Positive left atrial remodeling in patients with paroxysmal atrial fibrillation after a successful radiofrequency pulmonary vein isolation

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DOI: 10.33963/KP.a2023.0095

Received:
October 7, 2022

Accepted:
March 13, 2023

Early publication date:
April 25, 2023

ABSTRACT

Background: A potential relationship between the initial left atrial (LA) echocardiographic parameters and LA remodeling after pulmonary vein isolation using (PVI) radiofrequency energy energy with effectiveness of this treatment was discussed.

Aim: We aimed to determine the relationship between initial and post-follow-up transthoracic echocardiography-derived predictors of successful PVI in patients with paroxysmal atrial fibrillation (AF).

Methods: Eighty patients with paroxysmal AF (aged 58 [interquartile range, IQR, 50–63] years; male, 50 [62.5%]), hospitalized for the first PVI procedure were included. Before and after a minimum of 6 months of follow-up, clinical and echocardiographic evaluations were performed. LA morphological parameters (diameter, volumes, and other detailed LA parameters), as well as LA peak segmental and global longitudinal strains (PLS) and LA wall strain synchrony were assessed.

Results: In the whole group after the follow-up period, patients presented higher mean LA $Vol_{conduit}$. Patients with no AF recurrences had lower post-PVI LA volumes, higher LA ejection fraction, and LA expansion index when compared to the patients after ineffective PVI. Patients who maintained sinus rhythm after the PVI procedure were characterized by higher initial segmental strains: LA $PLS_{basal-inferior}$ and $PLS_{apical-septal}$, as well as higher LA wall strain dispersion over time.

Conclusions: Some echocardiographic parameters related to LA morphology improve after successful PVI treatment. LA strains and wall strain dispersion over time are not related to LA remodeling after a successful PVI procedure. However, the baseline LA standard and novel echocardiographic parameters cannot be used for remote evaluation of the effectiveness of the PVI procedure.

Key words: atrial fibrillation, left atrium, pulmonary vein isolation, strain

INTRODUCTION

Atrial fibrillation (AF) is a common supraventricular arrhythmia resulting mainly from progressive unfavorable remodeling of the left atrium (LA). Additionally, in the course of AF, the negative electrical and structural remodeling of LA is consolidated and intensified at the same time [1, 2]. LA remodeling is therefore a complex process, simply defined as a change in LA size and function. The observed structural changes in the LA do not always correlate with the changes observed during myocardial electrical remodeling in patients with recurrent AF [3]. It was found that LA dysfunction assessed using the 2-dimensional speckle-tracking echocardiography (STE) method may precede visible structural changes in the atria, also in potentially healthy individuals [4–6].

The complete isolation of pulmonary veins by linear lesions around their antrum is currently recognized as the most effective method of AF treatment, which is reflected in the growing number of procedures performed also in Poland [7, 8]. Actually, in the light of the latest 2020 European Society of Cardiology

WHAT'S NEW?

Our study aimed to determine the relationship between initial and post-follow-up standard and novel echocardiographic parameters of left atrial (LA) morphology and function and the effectiveness of pulmonary vein isolation (PVI) with radiofrequency energy) in patients with paroxysmal atrial fibrillation (AF). The presented study is unique in terms of the comprehensiveness of the detailed echocardiographic assessment of the LA (both morphology and deformations — segmental and global) in the entire study group. Although some of the echocardiographic parameters describing the morphology of the LA improve after a successful PVI procedure, there is still no single parameter to clearly define the possibility of recurrence of arrhythmia after PVI. Echocardiographic evaluation should be complex, using various available imaging techniques and potentially useful parameters to evaluate the morphology and function of heart chambers. Our observations might also be useful in daily clinical practice and turn out to be of interest to a large group of physicians and investigators focused on AF, especially in connection with long-term effectiveness of ablation treatment and detailed echocardiographic examination.

(ESC) guidelines on the treatment of AF, several randomized controlled trials and observational studies, pulmonary vein isolation (PVI) with radiofrequency (RF) energy or cryoballoon ablation are comparable methods of AF treatment in terms of effectiveness and possible complications, mostly as the first procedure [8, 9].

The pre-procedural echocardiographic assessment, taking into account both the LA morphology (analysis of dimensions and volume: passive, active, and phase) and LA function (analysis of global and segmental strains), may help assess the relationship between the effectiveness of the PVI procedure and early LA dysfunction in the group of patients with paroxysmal AF [10–13]. In turn, the post-procedural assessment will contribute to a more complete understanding of LA remodeling processes depending on maintaining sinus rhythm.

This study aimed to determine the influence of initial and post-follow-up transthoracic echocardiography-derived predictors of successful PVI in patients with paroxysmal AF undergoing the ablation procedure for the first time.

METHODS

We enrolled in the study eighty patients with diagnosed paroxysmal non-valvular AF who were hospitalized in the Department of Cardiology between 2013 and 2017 to have their first PVI procedure.

The standard inclusion criteria were: documented paroxysmal symptomatic non-valvular AF (European Heart Rhythm Association [EHRA] scale, IIb–III) despite the optimal treatment and qualification for PVI, adequate anticoagulant therapy before admission, maintaining sinus rhythm during hospitalization, preserved left ventricular systolic function (LVEF ≥50%), written informed consent, and >18 years of age.

