Paper:
Margulescu, A., Rees, E., Coulson, R., Rees, A., Vinereanu, D. & Fraser, A. (2015). Do left atrial strain and strain rate reflect intrinsic atrial function, or are they determined by left ventricular function?. *Kardiologia Polska*, 539-548.
http://dx.doi.org/10.5603/KP.a2015.0035

Kardiologia Polska 2015; 73, 7: 539–548; DOI: 10.5603/KP.a2015.0035 ISSN 0022–9032

ARTYKUŁ ORYGINALNY / *ORIGINAL ARTICLE*

Do left atrial strain and strain rate reflect intrinsic atrial function, or are they determined by left ventricular function?

Andrei Dumitru Margulescu[1], Emma Rees[2], Rose-Marie Coulson[3], Aled D. Rees[3], Dragos Vinereanu[1], Alan G. Fraser[4]

[1]Department of Cardiology, University and Emergency Hospital of Bucharest, University of Medicine and Pharmacy "Carol Davila", Bucharest, Romania

[2]College of Human and Health Sciences, Swansea University, Singleton Park, Swansea, United Kingdom

[3]Institute of Molecular and Experimental Medicine, School of Medicine, Cardiff University, Heath Park, United Kingdom

[4]Wales Heart Research Institute, School of Medicine, Cardiff University, Heath Park, United Kingdom

Abstract

Background: Left atrial (LA) strain (S) and strain rate (SR) are reported as measures of intrinsic function.

Aim: Since the LA and left ventricle (LV) are connected through the mitral annulus, we investigated: (1) if deformation indices in the LA are mostly predicted by deformation of the LV; (2) if timings of S and SR events are similar in both the LA and LV; and (3) if alteration of S and SR in patients with primarily LV dysfunction would be similar in the LA and LV.

Methods: We retrospectively assessed 50 asymptomatic women (Group 1) and 20 patients with recent (< 96 h) acute pulmonary oedema (10 women) (Group 2). Using speckle tracking, the amplitude and timings of S and SR were averaged from three apical views, for one cardiac cycle, starting from the P-wave.

Results: In Group 1, all deformation indices were higher in the LA compared with the LV ($p < 0.001$ for all). In Group 2, S and SR during LA contraction were higher in the LA vs. LV ($p < 0.05$ for both), but all other deformation indices were not different in the LA vs. LV. All timings of S and SR occurred simultaneously in LA and LV in both groups, except S during LA contraction in Group 1, which occurred slightly earlier in LA than in LV. By multiple regression analysis, the most important predictors of LA deformation indices were the corresponding LV deformation indices, especially in patients with LV dysfunction (Group 1: $r = 0.35–0.52$; Group 2: $r = 0.76–0.85$; $p < 0.05$ by Fisher r-to-z transform).

Conclusions: LA deformation strongly reflects LV deformation both in asymptomatic subjects and in patients with LV dysfunction. With the possible exception of LA contraction in asymptomatic individuals, discriminating intrinsic LA function from LV influence is difficult using deformation analysis.

Key words: left atrial function, echocardiography, strain, strain rate, speckle tracking

Kardiol Pol 2015; 73, 7: 539–548

INTRODUCTION

Left atrial (LA) function is commonly considered during three phases — pump function (when the LA contracts actively after the P wave and boosts left ventricular [LV] end-diastolic filling), reservoir function (when the LA fills and expands during LV systole while the mitral valve is closed), and conduit function (when the LA empties passively during early diastole and diastasis, while the mitral valve is open). Interest in diagnosing regional and global function of the LA during these different phases has increased since the introduction of myocardial velocity imaging and more recently, speckle tracking echocardiography (STE).

