRA = European Heart Rhythm Association, GFR = glomerular filtration rate, ICC = intraclass correlation coefficient, LA = left atrium, LAAD = left atrial anteroposterior diameter, LAAEV = left atrial appendage emptying velocity, LAAWMV = left atrial appendage wall motion velocity, LAEDVI = left atrial end-diastolic volume index, LAEF = left atrial emptying fraction, LAS = left atrial strain, LAVI = left atrial volume index, OR = odds ratio, pLASR = peak left atrial strain rate, PVI = pulmonary vein isolation, r = reservoir phase, RAEF = right atrial emptying fraction, RAVI = right atrial volume index, ROC = receiver operating characteristic, SD = standard deviation, SR = sinus rhythm, STE = speckle tracking echocardiography, TDI = tissue Doppler imaging.

Keywords: atrial fibrillation, cardioversion, dyskinesia, speckle tracking, strain, strain rate

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[a] Collegium Medicum, Jan Kochanowski University, 19 IX Wieków Kielc Street, Kielce, [b] 1st Clinic of Cardiology and Electrotherapy, Voivodship Hospital Kielce, Grunwaldzka 45, 25-736 Kielce, Poland.

[*] Correspondence: Paweł Wałek, 1st Clinic of Cardiology and Electrotherapy, Voivodship Hospital Kielce, Grunwaldzka 45, 25-736 Kielce, Poland (e-mail: pawel.walek@o2.pl).

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1. Introduction

Atrial fibrillation (AF) is the most common persistent supraventricular arrhythmia.[1] Patients with AF are at higher risk of developing circulatory failure and stroke and have higher cardiovascular mortality.[2] AF is a result of atrial remodeling, although it can also induce or enhance remodeling.[3] The treatment strategy for AF involves maintaining sinus rhythm (SR), that is, the strategy of heart rhythm control, or controlling the ventricular rate if SR cannot be maintained.[4] A high recurrence rate of AF after electrical (DCCV) or pharmacological cardioversion requires us to look for new risk factors for arrhythmia recurrence.[5]

To date, a number of reports have been published demonstrating clinical, biochemical, and echocardiographic risk factors for AF recurrence after DCCV.[6–10] Studies concerning echocardiographic parameters focus mainly on quantitative parameters, such as left atrial (LA) anteroposterior diameter (LAAD), left and right atrial volume index (LAVI, RAVI), left and right atrial emptying fraction (LAEF, RAEF), LA appendage emptying velocity (LAAEV), LA appendage wall motion velocity (LAAWMV), LA fibrillatory contraction flow, total atrial conduction time, strain, strain rate, and parameters assessing left ventricular filling pressure.[11–29]

There has been an increasing interest in the assessment of LA strain in patients with AF. Most of these studies have focused on evaluating global strain, and only some of them address the issue of evaluating segmental strain or dispersion between segments and the usefulness of these measurements in clinical practice.[22–29] When analyzing segmental strain and strain rate values, problems are often encountered. Difficulty in the assessment of the segmental strain rate during the contractile phase drew our attention, because the strain rate measurements in some LA wall segments were positive instead of negative like in adjacent segments. This meant that the LA wall expanded when it should have shortened. Paralleling ventricular wall dyskinesia, we called this phenomenon LA wall dyskinesia. We hypothesize that it is caused by segmental LA wall dysfunction, which can affect the prognosis of SR maintenance in patients who have undergone DCCV.

In this study, we analyze whether LA wall dyskinesia detected with transthoracic speckle tracking echocardiography (STE) 1 day after successful DCCV due to persistent AF has a predictive value regarding the prognosis of AF recurrence.

2. Methods

2.1. Study population

The study protocol was approved by the Institutional Review Board of the Świętokrzyskie Medical Chamber and informed consent was obtained from each patient. We included patients with persistent AF who underwent successful DCCV between November 2015 and August 2018. The inclusion criteria were as follows: symptomatic, persistent AF for 7 or more days; ejection fraction during SR ≥40%; and appropriate anticoagulation for 3 or more weeks before cardioversion (warfarin, acenocoumarol, dabigatran, rivaroxaban, or apixaban). The exclusion criteria were as follows: age <18 years, no consent to participate in the study, no consent for cardioversion, poor quality of echocardiographic visualization, failed acquisition of stable STE data, moderate or severe valve regurgitation or stenosis, valvular prosthesis, the presence of thrombus in the left atrial appendage, acute decompensation of heart failure, acute myocardial infarction, previous pulmonary vein isolation, dysthyroidism, anemia with Hb < 6.9 mmol/l, acute infection, immune disease, and neoplastic disease. Clinical data were collected directly before cardioversion. Echocardiographic data were collected the day after cardioversion. Blood samples were obtained immediately before cardioversion. Patients were followed up clinically and with electrocardiography at months 1, 6, and 12. Twenty-four-hour ambulatory Holter monitoring was performed at months 1 and 12 in all patients with SR. Patients were asked to report to our Cardiology Department when they felt palpitations or when routine medical care revealed the recurrence of AF.

