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Case report

Predictive Role of Left Atrial Strain in Atrial Fibrillation Recurrence Following Electrical Cardioversion: Results From a 24-Month Follow-Up

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Abstract

Introduction. Left atrial (LA) strain has emerged as a potential marker of atrial mechanical dysfunction and recurrence risk after electrical cardioversion (ECV). This study evaluated the prognostic value of baseline LA strain parameters and LA stiffness index (LASI) for atrial fibrillation (AF) recurrence during 24-month follow-up, with particular emphasis on recurrence timing.

Methods. This prospective observational follow-up study included 31 patients with persistent AF who underwent successful ECV. Baseline echocardiographic assessment included LA reservoir, conduit, and contractile strain, LASI, E/e', and left atrial volume index (LAVI). Patients were followed at 3, 6, 12, and 24 months. AF recurrence was analysed as overall recurrence during follow-up and according to the interval of first documented recurrence.

Results. During 24 months, AF recurred in 18 patients (58.1%). Patients with recurrence had lower baseline LA reservoir, conduit, and contractile strain and higher LASI and E/e', whereas LAVI did not differ significantly between groups. All three strain components and LASI showed good discrimination for 24-month recurrence. LA contractile strain was the only parameter that significantly distinguished early from late recurrence and showed the largest correlation coefficient with recurrence interval. Its discriminatory performance for early versus late recurrence was high (AUC 0.910).

Conclusion. Baseline LA functional impairment was associated with AF recurrence after successful ECV. LA contractile strain showed a particularly close relationship with recurrence timing and may provide additional prognostic information beyond the assessment of recurrence risk alone.

Key words atrial fibrillation; electrical cardioversion; left atrial strain; recurrence

Introduction

Atrial fibrillation (AF) is closely associated with structural and functional remodeling of the left atrium (LA), including progressive atrial fibrosis and impairment of atrial mechanics[1]. LA remodeling is a complex process driven by electrical, mechanical, and metabolic disturbances and is influenced by LA pressure and volume overload, left ventricular diastolic dysfunction, and ageing[2].

Left atrial strain analysis provides a non-invasive assessment of atrial deformation and has emerged as a sensitive marker of LA functional impairment. Reduced LA strain has been associated with the extent of atrial fibrosis assessed by cardiac magnetic resonance imaging and may provide information beyond conventional volumetric parameters such as left atrial volume index (LAVI)[3,4]. In addition, LA strain has shown associations with fibrosis burden according to established magnetic resonance-based classifications[5].

Restoration and maintenance of sinus rhythm remain important components of rhythm-control strategies in selected patients with AF. Electrical cardioversion (ECV) is an effective and widely used method for acute restoration of sinus rhythm; however, AF recurrence after successful cardioversion remains common[6]. A substantial proportion of recurrences occur early after ECV, although clinically relevant recurrence continues to accumulate during longer-term follow-up[7].

Identification of echocardiographic markers associated with both the occurrence and timing of AF recurrence

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may improve risk stratification after cardioversion. Conventional structural parameters such as LAVI may not fully reflect the degree of atrial functional remodeling, whereas LA strain and the left atrial stiffness index (LASI) may provide additional prognostic information.
The aim of this study was to evaluate the association between echocardiographic parameters of the left atrium and the recurrence of AF during a 24-month follow-up period.

Patients and methods

2.1. Study population and design

This prospective observational follow-up study included 31 patients with persistent AF who underwent successful ECV at the Department of Cardiology, General Hospital "Prim. Dr Abdulah Nakaš", Sarajevo, Bosnia and Herzegovina, between May 2023 and May 2024. The study represents an extended 24-month follow-up of the previously reported cohort.
Eligible patients were adults aged >18 years with persistent AF lasting between 7 days and 12 months and successful restoration of sinus rhythm following ECV. Exclusion criteria were prior AF ablation, significant valvular heart disease, left ventricular ejection fraction (LVEF) <30%, inadequate echocardiographic image quality, recent cardiac surgery, active infection, malignancy, autoimmune disease, untreated hyperthyroidism, advanced renal dysfunction (estimated glomerular filtration rate <30 mL/min/1.73 m^2), pregnancy, or inability to complete follow-up.
All participants provided written informed consent. The study was conducted in accordance with the Declaration of Helsinki and was approved by the institutional ethics committee.