Detailed invasive physiological studies have shown that LA contractile function is determined by intrinsic LA contrac-

Address for correspondence:
Andrei Dumitru Margulescu, MD, Department of Cardiology, University and Emergency Hospital of Bucharest, University of Medicine and Pharmacy "Carol Davila", Spl. Independentei 169, Sector 5, Bucharest, 050098, Romania, e-mail: andrei_marg@yahoo.com

Received: 25.10.2014 **Accepted:** 19.01.2015 **Available as AoP:** 23.02.2015

tility, LV compliance, LV filling pressures (LA afterload), and pulmonary vascular capacitance [1]. LA reservoir function is influenced primarily by LV contraction, which affects the ascent of the mitral annulus, and to a lesser degree by LA myocardial relaxation and stiffness [2]. In the absence of mitral stenosis, LA conduit function mostly reflects LV relaxation but is also influenced by preload [3].

The LA and LV share the common mitral annulus, which in health functions like a piston while the total volume and length of the heart remain almost constant throughout the cardiac cycle [4]. Thus LA and LV longitudinal function are closely inter-related, and changes in LA and LV volumes are nearly identical but opposite [1]. It is reasonable to conceive that LA and LV longitudinal deformation indices (strain [S] and strain rate [SR]) will also mirror each other, but many investigators have used STE to identify changes in LA longitudinal S and SR in different cardiac diseases. Since their results often reflect known alterations of LV longitudinal S and SR in these conditions, concerns have been raised that echocardiography, and STE in particular, may be unable to discriminate intrinsic LA function from the influence of LV systolic and diastolic properties [1, 3], and that it provides no added information compared to LV longitudinal systolic deformation parameters and LA volumes [5].

Thus, the aims of this study were to determine: (1) if deformation indices in the LA are mostly predicted by deformation in the LV — both in subjects without overt cardiac disease and in subjects with LV dysfunction; (2) if timings of S and SR events are similar in both LA and LV; and (3) if alteration of longitudinal deformation parameters in patients with LV dysfunction are similar in the LA and the LV.

METHODS

Patients

The study design was a retrospective analysis of echocardiographic images recorded in 50 asymptomatic women without overt cardiac disease (Group 1) and 20 patients with a recent history (< 96 h after admission) of acute hypertensive pulmonary oedema (Group 2). These opportunistic samples were selected to test the hypothesis that variations in LA deformation would be largely explained by variations in LV function, respectively, in subjects with normal or very mild heart disease and in subjects with abnormal LV function; the groups were not matched. Group 1 was recruited for a study of cardiovascular function in polycystic ovary syndrome (23 normal subjects; 27 with polycystic ovary syndrome). The protocol was approved by the South East Wales Research Ethics Committee, and all subjects gave written informed consent [6]. Group 2 was recruited from a study of cardiac adaptation in acute hypertensive pulmonary oedema. The study was approved by the institutional ethics committee of the University and Emergency Hospital of Bucharest, and all patients provided written informed consent [7]. Subjects were included in this analysis if they were in sinus rhythm and had excellent-quality grey-scale echocardiographic images acquired at 50 to 80 frames per second.

Echocardiography

All echocardiographic studies included in this analysis were performed using a Vivid 7 Dimension or Vivid I machine (GE Healthcare, Wisconsin, USA) equipped with a 2.5–4 MHz phased-array transducer. At least three cardiac cycles were recorded and stored digitally for later off-line analysis using Echopac software (Version BT 11.0). All measurements were performed by a single experienced operator (A.D.M.) blinded to all clinical data.

Baseline echocardiographic data

Systolic and diastolic blood pressure and heart rate were measured during the echocardiographic examination.

LV filling pattern was estimated using pulsed-wave Doppler of mitral flow (measuring peak early velocity [E]; peak atrial velocity [A]; and E-wave deceleration time [EDT]); colour M-mode of the LV inflow (measuring the flow propagation velocity [Vp]); and pulsed-wave tissue Doppler of the mitral annulus (measuring the mean velocity of the mitral annular motion in the longitudinal axis during early diastolic filling [E′], as the average of lateral and medial mitral annulus).

LV systolic function was estimated by the LV ejection fraction (EF) (by Simpson biplane method) and LV stroke work [8]. Systemic arterial elastance (Ea) was also estimated by the ratio between systolic blood pressure and LV stroke volume [9].