2.2. Clinical data

Baseline clinical data included age, sex, body mass index (BMI), body surface area (BSA), calculated with the Gehan and George formula), hypertension, diabetes mellitus, dyslipidemia, smoking status, coronary artery disease, heart failure, European Heart Rhythm Association (EHRA) score, dysthyroidism, obstructive pulmonary disease, renal disease, history of stroke or transient ischemic attack, and pharmacological treatment. Coronary artery disease was diagnosed if patients had a history of myocardial infarction, percutaneous coronary intervention, or aorto-coronary bypass grafting. The glomerular filtration rate (GFR) was estimated from the Cockcroft-Gault formula. The CHA2DS2-VASc and HAS-BLED scores were recorded according to the current European guidelines on AF treatment.[4]

2.3. Restoration of sinus rhythm

All DCCVs were performed under general anesthesia. If the effectiveness of anticoagulation was uncertain, transesophageal echocardiography was performed to assess for thrombi in the left atrium. All cardioversions were performed with paddles placed in the anterolateral position; a biphasic defibrillator was used to deliver 150 to 300 J. If the first shock was ineffective, another shock was delivered with an additional 100 J. The success of cardioversion was defined as the maintenance of SR for ≥24 hours after cardioversion. Patients with SR received anticoagulants, upstream therapy, or antiarrhythmic drugs as determined by clinical judgment. Based on the risk of AF recurrence, antiarrhythmic drugs (amiodarone or propafenone) were prescribed by a physician who was blinded to the echocardiographic data analyzed in the study.

2.4. Echocardiographic evaluation

Transthoracic echocardiography was performed with a Vivid S6 Echocardiographic device (General Electric Medical Systems, Horten, Norway) equipped with an M4S RS probe, according to current guidelines.[30,31] All examinations were done by 1 investigator. Standard M-mode Doppler imaging and 2-dimensional cine loops of parasternal long- and short-axis views and apical 2-, 3-, and 4-chamber views were obtained for each patient. All images and measurements were acquired from standard views and then stored. The digitally stored echocardiographic images were retrieved and analyzed with offline software (EchoPAC PC software, GE Medical Systems).

LA wall deformation analysis was performed using STE during SR. The LA myocardial deformation assessed during SR after successful cardioversion was presented as the LA strain during the reservoir phase (LASr), conduit phase (LAScd), and contractile phase (LASct) and as the peak strain rate during the reservoir phase (pLASRr), conduit phase (pLASRcd), and

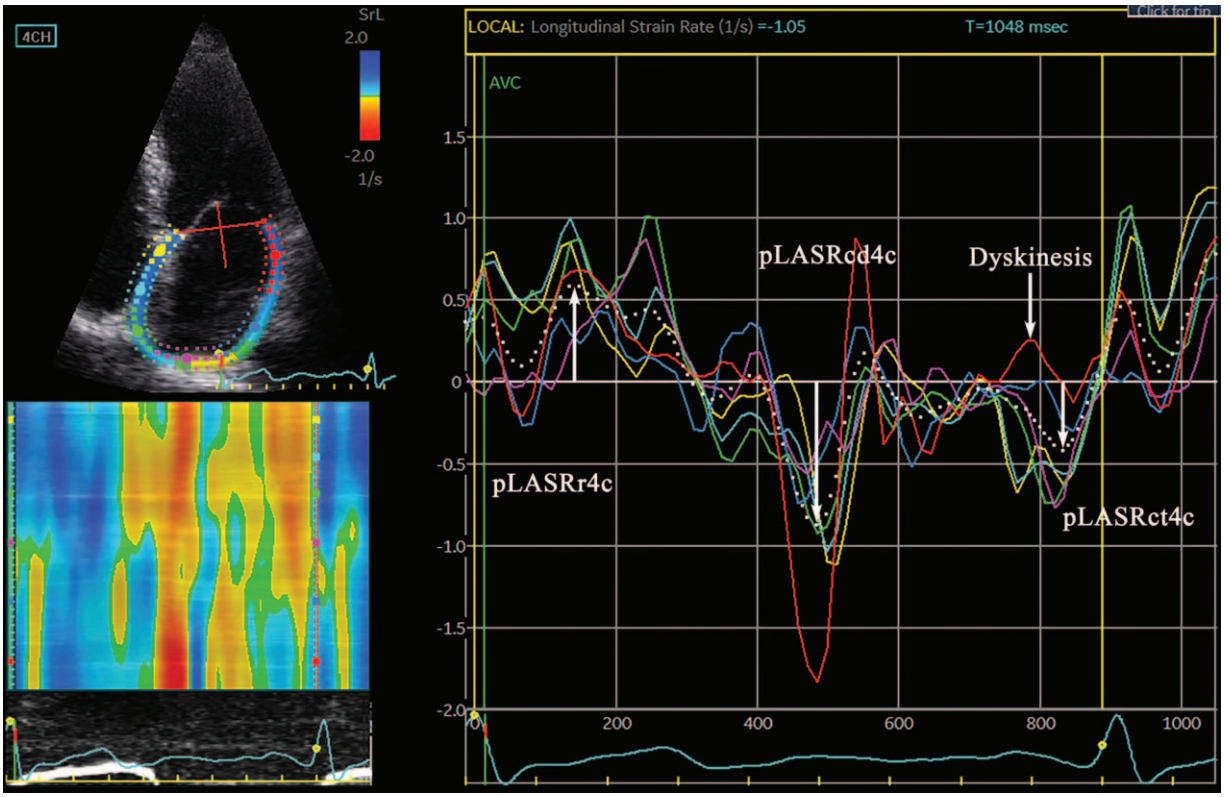

Figure 1. Recording of strain rate curves. Strain rate curves with registered dyskinesia of the basal lateral segment of the left atrial wall. 4c = apical 4-chamber view, cd = conduit phase, ct = contractile phase, pLASR = peak left atrial strain rate, r = reservoir phase.

contractile phase (pLASRct). LASr and LASct were directly determined as global strain in each phase, and LAScd was calculated as the difference between LASr and LASct. The measurements of the LA longitudinal strain were taken in the 4-chamber (4c) and 2-chamber (2c) views, and then the mean of both views was calculated as recommended by the consensus document of the European Association of Cardiovascular Imaging.[32] We used the upslope of the R-wave as the reference point for strain and strain rate measurements in the electrocardiogram, as recommended in the consensus document.