We excluded patients with a history of any artery pathology (stenosis defined as arterial stenosis ≥50% in the NASCET [14], vasculitis or dissection), connective tissue disease, a history of stroke or transient ischemic attack (TIA) in the past, structural heart disease (cardiomyopathies, significant valvular heart disease), states associated with hypercoagulability or a predisposition to systemic embolism, a history of PVI in the past, pregnancy, refusal to participate, acute kidney disease, chronic kidney disease with glomerular filtration rate (GFR) <30 ml/min/1.73 m^2.

Written informed consent was obtained from each patient. The study protocol was approved by the Bioethical Committee of the Medical University of Silesia and performed according to the ethical guidelines of the 1975 Declaration of Helsinki.

The study group was evaluated during hospitalization before the procedure and after the follow-up period. In the current study, up to 6 months after the ablation procedure, a telephone conversation was conducted with the patient to assess the arrhythmia sensation and the pharmacotherapy used. Due to assessing multiple endpoints, clinical evaluation was performed after a minimum of 6 months to a maximum of 12 months after PVI. This time is necessary, among other things, for full healing of damaged tissue after PVI with RF energy. On the other hand, it was necessary due to the technical requirements of 7-day Holter electrocardiogram (ECG) monitoring in each patient and other examinations resulting from the multi-endpoint study design.

On admission, we collected from each subject a detailed medical history that included the current course of the disease, the main symptoms (assessed with the EHRA classification), concomitant diseases (including coronary artery disease, type 2 diabetes mellitus, arterial hypertension, hyperlipidemia, peripheral artery disease), a familial history of arrhythmia, current pharmacotherapy (especially compliance with oral anticoagulants) and tobacco smoking. We also collected physical examination parameters: weight, height, body mass index (BMI), and body surface area (BSA). Before the ablation procedure, each patient underwent in-hospital Holter ECG monitoring (24 hours) as well as transthoracic and transesophageal echocardiography.

After a minimum of 6 months of follow-up period transthoracic echocardiography and Holter ECG home monitoring (7 days) were performed in all subjects. Furthermore, medical history, including possible recurrence of arrhythmia and pharmacotherapy was taken.

Holter ECG monitoring

Holter ECG recordings were made using Lifecard CF recorders, and the recordings were assessed using the Del Mar Reynolds Sentinel system (Sentinel, Spacelabs Healthcare, Snoqualmie, WA, US). The registration was made during the day immediately preceding the PVI procedure. Registration after the follow-up period was carried out at least 7 months after the procedure using the 7-day option with ECG recording at home. An episode of AF was considered to be arrhythmia lasting >30 seconds. Two episodes of AF at the same time separated by sinus rhythm lasting <30 seconds were considered as one episode.

Transthoracic and transesophageal echocardiography

On admission, ECG-gated transthoracic and transesophageal echocardiography were performed in all patients. An experienced physician took all of the measurements during sinus rhythm, using the same investigation protocol and techniques to reduce inter- and intra-observer variability. The echocardiography examination was performed using VIVID 7 echocardiographic devices — General Healthcare (Chicago, IL, US) equipment with a 2.5 MHz sector ultrasound transducer for transthoracic and a 2–7 MHz for transesophageal echocardiography. The examination results were stored for further analysis.

Evaluation of LA echocardiographic parameters of morphology and function

The $LA_{diameter}$ was measured in the long-axis (LAX) view while all LA volumes were measured in the four-chamber (4CH) apical view.

Assessed LA passive volumes included:

- Pre-atrial contraction LA volume — LA Vol_{preA}
- Minimal LA volume — LA Vol_{min}
- Maximal LA volume — LA Vol_{max}.

Assessed LA active volumes included:

- LA reservoir volume — LA $Vol_{reservoir}$
- LA conduit volume — LA $Vol_{conduit}$
- LA passive emptying volume — LA $Vol_{passive\ emptying}$
- LA contractile volume — LA $Vol_{contractile}$.

Other parameters were calculated from the volumes of passive and active LA:

- LA ejection fraction — LA EF;
- LA expansion index LA — $LA_{expansion\ index}$
- LA active emptying fraction — $LA_{active\ empt\ frac}$;
- LA passive emptying fraction — $LA_{passive\ empt\ frac}$.

Previously recorded echocardiographic images in the DICOM (Digital Imaging and Communications in Medicine) format were analyzed using an external workstation equipped with the EchoPAC PC Dimension software (version 7.1.2 by General Electric Healthcare), enabling semi-automatic deformation analysis.

Grayscale imaging for two-chamber (2CH) and 4CH projections was obtained with a frame rate of 60–80 Hz per second. The line along the endocardium was manually drawn starting at the endocardial border of the mitral ring and along the endocardial-lumen boundary of the LA excluding the pulmonary veins to the opposite side of the mitral ring. An additional epicardium line was automatically generated by the software, creating a region of interest (ROI). After manually adjusting the ROI shape, in both the 4CH and 2CH projections, the software split the LA into six segments and generated longitudinal strain curves. In the curve analysis, point zero was considered to be the beginning of the P-wave timing [15, 16]. During LA systolic phase, segmental and global longitudinal peak LA strains were assessed.