Definition of phases of cardiac cycle

For the purpose of this study, the cardiac cycle was divided into three phases using the following electrical and mechanical events:

- LA contraction phase: from the onset of the P wave on the electrocardiogram to the mitral valve closure (MVC);
- LV systole/contraction: from MVC to aortic valve closure (AVC). This corresponds to LA reservoir function;
- LV early diastolic relaxation and diastasis: from AVC to the next P wave onset. This corresponds to LA conduit function.

Two-dimensional (2D) strain and strain rate

We analysed 2D grey-scale images acquired from three standard apical windows (apical four chamber, apical two chamber, and apical long axis views) as previously described [10, 11]. In each patient, the three apical grey-scale images were acquired sequentially, at similar heart rates, sector width, and frame rates per second. We selected for analysis the cardiac cycle showing the best endocardial definition of both LA and LV. LA and LV speckle tracking was performed by manually tracking the endocardial border of the respective chamber. The width of the region of interest was adjusted such that, as far

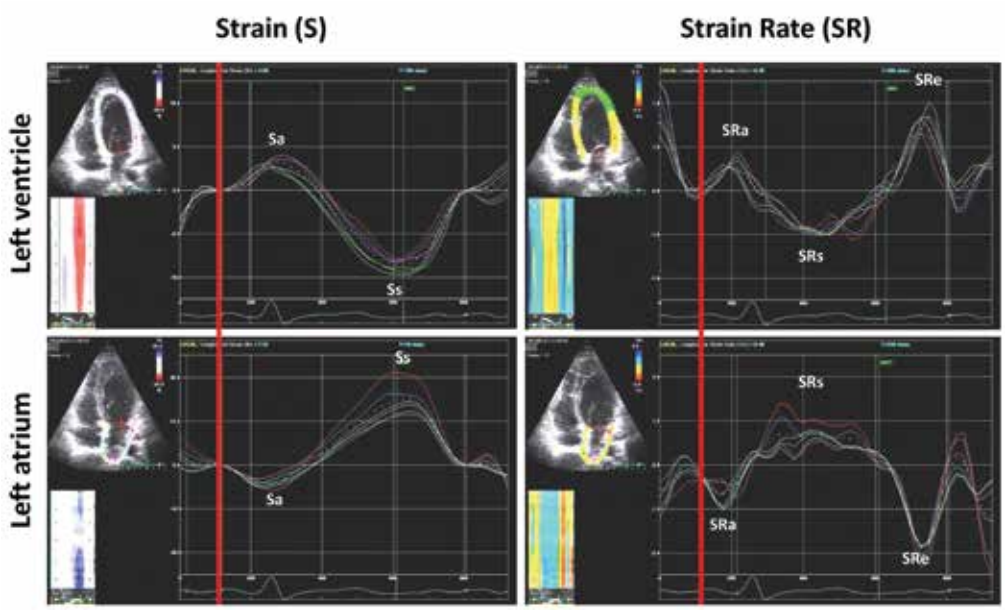

Figure 1. Example of measurement of left atrium (lower panels) and left ventricle (upper panels) strain (left) and strain rate (right) by two-dimensional speckle tracking echocardiography from apical four-chamber view in a normal subject. Similar acquisitions were performed from apical two-chamber view and apical long-axis view — see text for details. In all panels, the vertical red line marks the P wave onset; abbreviations as in Table 2.

as possible, the whole myocardium was included without extracardiac structures or pericardium. The automated speckle tracking was subsequently performed, inspected, adjusted, and approved as necessary.

Using the same cardiac cycle and gain settings, with the P-wave onset as reference, we measured peak amplitude and timings of:

— S and SR during LA contraction (S_a, SR_a, respectively);
— S and SR during LV contraction (S_s, SR_s, respectively);
— SR during LV early diastolic relaxation (SR_e).

These parameters were measured in each of 13 LA segments (three segments — annular, mid, basal — for each of the following LA walls: septal; inferior, posterior; two segments — annular and basal for the lateral and anterior LA walls; the LA roof — adjacent to the spine, and LA anterior septal wall — adjacent to the aortic root, were excluded from the analysis), and in 15 LV segments (three segments: annular, mid, apical — for each of the following LV walls: posterior septum, inferior, posterior, lateral and anterior; the anterior septal LV wall — corresponding to LA septal anterior wall, was excluded from the analysis) and then averaged for each chamber, giving the mean longitudinal S and SR parameter (Fig. 1).