2.2. Echocardiographic assessment

All patients underwent transthoracic and transesophageal echocardiography before ECV, irrespective of prior anticoagulation therapy. For the present analysis, baseline echocardiographic parameters included LAVI, E/e' ratio, and LA reservoir, conduit, and contractile strain. LA deformation was assessed using two-dimensional speckle-tracking echocardiography (2D STE). LASI was calculated as the E/e' ratio divided by LA reservoir strain.

2.3. Follow-up and study outcomes

Patients were evaluated at 3, 6, 12, and 24 months following successful ECV. AF recurrence was detected on standard electrocardiography (ECG) or ambulatory 24-hour ECG monitoring during follow-up. The timing of the first documented AF recurrence was categorized as 0–3, 3–6, 6–12, or 12–24 months after cardioversion. Patients without recurrence during the 24-month follow-up were considered recurrence-free. Additional analyses evaluated recurrence as a binary 24-month outcome and, among patients with recurrence, as early (≤6 months) or late (>6–24 months).

2.4. Statistical analysis

Analyses were performed using IBM SPSS Statistics, Version 26.0 (IBM Corp., Armonk, NY, USA; 2019). Normality of continuous variables was assessed using the Shapiro–Wilk test. Continuous variables were presented as mean ± standard deviation or median with interquartile range, as appropriate, and categorical variables as frequencies and percentages.
Baseline echocardiographic parameters were compared between patients with and without AF recurrence during the 24-month follow-up using the independent-samples t-test or non-parametric alternatives, as appropriate. Differences according to the timing of first recurrence were assessed using the Kruskal–Wallis test, while early (≤6 months) and late (>6–24 months) recurrence were compared using the Mann–Whitney U test. Spearman's rank correlation was used to assess associations between baseline echocardiographic parameters and the timing of first recurrence among patients with recurrent AF.
Receiver operating characteristic (ROC) curve analysis was used to assess the discriminatory performance of LA reservoir, conduit, and contractile strain, LASI, E/e', and LAVI for 24-month AF recurrence. Areas under the curve (AUCs) with 95% confidence intervals were calculated, and exploratory cut-off values were identified using the Youden index.
Univariable binary logistic regression was performed to evaluate associations between individual baseline echocardiographic parameters and 24-month AF recurrence, with results reported as odds ratios (ORs) with 95% confidence intervals. Multivariable modeling was not performed because of the limited sample size and substantial correlation among LA functional parameters.
A two-sided p-value <0.05 was considered statistically significant.

Results

Among 31 patients who underwent successful ECV, 18 (58.1%) experienced AF recurrence during the 24-month follow-up, whereas 13 (41.9%) remained recurrence-free. The first documented recurrence occurred within 0–3 months in 6 patients, 3–6 months in 6 patients, 6–12 months in 2 patients, and 12–24 months in 4 patients.
Patients with AF recurrence had significantly lower baseline LA reservoir, conduit, and contractile strain and significantly higher LASI and E/e' compared with patients who remained recurrence-free. LAVI did not differ significantly between the groups (Table 1).
ROC analysis demonstrated good discriminatory performance of LA functional parameters for 24-month AF recurrence. LA conduit strain showed the numerically highest AUC, followed by LA reservoir strain, LASI, and LA contractile strain. E/e' showed moderate-to-good discrimination, whereas LAVI demonstrated weaker discriminatory performance (Table 2).
In univariable logistic regression, higher LA reservoir, conduit, and contractile strain were associated with lower odds of AF recurrence, whereas higher LASI and E/e' were associated with increased odds of recurrence. LAVI was not significantly associated with 24-month AF

Table 1. Baseline echocardiographic parameters according to 24-month AF recurrence