Maximum LA peak longitudinal strain (LA PLS) corresponding to LA segments and maximum LA global PLS (LA PGLS), were measured in the LA contraction phase in 2CH (Figure 1) and 4CH (Figure 2) views:

- Basal for the inferior wall (basal-inferior) — LA $PLS_{bas\text{-}inf\ 2CH}$;
- Medial for the inferior wall (medial-inferior) — LA $PLS_{med\text{-}inf\ 2CH}$;
- Apical for the inferior wall (apical-inferior) — LA $PLS_{api\text{-}inf\ 2CH}$;
- Basal for the anterior wall (basal-anterior) — LA $PLS_{bas\text{-}ant\ 2CH}$;
- Medial for the anterior wall (medial-anterior) — LA $PLS_{med\text{-}ant\ 2CH}$;
- Apical for the anterior wall (apical-anterior) — LA $PLS_{api\text{-}ant\ 2CH}$;
- Global for all segments — LA $PGLS_{2CH}$;
- Basal for the lateral wall (basal-lateral) — LA $PLS_{bas\text{-}lat\ 4CH}$;

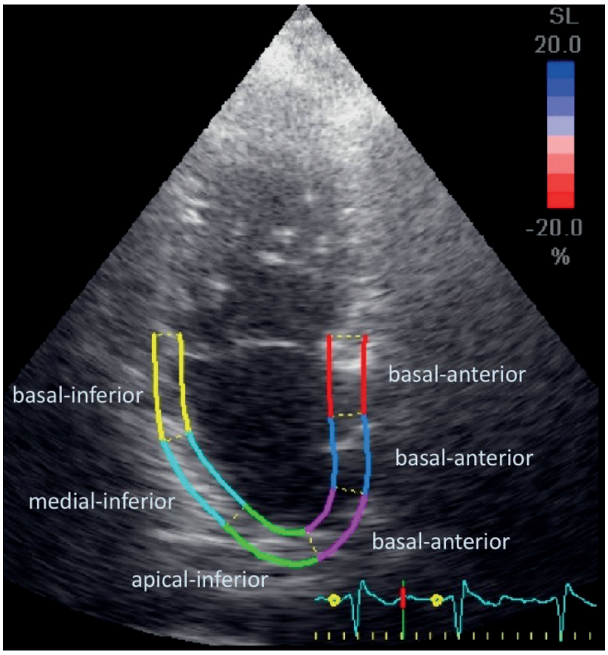

Figure 1. Division of the LA into segments corresponding to strains in the 2CH view

Abbreviations: LA, left atrium; 2CH, two-chamber

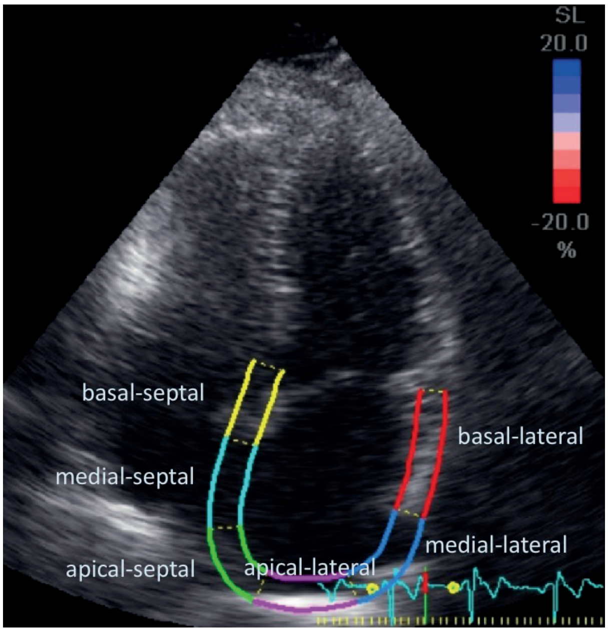

Figure 2. Division of the LA into segments corresponding to strains in 4CH view

Abbreviations: LA, left atrium; 4CH, four-chamber

- Medial for the lateral wall (medial-lateral) — LA $PLS_{med\text{-}lat\ 4CH}$
- Apical for the lateral wall (apical-lateral) — LA $PLS_{api\text{-}lat\ 4CH}$
- Basal for the septal wall (basal-septal) — LA $PLS_{bas\text{-}sept\ 4CH}$
- Medial for the septal wall (medial-septal) — LA $PLS_{med\text{-}sept\ 4CH}$
- Apical for the septal wall (apical-septal) — LA $PLS_{api\text{-}sept\ 4CH}$
- Global for all segments — LA $PGLS_{4CH}$.

In addition, the LA segmental wall strain dispersion in time (ms) (LA synchrony) in the 2CH and 4CH views was assessed and defined as the difference between the earliest and the latest maximum longitudinal LA strains for individual segments.