Annular displacement, longitudinal chamber dimensions

We used two apical windows (apical four chamber and apical two chamber) to assess the length of the LA and the LV and their variation during the cardiac cycle. The following parameters were measured:

— total heart length at P wave onset: from endocardial LV apex to LA roof;
— LV length at P wave onset: from endocardial LV apex to mitral annulus plane;
— maximum displacement of mitral annulus plane towards LA roof during ventricular diastole, from onset of P wave to peak displacement;
— maximum displacement of mitral annulus plane towards LV apex during LV systole from P wave onset to peak displacement.

The percentages of longitudinal change of chamber length during LA contraction (ΔCL_a) and LV contraction (ΔCL_s) were also calculated in both the LA and the LV, using the formula:

— LA ΔCL_a (%) = [(LA length at P-wave onset – maximal displacement of mitral annulus during LA contraction) / / LA length at P-wave onset] × 100;
— LA ΔCL_s (%) = [(LA length at P-wave onset + maximal displacement of mitral annulus during LV contraction) / / LA length at P-wave onset] × 100;
— LV ΔCL_a (%) = [(LV length at P-wave onset + maximal displacement of mitral annulus during LA contraction) / / LV length at P-wave onset] × 100;
— LV ΔCL_s (%) = [(LV length at P-wave onset – maximal displacement of mitral annulus during LV contraction) / / LV length at P-wave onset] × 100

LA and LV volumes at P wave onset, end-diastolic and end-systolic volumes were measured using the Simpson biplane method (from apical four chamber and apical two chamber views).

Statistical analysis

Statistical analysis was performed with SPSS software (version 14.0, Chicago, Illinois) and Graphpad InStat software (version 3.0, La Jolla, California). Results are presented as mean value ± standard deviation. Paired-samples t test was used for comparison of means when values were normally distributed, and Wilcoxon signed-rank test was used for skewed distributions.

Correlations between independent variables are reported using the Pearson correlation coefficient. Multiple stepwise regression analysis was used to identify predictors of LA S/SR. Independent variables included in the regression models were the corresponding LV S/SR value in relation to the atrial event (e.g. LV S_a as a predictor for LA S_a, etc.), the LA and LV volumes during the respective phase of the cardiac cycle (e.g. LA and LV volumes at P wave onset, and LA and LV end-diastolic volume as predictors for LA S_a/SR_a, etc.), indices of LV systolic (stroke work, EF) and diastolic (E, A, EDT, Vp) function, and arterial elastance. Differences between two correlation coefficients were analysed using the Fisher r-to-z transformation.

A $p \leq 0.05$ for a two-tailed test was considered significant.

Intra-observer reproducibility of S and SR measurements was assessed by repeating measurements in five subjects from Group 1 and five subjects from Group 2, randomly selected. Reproducibility is expressed as the coefficient of variation (CV). The CV was calculated using the formula: CV = SD / / (arithmetic mean of measurements) × 100, where SD is the standard deviation of the measurement error associated with a single measurement, calculated as the SD of residuals (measurement 1 – measurement 2) divided by √2.

RESULTS

The general characteristics of patients in Group 1 and 2 are given in Table 1.

In Group 1, peak S_a occurred slightly earlier in the LA compared with the LV ($p = 0.018$); however, all other events occurred at the same time in both chambers (p = NS). Also in Group 1, all deformation indices had higher absolute values when measured in the LA compared with the LV ($p < 0.001$ for all) (Table 2). In Group 2, all events occurred simultaneously in the LA and LV. In Group 2, S_a and SR_a were higher in the LA compared with the LV ($p < 0.05$ for both), but all other deformation indices were not different in LA and LV (p = NS) (Table 2).