2.5. Diagnosis of dyskinesia

The presence of LA wall dyskinesia was assessed during the contractile phase using the records of the strain rate curves. Dyskinesia was diagnosed when the strain rate of any segment of the LA wall displayed positive values during contraction, that is, above the zero line. Dyskinesia was sought on strain rate curves from echocardiographic recording, in the interval between the P peak and the R peak of the QRS complex. When the strain rate curve exhibited both positive and negative values after the P peak, dyskinesia was diagnosed if the area under the positively deflected strain rate curve was greater than the area under the negatively deflected strain rate curve (Figs. 1 and 2). None of the patients was diagnosed with atrial septal aneurysm.

2.6. Statistical analysis

Results are presented as means ± standard deviations (SD) or counts and percentages. Normally distributed variables were compared with Student's *t* test, and non-normally distributed variables were compared with the Mann-Whitney test or the chi-squared test. The Spearman rank correlation coefficient was used to study associations between pairs of variables. We analyzed the predictors of AF recurrence with univariate logistic regression.

Clinical and echocardiographic parameters with the lowest *P* values, as determined in the univariate logistic analysis, were included in a multivariable logistic analysis. These parameters assess structural and mechanical remodeling as well as left ventricular filling pressure. Receiver operating characteristic (ROC) curves for the prediction of SR maintenance for 12 months following DCCV were calculated for all parameters assessing strain and strain rate. Then, the differences in ROC curves between parameters assessing strain and strain rate in the same views were compared using the z test.

We calculated areas under the curve (AUCs) and optimal cut-offs based on Youden's J statistic. The differences between the 2 AUCs were compared using the *z* test. Statistical significance was set at $P < .05$. Intraobserver and interobserver reproducibility were computed by intraclass correlation coefficient (ICC) with 95% confidence intervals (CI). Statistical analyses were performed with the STATISTICA 13.3 software (TIBCO Software Inc., Tulsa, OK, USA).

3. Results

3.1. Clinical characteristics

The study included 89 patients who underwent DCCV and had SR restored between November 2015 and August 2018. After 12

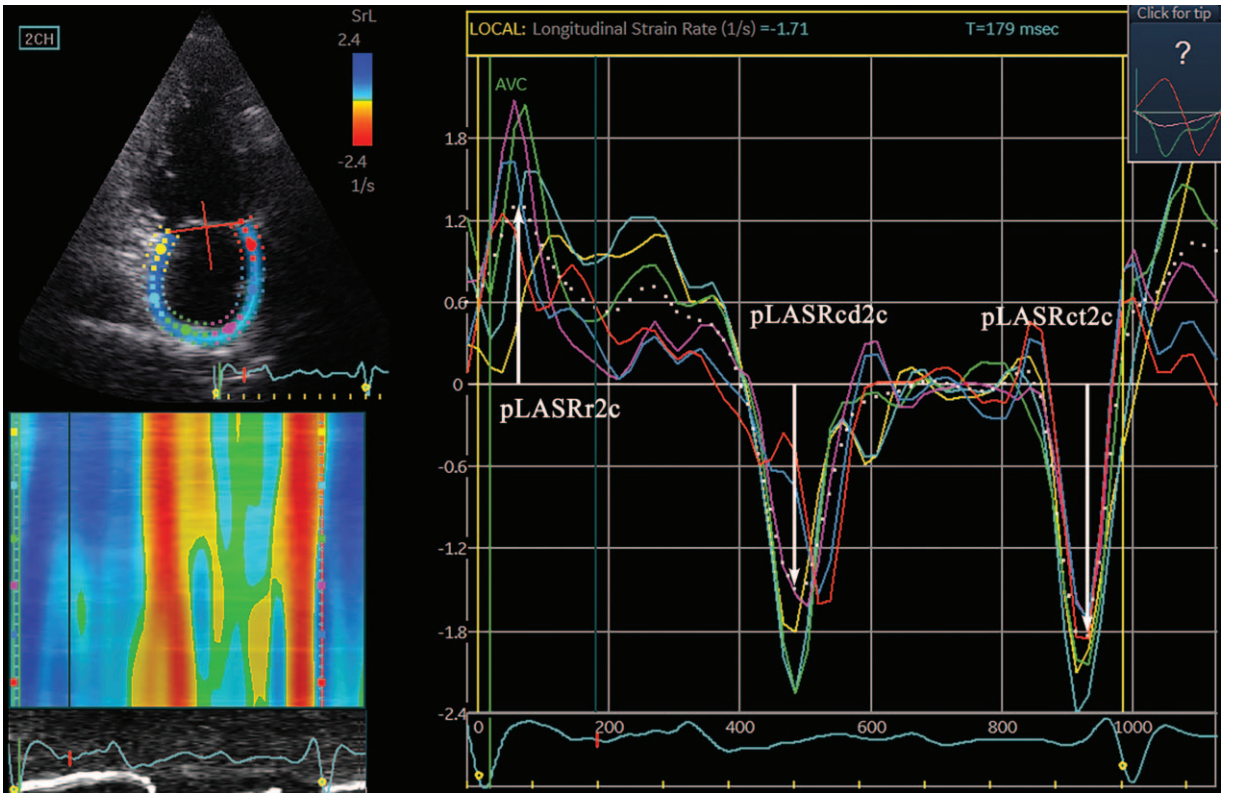

Figure 2. Recording of strain rate curves. Correct recording of strain rate curves. 2c = apical 2-chamber view, cd = conduit phase, ct = contractile phase, pLASR = peak left atrial strain rate, r = reservoir phase.