PVI procedure

At the beginning of the PVI procedure, rotational LA angiography was performed. Then, after a transseptal puncture, 3-dimensional electro-anatomical mapping was performed using the CARTO®3 system (Biosense Webster, Diamond Bar, CA, US). PVI was obtained by RF radiofrequency ablation with a ThermoCool® SmartTouch® SF catheter (Biosense Webster, Diamond Bar, CA, US). The procedure was performed using a Lasso electrode (Biosense Webster, Diamond Bar, CA, US) or Achieve (Medtronic, MN, US).

Immediately after the transseptal puncture, all patients received continuous infusion of unfractionated heparin (2000 IU/h) (preceded by an intravenous bolus of unfractionated heparin [100 IU/kg]) to obtain activated clotting time (ACT) above 300 seconds.

Statistical analysis

Statistical analysis was performed using STATISTICA software (version 13.1 PL). All data were collected in a Microsoft Office Excel spreadsheet (version 2016 PL). A *P*-value of less than 0.05 was considered to indicate statistical significance. Results for continuous variables were presented as mean with standard deviation for normal distributions or median with interquartile range (IQR) for non-normal distributions. The normality of the distribution of continuous variables was verified with the Shapiro-Wilk test. Ordinal variables in the Tables are shown as absolute numbers and percentages. Depending on the distribution of variables, for pre- and post-PVI comparisons, parametric (t-test for dependent variables) and non-parametric (Wilcoxon matched-pairs signed-rank test) tests for dependent variables were used. For separate groups (effective/ineffective PVI) parametric (t-test) and non-parametric (Mann-Whitney U test) tests for independent variables were used.

RESULTS

The study group characteristics

The median (IQR) follow-up was 9.9 (7.6–11.8) months. After the follow-up period, the effectiveness of the PVI procedure (sinus rhythm maintenance confirmed by 7-day Holter ECG examination) was confirmed in 53.8% of patients. Table 1 presents the basic parameters characterizing the

Table 1. Characteristics of the study group

	Study group (n = 80)
Demographics	
Age, year, median (IQR)	58 (50–63)
Male sex, n (%)	50 (62.5)
AF duration	
0–5 years, n (%)	37 (46)
5–10 years, n (%)	27 (34)
>10 years, n (%)	16 (20)
Baseline biometric evaluation, mean (SD)	
Height, cm	174.2 (9.2)
Weight, kg	88.3 (15.2)
BMI, kg/m^2	29.1 (4.25)
BSA, m^2	2.06 (0.22)
Functional class and risk scale	
EHRA, score, median (IQR)	3 (2–3)
CHA_2DS_2-VASc score, median (IQR)	2 (1–2.5)
Co-morbidities, n (%)	
Coronary artery disease	15 (19)
Arterial hypertension	56 (70)
Diabetes mellitus	15 (19)
Hyperlipidemia	55 (69)
Obesity	27 (34)
Tobacco smoking, n (%)	
Never	46 (57.5)
In the past	22 (27.5)
Active	12 (15)

Abbreviations: AF, atrial fibrillation; BMI, body mass index; BSA, body mass area

Table 2. LA echocardiographic parameters before PVI procedure and after the observation period

	Parameters	Before (n = 66)	After PVI (n = 66)	*P*-value
LA morphological parameters	$LA_{diameter}$, mm	39.6	—	—
	LA Vol_{preA}, ml	53 (35–64)	51 (37–66)	0.76
	LA Vol_{min}, ml	36.5 (25–49)	33 (26–51)	0.57
	LA Vol_{max}, ml	74.5 (60–103)	72.5 (62–88)	0.15
	$LAVI_{max}$, ml/m^2	36.3 (29.4–49.5)	35.7 (30–45.4)	0.16
	LA $Vol_{reservoir}$, ml	38 (32–49)	37 (32–44)	0.21
	LA $Vol_{conduit}$, ml	25.4 (15.1)	30.1 (13.3)	0.01
	LA $Vol_{passive\ emptying}$, ml	21 (16–35)	20 (15–26)	0.05
	LA $Vol_{contractile}$, ml	14.5 (8–20)	16 (11–22)	0.56
	LAEF, %	52 (46–58)	54 (44–59)	0.33
	$LA_{expansion\ index}$	1.17 (0.48)	1.15 (0.46)	0.75
	$LA_{active\ empt\ frac}$, %	31 (17–38)	33 (26–39)	0.63
	$LA_{passive\ empt\ frac}$, %	32 (13)	30 (12)	0.3
LA strains and LA wall strain dispersion	LA $PLS_{bas–inf\ 2CH}$, %	−17.5 (−21.8 to −13.4)	−19.4 (−22.3 to −13)	0.32
	LA $PLS_{med–inf\ 2CH}$, %	−15.2 (−18 to −11.8)	−14.6 (−18.3 to −11.5)	0.64
	LA $PLS_{api–inf\ 2CH}$, %	−10.9 (−14.3 to −6.4)	−10.1 (−12.6 to −6.8)	0.25
	LA $PLS_{bas–ant\ 2CH}$, %	−14.6 (−19.5 to −9.8)	−14.7 (−19.4 to −10.3)	0.97
	LA $PLS_{med–ant\ 2CH}$, %	−11.6 (−17.1 to −7)	−13.1 (−16.7 to −8.6)	0.83
	LA $PLS_{api–ant\ 2CH}$, %	−10.7 (−16.3 to −6.3)	−10.2 (−14.1 to −6.1)	0.12
	LA $PGLS_{2CH}$, %	−12.8 (4.7)	−12.4 (3.8)	0.53
	LA wall strain $dispersion_{2CH}$, ms	98.5 (45–182)	97 (63–164)	0.17
	LA $PLS_{bas–lat\ 4CH}$, %	−14.2 (−19 to −9.1)	−16.9 (−19.7 to −12.4)	0.26
	LA $PLS_{med–lat\ 4CH}$, %	−11.6 (−16.6 to −8.6)	−12.6 (−17.3 to −9.8)	0.8
	LA $PLS_{api–lat\ 4CH}$, %	−10.1 (−14.2 to −5.6)	−10.7 (−14.2 to −7)	0.92
	LA $PLS_{bas–sept\ 4CH}$, %	−14.1 (−18 to −10.6)	−16.8 (−19.9 to −14.5)	0.5
	LA $PLS_{med–sept\ 4CH}$, %	−14.7 (−18.1 to −9.9)	−15.6 (−19 to −11.8)	0.87
	LA $PLS_{api–sept\ 4CH}$, %	−11.6 (−16.3 to −7)	−12.4 (−17.9 to −7)	0.57
	LA $PGLS_{4CH}$, %	−12 (4.8)	−12.7 (4.3)	0.37
	LA wall strain $dispersion_{4CH}$, ms	101.5 (44–177)	97 (49–165.5)	0.35