Table 1. General characteristics of the study groups

	Group 1	Group 2
Men	0 (0%)	10 (50%)
Known diabetes	0 (0%)	2 (10%)
Prior myocardial infarction	0 (0%)	8 (40%)
Chronic renal failure	0 (0%)	3 (15%)
Arterial hypertension	1 (2%)	20 (100%)
Body mass index	29.0 ± 6.6	26.5 ± 3.6
Systolic blood pressure [mm Hg]	112.1 ± 10.4	136.2 ± 23.5
Diastolic blood pressure [mm Hg]	65.9 ± 8.0	79.9 ± 13.5
Mean blood pressure [mm Hg]	79.4 ± 7.5	103.1 ± 15.6
Heart rate [bpm]	70.5 ± 10.6	79.1 ± 17.7

In both groups, peak S correlated with chamber length change (ΔCL) during the respective cardiac cycle: LA S_a with LA ΔCL_a (in Group 1: $r = 0.39$, $p = 0.006$; in Group 2: $r = 0.71$, $p < 0.001$); LA S_s with LA ΔCL_s (in Group 1: $r = 0.63$, $p < 0.001$; in Group 2: $r = 0.74$, $p = 0.002$); LV S_a with LV ΔCL_a (in Group 1: $r = 0.73$, $p < 0.001$; in Group 2: $r = 0.83$, $p < 0.001$); LV S_s with LV ΔCL_s (in Group 1: $r = 0.50$, $p < 0.001$; in Group 2: $r = 0.78$, $p < 0.001$).

The independent parameters that correlated with LA S and SR in both groups are shown in Tables 3 and 4, respectively. Multiple stepwise regression analysis revealed that in both groups the single most important predictor of LA S and SR was the corresponding LV S and SR value; surrogate measurements of loading were also found to be predictors of several LA S and SR parameters on multiple stepwise regression analysis. The correlation of LA S_a, S_s, SR_a, and SR_s on the corresponding LV deformation parameter was higher in Group 2 compared with Group 1 (p: 0.024, 0.033, < 0.001, 0.022, respectively; Fisher r-to-z transform). In Group 2, LA SR_e was not predicted by the corresponding LV SR_e, probably because of the poor reproducibility of SR_e in this study group. Echocardiographic parameters of LV systolic function (stroke work, EF) were not found to be independent predictors of LA S and SR.

Intra-observer reproducibility of S and SR parameters was generally good in Group 1 but generally only moderate in Group 2 (Table 5).

DISCUSSION

In this study, we showed that: 1) the most important predictors of LA S and SR events are the corresponding LV S and SR events, both in asymptomatic subjects and — possibly to a greater extent — in patients with LV dysfunction; 2) all timings of S and SR occurred simultaneously in LA and LV in both groups (except S during LA contraction in Group 1, which occurred slightly earlier in LA than in LV); and 3) in patients with LV dysfunction, reductions of S and SR are equally reflected both in the LV and the LA when the LA is the passive chamber (during LV contraction — corresponding to LA 'reservoir' function, and LV early diastolic filling — corresponding to LA 'conduit' function). These results are important, because they suggest that: 1) intrinsic LA reservoir and conduit function (i.e. relaxation and stiffness of the chamber) assessed by STE-derived deformation indices (S and SR) are difficult to separate from the influence of corresponding LV longitudinal deformation indices, regardless of whether the