months, 47 (52.8%) patients maintained SR. Males predominated among patients who maintained SR, compared with patients who had AF recurrence (78.57 vs 55.32%; $P=.021$). No differences were found in age, BMI, coexisting diseases, time since diagnosis of AF, time since the onset of the current AF attack, number of previous DCCVs, risk of thromboembolic complications, and pharmacological treatment pre- and post-DCCV. There were also no differences between patients with recurrent AF and patients with SR in terms of biochemical parameters, such as creatinine, creatinine clearance, troponin T, B-type natriuretic peptide (BNP), and HbA1c (Table 1).

3.2. Echocardiographic characteristics

There were no differences in the intraventricular septal thickness, right and left ventricular cavity sizes, and left ventricular systolic function. Regarding structural remodeling parameters, patients with SR had lower values of LA end-diastolic volume index (LAEDVI) (30.17 ± 10.56 vs $36.46\pm11.85\,ml/m^2$; $P=.003$) than patients with AF recurrence, but there were no differences in LAVI (49.72 ± 11.58 vs $51.64\pm10.42\,ml/m^2$; $P=.410$) and LAAP (43.27 ± 4.48 vs 44.43 ± 4.78 mm; $P=.245$) between these groups. With regard to the echocardiographic parameters assessing the mechanical remodeling of the left atrium, patients with SR had higher values of LAEF (40.11 ± 10.13 vs $32.76\pm12.37\%$; $P=.003$) and a′ mean (6.05 ± 2.85 vs 4.49 ± 1.77 cm/s; $P=.015$). Patients with SR also had higher values of the parameters assessing strain and strain rate in the apical 4c and 2c views and the mean of the 4c and 2c views: LASr4c (14.54 ± 5.11 vs $11.38\pm4.63\%$; $P=.004$), LASct4c (5.09 ± 3.29 vs $2.51\pm2.3\%$; $P<.001$), pLASRct4c (0.62 ± 0.4 vs $0.36\pm0.24\,s^{-1}$; $P<.001$), LASr2c (14.93 ± 6.82 vs $11.05\pm4.1\%$; $P=.006$), LASct2c (5.67 ± 4.23 vs $3.6\pm2.98\%$; $P=.008$), pLASRct2c (0.79 ± 0.53 vs $0.49\pm0.30\,s^{-1}$; $P=.01$), LASr mean ($14.68\pm5,33$ vs $11.22\pm3.93\%$; $P=.001$), LAScd mean (9.29 ± 3.06 vs $8.16\pm2.75\%$; $P=.044$), LASct mean (5.39 ± 3.5 vs $3.05\pm2.48\%$; $P<.001$), pLASRct mean (0.7 ± 0.44 vs $0.42\pm0.26\,s^{-1}$; $P=.001$). Regarding the echocardiographic parameters assessing left ventricular filling pressure, patients with SR had lower values of E wave (0.81 ± 0.35 vs 0.92 ± 0.18 m/s; $P=.001$), E/e′ ratio mean (8.85 ± 3.77 vs 11.31 ± 3.95; $P<.001$), and E/A ratio (2.16 ± 0.88 vs 2.95 ± 1.46; $P=.004$) and higher values of e′ mean wave (9.62 ± 1.92 vs 8.46 ± 2.04 cm/s; $P=.016$) and E DT (205.17 ± 50.38 vs 173.34 ± 37.2ms; $P<.001$) than patients with AF recurrence. LA wall dyskinesia was observed less frequently in patients with SR than in patients with AF recurrence, in the apical 4c view (17.5 vs 59.57%; $P<.001$), 2c view (33.33 vs 51.06%; $P=.098$), both views (12.82 vs 36.17%; $P=.013$), and in 4c or 2c view (38.46 vs 74.47%; $P=.001$) (Table 2).

3.3. Regression analysis

In the univariate logistic regression analysis, male gender [odds ratio (OR) 0.34; 95%CI 0.13–0.86; $P=.023$], LAEDVI (OR 1.06; 95%CI 1.01–1.1; $P=.014$), LAEF (OR 0.94; 95%CI 0.91–0.98; $P=.005$), e′ mean (OR 0.77; 95%CI 0.62–0.97; $P=.027$), a′ mean (OR 0.74; 95%CI 0.6–0.91; $P=.005$), E wave (OR 13.57; 95%CI 1.40–131.19; $P=.024$), E DT (OR 0.98; 95%CI

Table 1

Clinical characteristics.