Results are given as the mean with standard deviation (SD) for normal distributions or the median with interquartile range (IQR) for non-normal distributions

Abbreviations: api-ant, apical-anterior; api-inf, apical-inferior; api-lat, apical-lateral; api-sept, apical-septal; bas-ant, basal-anterior; bas-inf, basal-inferior; bas-lat, basal-lateral; bas-sept, basal-septal; empt frac, emptying fraction; LA, left atrium; PGLS, maximum left atrial peak global longitudinal strain; PLS, maximum left atrial peak longitudinal strain; max, maximal; min, minimal; med-ant, medial-anterior; med-inf, medial-inferior; med-lat, medial-basal; med-sept, medial-septal; RF, radiofrequency pulmonary vein isolation; preA, preatrial; PVI, pulmonary vein isolation with RF energy; TTE, transthoracic echocardiography; Vol, volume; 2CH, two-chamber view; 4CH, four-chamber view

study group. Patent foramen ovale was found in 23 patients (28.2%) while patients with LA appendage thrombus were excluded from the study.

Echocardiographic evaluation before the PVI procedure and after the follow-up period

The analyzed LA echocardiographic parameters are summarized in Table 2.

After the follow-up period, patients had statistically significantly higher mean LA $Vol_{conduit}$. Moreover, a trend towards the difference in the LA $Vol_{passive\ emptying}$ parameter was shown — after the PVI procedure, lower values were obtained as compared to the initial results ($P = 0.05$).

Additionally, in the study group, a difference in left ventricular end-systolic diameter (LV ESD) was demonstrated — lower LV ESD was observed before the PVI procedure compared to the results after the follow-up period (30 [28–33] vs. 32 [29–34]; $P = 0.02$). There were no statistically significant differences between LV ejection fraction (LVEF), other LV dimensions and volumes, as well as LV stroke volume initially and after the follow-up period.

LA echocardiographic parameters and the effectiveness of the PVI procedure

An analysis of the relationship between the pre- and post-PVI procedure echocardiographic parameters and the effectiveness of the procedure (patients with and without AF recurrence after the follow-up period) was performed (Tables 3 and 4).

Patients after successful PVI procedure were characterized by statistically significant higher initial segmental deformations: $LAPLS_{bas\text{-}inf\ 2CH}$ and $LAPLS_{api\text{-}sept\ 4CH}$, as well as a higher initial LA wall strain dispersion in time in the 2CH view (Table 3). The analysis performed after the follow-up period showed lower LA Vol_{min}, LA Vol_{max}, and $LAVI_{max}$, and higher LA EF and $LA_{expansion\ index}$ in patients who underwent successful PVI treatment (Table 4).

DISCUSSION

This article reports partial results of a single-center, non-randomized, prospective study of a population consisting of relatively young patients with a history of paroxysmal, symptomatic AF, without significant structural heart disease, and with a low score obtained in the CHA_2DS_2-VASc

Table 3. Initial LA echocardiographic parameters depending on the effectiveness of the PVI procedure