Parameter	No recurrence (n=13)	AF recurrence (n=18)	p-value
LA reservoir strain, %	26.62 ± 4.35	21.00 ± 3.97	0.001*
LA conduit strain, %	14.23 ± 3.22	9.72 ± 2.82	<0.001*
LA contractile strain, %	9.69 ± 1.93	6.78 ± 2.32	0.001*
LASI	0.595 ± 0.200	0.913 ± 0.294	0.002*
E/e'	15.14 ± 2.69	18.09 ± 2.59	0.004*
LAVI, mL/m²	51.69 ± 11.06	58.42 ± 8.78	0.069

Data are presented as mean ± standard deviation. P-values were obtained using the independent-samples t-test. AF, atrial fibrillation; LA, left atrial; LASI, left atrial stiffness index; LAVI, left atrial volume index. *p-value <0.05 was considered statistically significant.

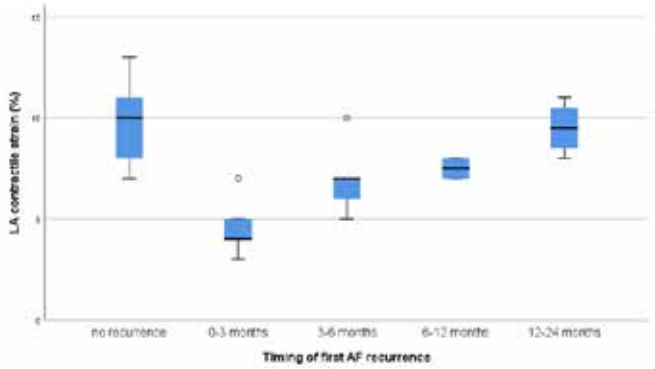


Figure 1. Baseline LA contractile strain according to timing of first AF recurrence.
Kruskal–Wallis p=0.001. AF, atrial fibrillation; LA, left atrial.

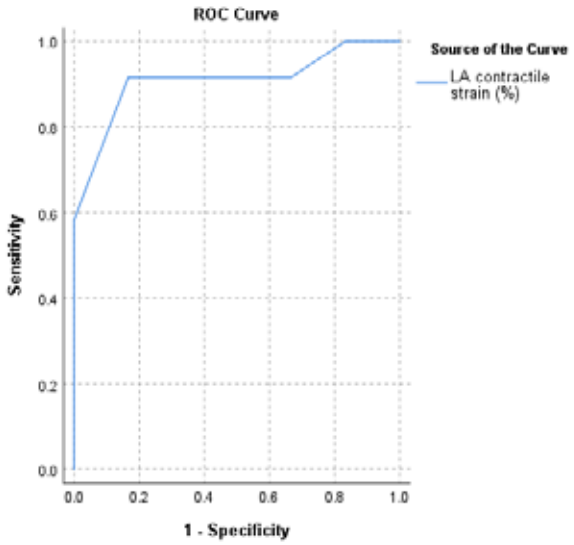


Figure 2. ROC curve of baseline LA contractile strain for discrimination of early (≤6 months) versus late (>6–24 months) AF recurrence.
AF, atrial fibrillation; LA, left atrial; ROC, receiver operating characteristic.

recurrence (Table 2). Exploratory ROC-derived thresholds included LA conduit strain ≤13.5%, with 94.4% sensitivity and 61.5% specificity, and LASI ≥0.69, with 77.8% sensitivity and 76.9% specificity for 24-month AF recurrence.

Baseline LA functional parameters differed significantly according to the timing of first AF recurrence, whereas LAVI did not (Table 3). Among the 18 patients with recurrent AF, 12 experienced early recurrence (≤6 months) and 6 experienced late recurrence (>6–24 months). Higher baseline LA contractile strain values were observed across progressively later recurrence intervals, as illustrated in Figure 1.

LA contractile strain also showed the strongest association with the timing of first recurrence (Table 3). ROC analysis demonstrated excellent discrimination of early versus late recurrence (AUC 0.910, p<0.001), with an exploratory threshold of ≤7.5% yielding 91.7% sensitivity and 83.3% specificity (Figure 2).