	Study population n = 89	SR maintenance n = 42 (47.2%)	AF recurrence within 12 mo n = 47 (52.8%)	*P* value
Age (yr)	64.13 ± 9.35	62.38 ± 10.21	65.70 ± 8.3	.110
Age < 65 (n, %)	39 (43.82)	23 (54.76)	16 (34.04)	.139
Age 65–74 (n, %)	38 (42.7)	14 (33.33)	24 (51.06)	
Age ≥ 75 (n, %)	12 (13.48)	5 (11.9)	7 (14.89)	
Male (n, %)	59 (66.29)	33 (78.57)	26 (55.32)	.021
BMI (kg/m^2)	31.17 ± 4.95	30.39 ± 4.33	31.88 ± 5.39	.237
Hypertension (n, %)	77 (86.52)	34 (80.95)	43 (91.49)	.146
Diabetes mellitus (n, %)	18 (20.22)	8 (19.05)	10 (21.28)	.794
Coronary artery disease (n, %)	12 (13.48)	8 (19.05)	4 (8.51)	.146
Stroke/TIA (n, %)	9 (10.11)	6 (14.29)	3 (6.38)	.217
CHA2DS2-VASC	2.67 ± 1.42	2.50 ± 1.58	2.83 ± 1.26	.181
CHA2DS2-VASC = 0 (n, %)	67 (75.28)	2 (4.76)	1 (2.13)	.203
CHA2DS2-VASC = 1 (n, %)	19 (21.35)	12 (28.57)	7 (14.89)	
CHA2DS2-VASC ≥2 (n, %)	3 (3.37)	28 (66.67)	39 (82.98)	
HAS-BLED	0.45 ± 0.6	0.38 ± 0.58	0.51 ± 0.62	.286
Smokers (n, %)	7 (7.87)	4 (9.52)	3 (6.38)	.583
Number of previous DCCVs	0.33 ± 0.72	0.33 ± 0.75	0.32 ± 0.69	.996
Total AF duration (mo)	28.36 ± 45.15	29.45 ± 41.23	27.38 ± 48.81	.714
AF duration current episode (wk)	12.58 ± 16.45	13.68 ± 18.97	11.60 ± 13.98	.979
GFR (ml/min)	85.32 ± 35.5	88.65 ± 33.13	82.35 ± 37.6	.161
Beta-blockers pre (n, %)	84 (94.38)	41 (97.62)	43 (91.49)	.210
Amiodarone pre (n, %)	9 (10.11)	4 (9.52)	5 (10.64)	.862
ACE inhibitors/ARB pre (n, %)	80 (89.89)	37 (88.1)	43 (91.49)	.596
Statins pre (n, %)	53 (59.55)	27 (64.29)	26 (55.32)	.390
Diuretics pre (n, %)	31 (34.83)	12 (28.57)	19 (40.43)	.241
Spironolactone/eplerenone pre (n, %)	17 (19.1)	9 (21.43)	8 (17.02)	.597
Beta-blockers post (n, %)	69 (77.53)	33 (78.57)	36 (76.6)	.824
Amiodarone post (n, %)	27 (30.34)	12 (28.57)	15 (31.91)	.732
Propafenone post (n, %)	31 (34.83)	16 (38.1)	15 (31.91)	.541
ACE inhibitors/ARB post (n, %)	82 (92.13)	37 (88.1)	45 (95.74)	.182
Statins post (n, %)	54 (60.67)	27 (64.29)	27 (57.45)	.510
Diuretics post (n, %)	32 (35.96)	12 (28.57)	20 (42.55)	.170
Spironolactone/eplerenone post (n, %)	19 (21.35)	9 (21.43)	10 (21.28)	.986
Creatinine (mg/dl)	1.13 ± 0.2	1.12 ± 0.19	1.15 ± 0.2	.409
Troponin T (ng/l)	11.11 ± 3.39	10.65 ± 7.7	11.53 ± 10.75	.758
HbA1c (%)	6.09 ± 0.77	6.09 ± 0.65	0.09 ± 0.88	.711
BNP (pg/ml)	230.76 ± 409.87	302.60 ± 562.1	156.45 ± 97.46	.660

ACE inhibitors/ARB = angiotensin-converting enzyme inhibitors/angiotensin II receptor blockers, AF = atrial fibrillation, BMI = body mass index, BNP = B-type natriuretic peptide, DCCV = direct current cardioversion, GFR = glomerular filtration rate, HbA1c = hemoglobin 1, post = after cardioversion, pre = before cardioversion, SR = sinus rhythm, TIA = transient ischemic attack.

0.97–0.99; *P* = .002), E/e' mean ratio (OR 1.21; 95%CI 1.05–1.38; *P* = .007), and the E/A ratio (OR 1.85; 95%CI 1.2–2.9; *P* = .006) were significant independent predictors of AF recurrence within the 12-month follow-up. Among the parameters assessing strain and strain rate, measurements in 4c view, including LASr4c (OR 0.87; 95%CI 0.8–0.96; *P* = .005), LASct4c (OR 0.69; 95%CI 0.56–0.85; *P* < .001), pLASRct4c (OR 0.06; 95%CI 0.01–0.34; *P* = .001), LASr2c (OR 0.88; 95% CI 0.8–0.96; *P* = .004), LAScd2c (OR 0.87; 95%CI 0.77–0.99; *P* = .03), LASct2c (OR 0.84; 95%CI 0.73–0.97; *P* = .014), and pLASRct2c (OR 0.18; 95%CI 0.06–0.57; *P* = .004) and the averages of 4c and 2c views, including LASr mean (OR 0.85; 95%CI 0.76–0.94; *P* = .002), LASct mean (OR 0.75; 95%CI 0.62–0.9; *P* = .002), and pLASRct mean (OR 0.09; 95%CI 0.02–0.41; *P* = .002), were significant predictors of AF recurrence within the 12-month follow-up.

The univariate logistic regression analysis revealed that LA wall dyskinesia in any segment of the LA wall recorded from 4c view (OR 6.95; 95%CI; 2.55–18.93; *P* < .001), LA wall dyskinesia in both 4c and 2c views (OR 3.85; 95%CI 1.27–11.71; *P* = .017), and LA wall dyskinesia in 4c or 2c view (OR 4.67; 95%CI 1.86–11.71; *P* = .001) increased the risk of AF recurrence in the 12-month follow-up.