LA echocardiographic parameters before PVI procedure	Effective PVI (n = 43)	Ineffective PVI (n = 35)	*P*-value
$LA_{diameter,}$ mm	39.4 (4.4)	39.7 (4.1)	0.78
LA $Vol_{preA,}$ ml	51.6 (17.3)	58.2 (24.7)	0.26
LA $Vol_{min,}$ ml	33 (24–48)	40 (30–55)	0.18
LA $Vol_{max,}$ ml	70 (57–96)	82 (67–104)	0.36
$LAVI_{max,}$ ml/m^2	36.9 (9.8)	41.9 (13.6)	0.07
LA $Vol_{reservoir,}$ ml	40.6 (12.9)	39.9 (11.4)	0.83
LA $Vol_{conduit,}$ ml	28 (12–39)	22 (16–32)	0.37
LA $Vol_{passive\ emptying,}$ ml	24 (16–37)	21 (17–34)	1
LA $Vol_{contractile,}$ ml	14.9 (9.2)	14.7 (8.1)	0.95
LA EF, %	54 (47–60)	49 (40–60)	0.15
$LA_{expansion\ index}$	1.16 (0.9–1.5)	0.98 (0.8–1.3)	0.15
$LA_{active\ empt\ frac,}$ %	33 (17–40)	24 (20–40)	0.45
$LA_{passive\ empt\ frac,}$ %	33 (10)	31 (10)	0.6
LA $PLS_{bas-inf\ 2CH,}$ %	–19.4 (4.7)	–15.8 (6.2)	0.02
LA $PLS_{med-inf\ 2CH,}$ %	–15.6 (4.7)	–13 (5.6)	0.06
LA $PLS_{api-inf\ 2CH,}$ %	–10.5 (–14.6– 6.1)	–11.4 (–13.9 to –7)	0.8
LA $PLS_{bas-ant\ 2CH,}$ %	–14.6 (–19.4 to –10.6)	–15.3 (–19.5– 8)	0.8
LA $PLS_{med-ant\ 2CH,}$ %	–11.4 (–17.7 to –8.6)	–11.8 (–15.4 to –6.6)	0.75
LA $PLS_{api-ant\ 2CH,}$ %	–11.7 (7.9)	–11.2 (6)	0.76
LA $PGLS_{2CH,}$ %	–12.4 (5)	–11.8 (4.6)	0.59
LA wall strain $dispersion_{2CH,}$ ms	115 (50–200)	63 (38–147)	0.02
LA $PLS_{bas-lat\ 4CH,}$ %	–13.8 (–18.4 to –8.9)	–14.9 (–21.7 to –9.2)	0.62
LA $PLS_{med-lat\ 4CH,}$ %	–11.6 (–16 to –8.4)	–13.1 (–17 to –9.6)	0.62
LA $PLS_{api-lat\ 4CH,}$ %	–10.3 (–14 to –5.7)	–10.1 (–17.3 to –5.8)	0.78
LA $PLS_{bas-sept\ 4CH,}$ %	–15.5 (5.6)	–14 (6.6)	0.37
LA $PLS_{med-sept\ 4CH,}$ %	–15.9 (–17.9 to –12)	–11.1 (–18.6 to –7.7)	0.05
LA $PLS_{api-sept\ 4CH,}$ %	–13.4 (–16.3 to –9.6)	–8.6 (–13.3 to –6)	0.02
LA $PGLS_{4CH,}$ %	–12 (4.3)	–11 (5.4)	0.45
LA wall strain $dispersion_{4CH,}$ ms	86.5 (32.5–171)	133 (59–179)	0.34

Results are given as the mean with standard deviation (SD) for normal distributions or the median with interquartile range (IQR) for non-normal distributions

Abbreviations: see Table 2

classification who were qualified for their first PVI procedure with RF energy.

In the whole group, after the follow-up period, patients presented statistically significantly higher mean LA $Vol_{conduit}$. In the analysis of LA echocardiographic parameters after the follow-up period, patients with no AF recurrences had statistically significant lower LA volumes (minimal, maximal, and maximal indexed), higher LA ejection fraction and LA expansion index, when compared to the patients after ineffective PVI treatment. Patients who maintained sinus rhythm after the PVI procedure were characterized by statistically significant higher initial segmental strains: LA $PLS_{bas-inf}$ and $PLS_{api-sept}$, as well as higher LA wall strain dispersion in time in the 2CH projection.

In recent years, there has been a growing interest in the use of novel techniques for assessing function of heart chambers in clinical practice, in this case, LA strains. More and more information about the 2D LA PGLS can be found in the available literature [11, 17–19]. However, the assessment of deformation of individual LA segments may provide valuable information about the risk of arrhythmia, a detailed assessment of potential wall fibrosis/weakening that takes into account LA symmetric and asymmetric remodeling, an additional assessment of cardioembolic risk, or an evaluation of the effectiveness in a time of a sinus rhythm recovery procedures. In this study, in the analysis of the pre-procedural LA PLS, both global and segmental, two initial segmental strains that had a statistically significant impact on the effectiveness after the follow-up period were identified. The lower (better) values for pre-procedural LA $PLS_{bas-inf}$ assessed in the 2CH view and LA $PLS_{api-sept}$ in the 4CH view were associated with the maintenance of a sinus rhythm after follow-up. Moreover, statistical significance was obtained for the LA wall strain dispersion in time — initially, greater LA dyssynchrony was observed in patients in whom PVI treatment turned out to be effective in time. These results seem to be random.