Discussion

The main finding of this study is that baseline LA functional impairment was associated with AF recurrence after successful ECV. Patients who experienced recurrence had lower baseline LA reservoir, conduit, and contractile strain and higher LASI and E/e', whereas LAVI did not differ significantly between groups. Importantly, LA contractile strain was closely related to recurrence timing, with lower baseline values associated with earlier recurrence. These findings suggest that LA functional parameters may retain prognostic relevance beyond the early post-cardioversion period.

Table 2. ROC analysis and univariable logistic regression for 24-month AF recurrence

Parameter	AUC (95% CI)	ROC p-value	OR (95% CI)	Regression p-value
LA reservoir strain	0.838 (0.691–0.984)	<0.001*	0.721 (0.569–0.914)	0.007*
LA conduit strain	0.853 (0.718–0.987)	<0.001*	0.581 (0.391–0.863)	0.007*
LA contractile strain	0.831 (0.691–0.972)	<0.001*	0.531 (0.335–0.841)	0.007*
LASI	0.833 (0.687–0.979)	<0.001*	1.72 (1.13–2.61)	0.011*
E/e'	0.788 (0.622–0.955)	0.001*	1.521 (1.097–2.109)	0.012*
LAVI	0.703 (0.508–0.898)	0.042*	1.079 (0.991–1.175)	0.080

ORs for LA strain parameters, E/e', and LAVI are reported per one-unit increase. LASI OR is expressed per 0.1-unit increase. AF, atrial fibrillation; AUC, area under the curve; CI, confidence interval; OR, odds ratio; LA, left atrial; LASI, left atrial stiffness index; LAVI, left atrial volume index. *p-value <0.05 was considered statistically significant.

Table 3. Association of baseline echocardiographic parameters with timing of first AF recurrence

Parameter	Kruskal–Wallis H	p-value	Spearman ρ	p-value	Early vs late p-value
LA reservoir strain	15.915	0.003*	0.687	0.002*	0.074
LA conduit strain	18.013	0.001*	0.634	0.005*	0.201
LA contractile strain	19.045	0.001*	0.835	<0.001*	0.003*
LASI	16.985	0.002*	−0.705	0.001*	0.092
E/e’	16.065	0.003*	−0.680	0.002*	0.159
LAVI	5.212	0.266	−0.073	0.772	0.512

Spearman correlations were calculated among patients with AF recurrence (n=18). Early versus late recurrence was compared using the Mann–Whitney U test. AF, atrial fibrillation; LA, left atrial; LASI, left atrial stiffness index; LAVI, left atrial volume index. *p-value <0.05 was considered statistically significant.

The persistence of these associations over longer follow-up suggests that LA functional measures may reflect clinically relevant atrial remodeling not fully captured by atrial size alone[8-10]. Although LAVI remains an important marker of structural remodeling, patients with similar atrial volumes may differ substantially in residual atrial mechanical function and susceptibility to recurrent AF[9-12]. This may explain the stronger associations observed for LA strain parameters compared with LAVI in the present cohort.

LA reservoir, conduit, and contractile strain reflect different phases of atrial function and may therefore provide complementary information on the AF substrate. Progressive atrial fibrosis and remodeling can impair all three components, while CMR-based assessment, including the Utah classification, has linked greater fibrotic burden with more advanced atrial disease and recurrent arrhythmia[13,14]. Fibrosis promotes conduction heterogeneity and re-entry, providing a plausible substrate through which impaired atrial mechanics may relate to AF recurrence. In this context, LA strain assessment may offer a non-invasive functional marker of atrial substrate severity and could potentially contribute to risk stratification before electrophysiological rhythm-control procedures[15,16].

The most distinctive finding was the relationship between LA contractile strain and recurrence timing. Contractile strain was the only evaluated parameter that significantly distinguished early from late recurrence and showed the largest correlation coefficient with recurrence interval. It also demonstrated high discriminatory performance for identifying early recurrence. Reduced contractile deformation may reflect impaired atrial pump function and loss of mechanical reserve in patients with more advanced atrial myopathy, potentially contributing to earlier recurrence after restoration of sinus rhythm[8,17].