The multivariable forward stepwise logistic regression showed that LASct4c (OR 0.78; 95%CI 0.63–0.97; *P* = .027) and dyskinesia in 4c view (OR 3.53; 95%CI 1.16–10.76; *P* = .027) were independent predictors of AF recurrence following DCCV during the 12-month follow-up (Table 3).

In the ROC curve analysis, the AUC for the diagnosis of LA dyskinesia was 0.71 (95%CI 0.6–0.82; *P* < .001) for predicting AF recurrence after DCCV, with sensitivity of 59.57%, specificity of 82.5%, positive predictive value of 80%, and negative predictive value of 63.46% (Fig. 3).

The AUC for LASct4c was 0.765 (95%CI 0.667–0.863; *P* < .001) for predicting AF recurrence after DCCV (optimal cut-off, 3.28%; sensitivity, 74.47%; specificity, 69.05%; positive predictive value, 72.92%; negative predictive value, 70.73%; Fig. 3).

Table 2

Echocardiographic characteristics.

	Study population n = 89	SR maintenance n = 42 (47.2%)	AF recurrence within 12 mo n = 47 (52.8%)	*P* value
RV prox (mm)	31.1 ± 4.36	31.81 ± 4.47	30.61 ± 4.22	.198
IVS (mm)	10.77 ± 1.93	10.61 ± 1.83	10.91 ± 2.02	.699
LVEDD (mm)	50.88 ± 6.25	51.74 ± 6.24	50.09 ± 6.22	.217
LVESD (mm)	34.77 ± 7.1	35.9 ± 7.86	33.74 ± 6.23	.154
LVEF (%)	60.78 ± 9.72	59.67 ± 10.51	61.77 ± 8.95	.312
LAAP (mm)	43.89 ± 4.65	43.27 ± 4.48	44.43 ± 4.78	.245
LAVI (ml/m^2)	50.73 ± 10.96	49.72 ± 11.58	51.64 ± 10.42	.410
LAEDVI (ml/m^2)	33.49 ± 1.64	30.17 ± 10.56	36.46 ± 11.85	.004
LAEF (%)	36.23 ± 11.89	40.11 ± 10.13	32.76 ± 12.37	.003
RAAs (cm^2)	23.93 ± 5.3	24.77 ± 5.72	23.24 ± 4.89	.197
RAAd (cm^2)	16 ± 4.21	16.21 ± 4.39	15.82 ± 4.1	.676
s' wave mean (cm/s)	6 ± 1.17	6.24 ± 1.23	5.78 ± 1.09	.156
e' wave mean (cm/s)	9.11 ± 2.03	9.62 ± 1.92	8.46 ± 2.04	.016
a′ wave mean (cm/s)	5.23 ± 2.46	6.05 ± 2.85	4.49 ± 1.77	.015
E/e' mean ratio	10.12 ± 4.04	8.85 ± 3.77	11.31 ± 3.95	<.001
E wave (m/s)	0.87 ± 0.22	0.81 ± 0.35	0.92 ± 0.18	.001
A wave (m/s)	0.4 ± 0.18	0.43 ± 0.18	0.38 ± 0.17	.078
E/A ratio	2.58 ± 1.28	2.16 ± 0.88	2.95 ± 1.46	.004
E DT (ms)	188.36 ± 46.49	205.17 ± 50.38	173.34 ± 37.2	<.001
LASr4c (%)	12.87 ± 5.09	14.54 ± 5.11	11.38 ± 4.63	.004
LAScd4c (%)	9.14 ± 3.63	9.45 ± 3.32	8.87 ± 3.91	.460
LASct4c (%)	3.73 ± 3.08	5.09 ± 3.29	2.51 ± 2.3	<.001
pLASRr4c (s^{-1})	0.64 ± 0.24	0.67 ± 0.24	0.62 ± 0.24	.304
pLASRcd4c (s^{-1})	−0.81 ± 0.3	−0.83 ± 0.29	−0.79 ± 0.3	.513
pLASRct4c (s^{-1})	−0.49 ± 0.35	−0.62 ± 0.4	−0.36 ± 0.24	<.001
LASr2c (%)	12.86 ± 5.84	14.93 ± 6.82	11.05 ± 4.1	.006
LAScd2c (%)	8.3 ± 3.79	9.26 ± 4.47	7.45 ± 2.87	.117
LASct2c (%)	4.56 ± 3.74	5.67 ± 4.23	3.6 ± 2.98	.008
pLASRr2c (s^{-1})	0.65 ± 0.25	0.71 ± 0.29	0.6 ± 0.21	.107
pLASRcd2c (s^{-1})	−0.73 ± 0.33	−0.81 ± 0.37	−0.67 ± 0.28	.077
pLASRct2c (s^{-1})	−0.63 ± 0.45	−0.79 ± 0.53	−0.49 ± 0.3	.010
LASr mean (%)	12.83 ± 4.92	14.68 ± 5.33	11.22 ± 3.93	.001
LAScd mean (%)	8.69 ± 2.94	9.29 ± 3.06	8.16 ± 2.75	.044
LASct mean (%)	4.14 ± 3.21	5.39 ± 3.5	3.05 ± 2.48	<.001
pLASRr mean (s^{-1})	0.64 ± 0.22	0.68 ± 0.23	0.61 ± 0.2	.175
pLASRcd mean (s^{-1})	−0.77 ± 0.26	−0.82 ± 0.28	−0.73 ± 0.24	.116
pLASRct mean (s^{-1})	−0.55 ± 0.38	−0.7 ± 0.44	−0.42 ± 0.26	.001
LA dyskinesia 4c (n, %)	35 (40.23)	7 (17.5)	28 (59.57)	<.001
LA dyskinesia 2c (n, %)	37 (43.02)	13 (33.33)	24 (51.06)	.098
LA dyskinesia 4c and 2c (n, %)	22 (25.58)	5 (12.82)	17 (36.17)	.013
LA dyskinesia 4c or 2c (n, %)	50 (58.14)	15 (38.46)	35 (74.47)	.001