PVI procedure is currently considered to be the most effective therapy to restore sinus rhythm in AF patients. In this study, patients who maintained sinus rhythm after a successful first-time PVI procedure were characterized by LA-positive remodeling. In the study group, after the follow-up period, a significant reduction in the LA volumes — minimum, maximum, and maximum indexed to BSA – was observed. These results are consistent with the published meta-analysis by Augustine Njoku et al. [12] of twenty-one studies (3822 subjects), where patients with AF recurrence after PVI treatment had a higher mean LA

Table 4. LA echocardiographic parameters after follow-up period depending on the effectiveness of the PVI procedure

LA echocardiographic parameters after follow–up period	Effective PVI (n = 43)	Ineffective PVI (n = 35)	*P*-value
LA Vol_{preA}, ml	47.5 (37–57)	55 (37–78)	0.27
LA Vol_{min}, ml	30 (25–43)	45 (27–61)	0.02
LA Vol_{max}, ml	72.6 (18.8)	84.1 (20.8)	0.02
$LAVI_{max}$, ml/m^2	34.5 (7)	41.4 (13)	<0.001
LA $Vol_{reservoir}$, ml	38 (33–46)	35.5 (28.5–41)	0.22
LA $Vol_{conduit}$, ml	29.9 (14.6)	31.3 (13.5)	0.7
LA $Vol_{passive\ emptying}$, ml	22.2 (9.8)	19.1 (6.4)	0.14
LA $Vol_{contractile}$, ml	16 (11–19)	14 (11–24)	0.97
LA EF, %	57 (49–60)	46 (38–56)	0.002
$LA_{expansion\ index}$	1.3 (0.4)	0.9 (0.45)	0.004
$LA_{active\ empt\ frac}$, %	30 (10)	30 (10)	0.4
$LA_{passive\ empt\ frac}$, %	30 (13)	30 (10)	0.14
$LA_{passive\ empt\ frac}$, %	33 (10)	31 (10)	0.6
LA $PLS_{bas–inf\ 2CH}$, %	−19.7 (−23.5 to −12.5)	−19.4 (−21.8 to −15.5)	0.84
LA $PLS_{med–inf\ 2CH}$, %	−15.6 (−18.4 to −11.5)	−14.1 (−17.5 to −11.2)	0.62
LA $PLS_{api–inf\ 2CH}$, %	−10.1 (−12.5 to −4.8)	−9.7 (−12.7 to −7.9)	0.47
LA $PLS_{bas–ant\ 2CH}$, %	−15.6 (−20.1 to −11.1)	−12.9 (−18.4 to −9.6)	0.41
LA $PLS_{med–ant\ 2CH}$, %	−13.6 (5.3)	−12.1 (5.6)	0.3
LA $PLS_{api–ant\ 2CH}$, %	−11 (−13.3 to −7.2)	−9.1 (−15.5 to −6)	0.94
LA $PGLS_{2CH}$, %	−12.2 (3.5)	−12.1 (4)	0.3
LA wall strain $dispersion_{2CH}$, ms	100 (56–154)	89 (67–198)	0.76
LA $PLS_{bas–lat\ 4CH}$, %	−17.2 (−19.7 to −11.5)	−16.4 (−19.7 to −13.7)	0.36
LA $PLS_{med–lat\ 4CH}$, %	−12.4 (−19.7 to −9.8)	−13.2 (−16.9 to −8.6)	0.87
LA $PLS_{api–lat\ 4CH}$, %	−10.3 (−16.6 to −6.8)	−11.5 (−12.9 to −7.1)	0.85
LA $PLS_{bas–sept\ 4CH}$, %	−16.3 (−19.1 to −13.6)	−18 (−21.4 to −15.6)	0.07
LA $PLS_{med–sept\ 4CH}$, %	−15.3 (−18 to −10.8)	−16.1 (−20 to −12)	0.29
$PLS_{api–sept\ 4CH}$, %	−12.8 (−17.7 to −7.4)	−12.3 (−18.2 to −6.2)	0.75
LA $PGLS_{4CH}$, %	−12.6 (4.6)	−13.6 (4.8)	0.4
LA wall strain $dispersion_{4CH}$, ms	105 (70–167)	87 (32–164)	0.38

Results are given as the mean with standard deviation (SD) for normal distributions or the median with interquartile range (IQR) for non-normal distributions

Abbreviations: see Table 2

volume/LA volume indexed to BSA when compared to patients without AF recurrence.

On the other hand, in our study no statistically significant difference in the $LAVI_{max}$ was found, assessed in the whole group before and after PVI treatment, without taking into account the effectiveness of the procedure. That parameter is commonly considered to be prognostic for AF recurrences [12]. However, in the available literature, there is a cut-off point of $LAVI_{max}$ <34.4 ml/m^2 that is associated with the best AF ablation outcome [20, 21], while Shin et al. [22] found that $LAVI_{max}$ of 34 ml/m^2 showed sensitivity of 70% and specificity of 91% in predicting AF recurrence. In the current study patients in whom PVI proved to be effective in the follow-up period had a lower mean value of the $LAVI_{max}$ parameter when compared to the patients with AF recurrences – assessed before the PVI procedure (the mean [SD] 36.9 [9.8] ml vs. 41.9 [13.6] ml; trend towards statistical significance — *P*=0.07) and after the PVI procedure (34.5 [7] ml vs. 41.4 [13] ml; *P* <0.001).