These findings build on the previously reported 6-month analysis of the same cohort, in which LA contractile strain was the only strain component that retained prognostic significance at the later follow-up point (2). The extended follow-up adds information on first recurrence across predefined intervals up to 24 months and further supports the hypothesis that contractile strain may represent a relatively durable marker of atrial mechanical dysfunction.

Previous studies have predominantly focused on LA reservoir strain as a predictor of rhythm outcome after ECV or catheter ablation, whereas conduit and contractile strain have been less extensively studied. Nevertheless, both have been evaluated in AF populations. Conduit strain appears to reflect the extent of atrial remodeling, while contractile strain may provide complementary information on residual atrial pump function and vulnerability to recurrent atrial arrhythmia[8,9,15,18-20]. In the present cohort, higher LASI and E/e’ were also associated with 24-month recurrence and earlier recurrence intervals. The opposing relationships of LA reservoir strain and LASI with the predicted probability of 24-month AF recurrence are illustrated in Figure 3. LASI may reflect the combined effects of atrial mechanical dysfunction and increased diastolic load, consistent with previous reports linking increased LA stiffness with recurrent AF after rhythm-control interventions[2,11]. However, the

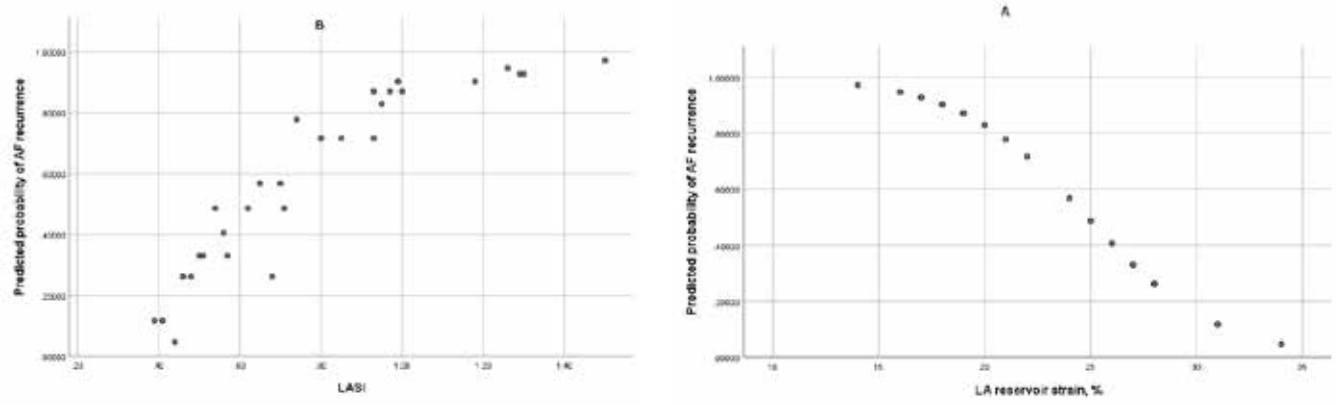


Figure 3. Predicted probability of 24-month atrial fibrillation recurrence according to baseline left atrial reservoir strain (A) and left atrial stiffness index (B), derived from separate univariable logistic regression models.
AF, atrial fibrillation; LA, left atrial; LASI, left atrial stiffness index.

strong correlations among LASI, E/e', and LA strain parameters limited assessment of their independent prognostic contributions.

Previous studies have predominantly focused on LA reservoir strain as a predictor of rhythm outcome after ECV or catheter ablation, while conduit and contractile strain have been less extensively investigated[8,9,18-20]. These components reflect different aspects of atrial mechanics: conduit strain represents passive atrial emptying during early diastole, whereas contractile strain reflects active atrial pump function and residual atrial mechanical reserve. Both may therefore provide complementary information on the underlying atrial substrate, although their prognostic relevance in AF has been less consistent than that of reservoir strain. In the present cohort, higher LASI and E/e' were also associated with 24-month recurrence and earlier recurrence intervals.

ROC analysis further supported the discriminatory value of LA functional parameters for 24-month AF recurrence. All three strain components and LASI showed good discrimination, whereas LAVI performed less well. LA conduit strain had the numerically highest AUC for overall recurrence; however, the AUCs were not formally compared, and superiority of one strain component over another cannot be inferred.