2c = 2-chamber view, 4c = 4-chamber view, A wave = late mitral inflow wave, a′ wave = late diastolic mitral annular velocity, cd = conduit phase, ct = contractile phase, d = diastolic, E = early mitral inflow wave, E DT = deceleration time of E wave, e′ = early diastolic mitral annular velocity, IVS = intraventricular septum wall thickness, LAAP = left atrial antero-posterior diameter, LAEDVI = left atrial end-diastolic volume index, LAEF = left atrial emptying fraction, LAS = left atrial strain, LAVI = left atrial volume index, LVEDD = left ventricular end-diastolic diameter, LVEF = left ventricular ejection fraction, LVESD = left ventricular end-systolic diameter, pLASR = peak left atrial strain rate, r = reservoir phase, RAA = right atrium area, RV prox = right ventricular proximal diameter, s = systolic, s′ wave = systolic mitral annular velocity.

Table 3

Regression analysis.

	Univariate logistic regression			Multivariable logistic regression		
	OR	95%CI	*P* value	OR	95%CI	*P* value
LAEDVI	1.06	1.01–1.1	.014			
LAEF	0.94	0.91–0.98	.005			
a′ wave mean	0.74	0.6–0.91	.005			
E/e' mean ratio	1.21	1.05–1.38	.007			
LASr4c	0.87	0.8–0.96	.005			
LASct4c	0.69	0.56–0.85	<.001	0.78	0.63–0.97	.027
LA dyskinesia 4c	6.95	2.55–18.93	<.001	3.53	1.16–10.76	.027

a′ wave = late diastolic mitral annulus velocity, CI = confidence interval, E = early mitral inflow wave, e′ = early diastolic mitral annular velocity, LAEDVI = left atrial end diastolic volume index, LAEF = left atrial emptying fraction, LASct 4c = strain during the contractile phase measured in the 4-chamber apical view, LASr 4c = strain during the reservoir phase measured in a 4-chamber apical view, OR = odds ratio.

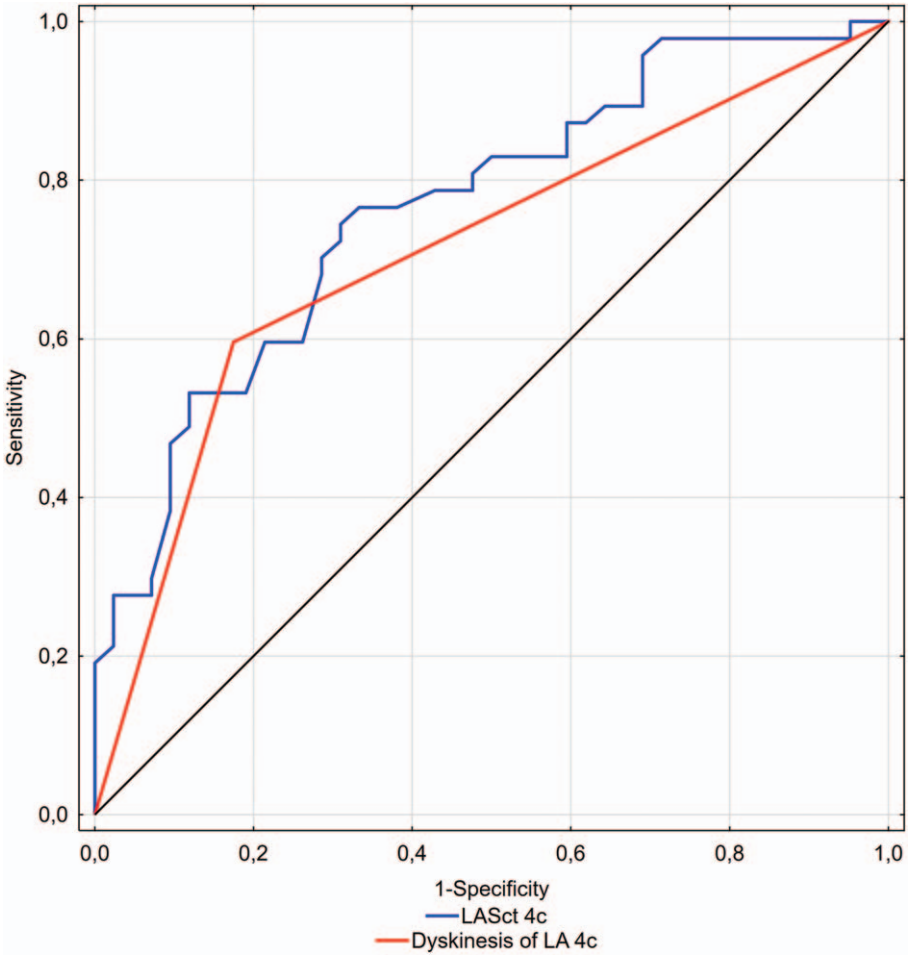

Figure 3. ROC curve analysis for LASct4c and LA dyskinesia. 4c = apical 4-chamber view, LASct = left atrial strain during the contractile phase.