At the same time, in patients without post-PVI AF recurrence, an improvement in LA function measured by an increase in $LA_{expansion\ index}$ and thus higher LA EF were observed. A lower median of LA $Vol_{passive\ emptying}$ after PVI (trend towards significance) was also noted, compared to the results obtained before the procedure. This demonstrates positive LA remodeling in these patients, which, in turn, may favor the continued maintenance of sinus rhythm in the future. It is puzzling that there is no coincident improvement in LA function as measured by the evaluation of LA global and segmental strains and LA wall strain synchrony. It should be noted, however, that the study population included selected, relatively young patients with an initially non-sustained form of atrial arrhythmia, not burdened with significant cardiovascular diseases. Perhaps they did not have significant LA dysfunction at baseline, and the lack of statistical variability in the post-procedural evaluation should be treated as a success, together with the absence of complications related to the procedure itself, e.g. narrowing of the pulmonary veins or complications following a transseptal puncture.

There are several studies indicating that LA strain has a higher predictive value than LA size obtained in conventional echocardiography [13, 23]. Data published so far, strongly suggest that the longitudinal 2D strains of LA may be useful in predicting AF recurrence after PVI procedures [11, 17, 23–26]. 2D STE analysis enables detection of decreased LA reservoir function in patients with paroxysmal AF even before changes in LA volume are detected [14], which may be potentially associated with greater sensitivity of the method in detecting and predicting AF recurrence. Mirza et al. [23] showed that regardless of LA enlargement, pre-procedural strain of the LA lateral wall can be considered an independent determinant of AF recurrence after PVI. However, the effectiveness of the treatment was assessed 18 months after the procedure, using TomTec software, which differs significantly from the methodology presented in the current study. On the other hand, in the work of Hammerstingl et al. [13], independent predictors of AF recurrence after the PVI procedure were global LA strains obtained in the 2CH and 4CH views and regional LA septal wall strain. Those researchers also used TomTec software to analyze STE in 76 patients with paroxysmal and 27 patients with persistent AF, as well as in a 30-person control group. Similarly, as in our study, the effectiveness of the PVI procedure was assessed after a minimum of 6 months of follow-up.

Recently, there has been an increase in data on new cardiac visualization techniques assessing LA volumes and strains using 3D techniques. What is more, it turns out that these techniques are potentially more accurate in patients with AF and surpass the 2D visualizations widely used so far [27–29]. For example, in a group of 348 patients with symptomatic paroxysmal or persistent AF, Montserrat et al. [30] showed that none of the echocardiographic parameters considered, including LAVI, was associated with AF recurrence after the PVI procedure. Only volumetric assessment of LA with 3D rotational angiography showed in a multivariate analysis that LAVI is the only independent predictor for AF recurrence. Measuring LA volume with this method may be superior to transthoracic echocardiography (TTE) assessment and AF history in predicting arrhythmia recurrence after PVI. There are also reports showing that LA strain determined by 3D STE is a novel and better predictor of AF recurrence after PVI than LA strain determined by 2D STE or other known predictors [27]. These new 3D techniques were not evaluated in the present study, and though less common in routine echocardiographic assessment, they may help to assess more accurately LA morphology and function.

One should certainly bear in mind that there is no single parameter to clearly define the possibility of arrhythmia recurrence after PVI. Echocardiographic assessment should be complex, using various available imaging techniques and potentially useful parameters to assess the morphology and function of the heart chambers, which may help improve prediction of the success of rhythm-control strategy in AF [31].

Limitations

The analyzed group was relatively small, and the statistical power of this study is limited. The conclusions should be used in relation to the population of relatively young patients with a history of paroxysmal, symptomatic AF, without significant structural heart disease, and with a low score obtained in the CHA_2DS_2-Vasc classification who underwent their first-time PVI procedure with RF energy. A larger study population could influence other relationships, especially in the case of parameters where only a trend toward statistical significance was achieved. On the other hand, the size of the group in the presented study did not differ significantly from other studies on related topics. An additional study limitation is associated with the absence of a control group. At the time of the study, no software was available to evaluate LA strains, and there were no guidelines for evaluating LA strains in patients during AF. Additionally, a significant limitation of the presented work is the lack of LV deformation analysis, all the more so since the LV EF change significantly influenced the effectiveness of the PVI procedure.

We are aware of data gaps. Around 20% of the first described population was not included in some of the analyses, which reduces the size of the analyzed population. We showed population numbers that are slightly different from the general population numbers because in each major test missing data were eliminated casewise.

CONCLUSIONS

Some echocardiographic parameters related to LA morphology improve after successful PVI treatment, which may be associated with positive LA remodeling. LA strains and wall strain dispersion in time are not related to LA remodeling after a successful PVI procedure.

The baseline, standard and novel, LA echocardiographic parameters cannot be used for remote evaluation of the effectiveness of the PVI procedure. Further research is needed in this area, especially taking into account the limitations of our study.

Article information

Conflict of interest: None declared.

Funding: None.

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