Several limitations should be acknowledged. This was a single-center study with a small sample size and a limited number of recurrence events, particularly in the later follow-up intervals, which reduced statistical power and precluded reliable multivariable adjustment. Recurrence was assessed using scheduled standard or ambulatory ECG monitoring rather than continuous rhythm monitoring, and asymptomatic or intermittent AF episodes may therefore have been missed. Recurrence timing was categorized according to predefined intervals rather than exact time-to-event data, precluding conventional survival analysis. In addition, strain measurements were obtained at a single baseline time point using 2D STE. Finally, the ROC-derived cut-off values were generated and evaluated within the same cohort and should be considered exploratory until externally validated.

Conclusion

Assessment of LA mechanics before cardioversion may contribute to post-procedural risk stratification. Patients with markedly impaired LA strain, particularly reduced contractile strain, may be at greater risk of earlier recurrence and could therefore benefit from closer rhythm surveillance and earlier reassessment of rhythm-control strategies. However, strain parameters should not be used as stand-alone criteria for treatment decisions, and their incremental value over established clinical predictors requires confirmation in larger prospective studies.

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Sažetak

Prediktivna uloga strain-a leve pretkomore u recidivu atrijalne fibrilacije nakon električne kardioverzije: rezultati 24-mesečnog praćenja

Nejra Mlačo-Vražalić[1], Ada Đozić[1], Buena Aziri[2], Amer Iglica[3], Zijo Begić[4], Nirvana Šabanović-Bajramović[3], Edin Begić[5], Akif Mlačo[5,6], Tamara Kovačević-Preradović[7], Željko Živanović[7], Bojan Stanetić[7], Miodrag Ostojić[7,8]

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Uvod. *Strain leve pretkomore (LP) predstavlja potencijalni marker mehaničke disfunkcije pretkomore i rizika od recidiva atrijalne fibrilacije (AF) nakon električne kardioverzije (ECV). Cilj ovog istraživanja bio je da se ispita prognostička vrednost parametara analize strain-a LP i indeksa krutosti leve pretkomore (LASI) za recidiv AF tokom 24-mesečnog praćenja, sa posebnim osvrtom na vreme pojave recidiva.*

Metode. *Istraživanje je imalo prospektivni i opservacioni karakter, te je obuhvatilo 31 pacijenta sa dijagnozom perzistentne AF kod kojih je uspešno izvršena ECV. Bazalna ehokardiografska procena obuhvatala je rezervoarski, konduitni i kontraktilni strain LP, LASI, odnos E/e' i indeksirani volumen LP (LAVI). Pacijenti su praćeni nakon 3, 6, 12 i 24 meseca. Recidiv AF analiziran je kao ukupna pojava recidiva tokom praćenja i prema intervalu prvog dokumentovanog recidiva.*

Rezultati. *Tokom 24 meseca, recidiv AF zabeležen je kod 18 pacijenata (58,1%). Pacijenti sa recidivom imali su niže vrednosti rezervoarskog, konduitnog i kontraktilnog strain-a LP i više vrednosti LASI i E/e', dok se LAVI nije značajno razlikovao između grupa. Sve tri komponente strain-a LP i LASI pokazale su dobru diskriminativnu sposobnost za 24-mesečni recidiv. Kontraktilni strain leve pretkomore bio je jedini parametar koji je značajno razlikovao rani od kasnog recidiva i pokazao najveći koeficijent korelacije sa intervalom recidiva. Njegova diskriminativna sposobnost za rani u odnosu na kasni recidiv bila je visoka (AUC 0,910).*

Zaključak. *Paramatri straina LP su bili povezani sa recidivom AF nakon uspešne ECV. Kontraktilni strain LP pokazao je posebno blisku povezanost sa vremenom pojave recidiva i može predstavljati parametar stratifikacije rizika od recidiva.*

Ključne reči: *atrijalna fibrilacija; električna kardioverzija; strain leve pretkomore; recidiv*