3.4. Reproducibility

Intraobserver correlation coefficients for diagnosis of LA dyskinesia was 0.954 (95%CI 0.929–0.969). Interobserver correlation coefficients for the same parameter was 0.909 (95%CI 0.863–0.939).

4. Discussion

This study has shown that the presence of segmental dyskinesia of the LA wall, visualized during a strain rate analysis, is an independent predictor of AF recurrence after DCCV. Multivariable logistic regression showed that, from the echocardiographic parameters assessing structural and mechanical remodeling and left ventricular filling pressure, only the strain measured during the contractile phase in 4c view and LA wall dyskinesia recorded from 4c view were independent predictors of AF recurrence after DCCV. To our knowledge, this is the first study demonstrating the predictive value of segmental dyskinesia of the LA wall in terms of the risk of AF recurrence after DCCV.

STE is a technique used in echocardiographic examination that helps assess segmental and global velocity, as well as ventricular and atrial strain and strain rate. The LA strain and strain rate were initially assessed using tissue Doppler imaging (TDI), but measurements taken with this technique are prone to error due to its angle dependence. STE does not share this disadvantage and is currently used to measure the strain and strain rate. Di Salvo et al showed that the strain and strain rate assessed in patients before DCCV have prognostic value in predicting the maintenance of SR after DCCV in patients with recent-onset lone AF.[23] Wang et al demonstrated that the LA strain rate has predictive value for SR maintenance after DCCV, but they focused mainly on the basal segments of the LA.[24] Di Salvo et al and Wang et al used TDI to assess the strain and strain rate. In contrast, Shaikh et al used STE to measure the LA strain before and after DCCV and found that it had no value in predicting the maintenance of SR after DCCV.[25] They observed that the prognostic value for SR maintenance differed between pre- and post-DCCV measurements. Moreno-Ruiz et al used STE to measure the strain and showed that LA strain evaluated before DCCV can be useful to assess the prognosis of SR maintenance after DCCV.[26] Thus far, the measurements of segmental LA wall dysfunction that have been used include segmental strain and strain rate values and LA wall motion dispersion analyzed in strain recordings.[24,27–29] Wall motion dispersion is the difference in the time needed to obtain the maximum strain of individual LA wall segments. Dispersion is usually analyzed in reservoir and contractile phases. Doruchowska et al showed that the dispersion of the time to the maximal longitudinal strain in the reservoir phase has prognostic value for SR maintenance after DCCV.[27] Sarvari et al assessed the predictive value of LA strain measurements and

dispersion to maximum strain during LA contraction in patients who underwent pulmonary vein isolation (PVI) for AF. The study did not reveal differences in the LA strain measurements in the contractile phase between patients who maintained SR and patients with AF recurrence after PVI.[33] A group of patients with AF who were eligible for PVI had lower values of LASct compared with controls without AF. They demonstrated that patients with AF recurrence after PVI had a greater dispersion during LA contraction despite the lack of differences in strain values. Sarvari et al did not address the difficulty in measuring LASct in case of features indicating LA wall dyskinesia.[33]

5. Limitations

Our study was carried out in 1 center and included a small number of patients. We assessed AF duration retrospectively based on the patients' reports. When interpreting our results, 1 should remember that echocardiography is operator-dependent and requires experience and skill. Therefore, in our study, all echocardiographic measurements were taken by 1 experienced investigator. Because using constant heart rhythm monitoring was not feasible in our long-term study, we might have missed self-limiting episodes of AF recurrence. We performed all cardioversions in the antero-lateral position, without changing the paddle position in case of cardioversion failure, which might have influenced the success rate. The assessment of strain, strain rate, and the presence of dyskinesia was carried out a day after DCCV, when LA myocardial function may still be disturbed. We did not analyze whether the location, extent, and depth of dyskinesia had any impact on the prediction of AF recurrence after DCCV. The location and number of dyskinetic segments and the influence of these variables on the prediction of AF recurrence after DCCV will be further investigated. We did not perform echocardiography during follow-up visits at the Heart Rhythm Disorders Clinic. Therefore, we do not know how the results of strain and strain rate measurements changed and whether LA wall dyskinesia subsided.

6. Conclusions

Segmental disorders of LA wall contractility in the form of dyskinesia can be detected by transthoracic echocardiography with STE during strain rate analyses. LA wall dyskinesia and the strain measured during the contractile phase in 4c view (LASct4c) are independent risk factors for AF recurrence following DCCV.

Author contributions

Conceptualization: Paweł Wałek, Beata Wożakowska-Kapłon.
Data curation: Paweł Wałek, Iwona Gorczyca.
Formal analysis: Paweł Wałek, Elzbieta Ciesla, Beata Wożakowska-Kapłon.
Funding acquisition: Paweł Wałek.
Investigation: Paweł Wałek, Elzbieta Ciesla, Beata Wożakowska-Kapłon.
Methodology: Paweł Wałek, Beata Wożakowska-Kapłon.
Resources: Paweł Wałek, Iwona Gorczyca.
Software: Paweł Wałek.
Supervision: Beata Wożakowska-Kapłon.
Validation: Beata Wożakowska-Kapłon.
Visualization: Paweł Wałek.
Writing – original draft: Paweł Wałek.
Writing – review & editing: Beata Wożakowska-Kapłon.

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