Table 2. Echocardiographic characteristics of the study groups

	Group 1	Group 2	P
Conventional and Doppler-derived echocardiography parameters			
Indexed LA maximal volume [mL/m^2]	33.3 ± 9.4	48.1 ± 16.3	< 0.001
LV EDV [mL]	122.6 ± 24.4	132.1 ± 56.5	0.35
E wave [cm/s]	79.3 ± 20.5	63.6 ± 21.9	0.006
A wave [cm/s]	43.7 ± 10.5	74.5 ± 26.7	< 0.001
E/A ratio	1.9 ± 0.5	1.1 ± 0.9	< 0.001
E wave deceleration time [ms]	201.1 ± 36.1	208.2 ± 73.1	0.59
Vp [cm/s]	49.4 ± 13.5	29.8 ± 7.6	< 0.001
E/Vp ratio	1.7 ± 0.5	2.1 ± 0.7	0.007
E' [cm/s]	13.9 ± 2.3	4.8 ± 1.4	< 0.001
E/E' ratio	5.9 ± 1.8	14.5 ± 6.7	< 0.001
LV EF [%]	53.1 ± 9.3	39.8 ± 16.5	< 0.001
Stroke work [cJ]	70.1 ± 16.7	73.8 ± 23.0	0.45
Arterial elastance [mm Hg/s]	1.7 ± 0.3	2.8 ± 1.1	< 0.001
Strain and strain rate parameters			
LA S_a [%]	9.8 ± 2.3	10.6 ± 4.0	0.28
LV S_a [%]	5.8 ± 1.6	8.2 ± 3.4	< 0.001
LA S_s]%]	19.6 ± 5.3	8.2 ± 4.4	< 0.001
LV S_s [%]	13.6 ± 2.4	7.4 ± 4.2	< 0.001
LA SR_a [1/s]	1.49 ± 0.90	1.45 ± 0.64	0.83
LV SR_a [1/s]	0.63 ± 0.15	0.86 ± 0.33	< 0.001
LA SR_e [1/s]	1.69 ± 0.50	0.92 ± 0.37	< 0.001
LV SR_e [1/s]	1.29 ± 0.28	0.90 ± 0.50	< 0.001
LA SR_s [1/s]	1.41 ± 0.32	1.11 ± 0.50	0.004
LV SR_s [1/s]	1.03 ± 0.17	0.91 ± 0.41	0.09
Timing of strain and strain rate parameters			
LA time to S_a [ms]	170 ± 20	188 ± 45	0.026
LV time to S_a [ms]	179 ± 19	193 ± 44	0.06
LA time to S_s [ms]	558 ± 46	554 ± 91	0.83
LV time to S_s [ms]	546 ± 39	579 ± 136	0.13
LA time to SR_a [ms]	110 ± 15	115 ± 42	0.45
LV time to SR_a [ms]	114 ± 15	115 ± 30	0.82
LA time to SR_e [ms]	673 ± 46	651 ± 111	0.26
LV time to SR_e [ms]	667 ± 43	644 ± 126	0.27
LA time to SR_s [ms]	325 ± 51	353 ± 101	0.13
LV time to SR_s [ms]	339 ± 31	342 ± 99	0.84
Longitudinal chamber dimensions and percentages of chamber length change			
LA length [cm]	4.0 ± 0.5	5.1 ± 0.8	< 0.001
LV length [cm]	8.6 ± 0.5	8.0 ± 1.1	0.017
LA ΔCL_a [%]	–10.6 ± 2.4	–8.7 ± 4.0	0.057
LV ΔCL_a [%]	4.9 ± 1.3	5.4 ± 2.2	0.37
LA ΔCL_s [%]	21.3 ± 3.1	8.2 ± 3.8	< 0.001
LV ΔCL_s [%]	–12.5 ± 1.6	–5.6 ± 2.5	< 0.001

LV is normal or affected by disease; and 2) LA booster function may be characterised by LA S/SR measurements, but this may only apply to asymptomatic subjects and not patients with LV dysfunction.

LA mechanics; the role of near constant-volume, constant-length relationship of cardiac chambers

Previous studies have demonstrated that LA function during its relaxation (i.e. reservoir and conduit phases) is determined primarily by LV systolic and early relaxation function, respectively. Vice-versa, the influence of LA contraction on LV end-diastolic properties has also been proven: the LV pressure-volume relationship during diastasis is better suited to describe LV diastolic properties (i.e. stiffness) than the classical end-diastolic pressure volume relationship (when the LA contraction shifts the force equilibrium established during diastasis) [12]. This interdependence is not surprising, since the LV and LA share the mitral annulus; moreover, the combined LA and LV volumes change < 5% during a cardiac cycle, and the combined longitudinal LA and LV dimensions remain constant throughout the cardiac cycle [4]. Therefore, changes in longitudinal dimensions and volume in one chamber are mirrored by similar changes in the opposite chamber. It follows that longitudinal strain (the ratio between the variation of longitudinal dimension to the initial dimension) in each chamber should reflect changes in the opposite chamber, and that strain curves in both chambers would closely follow the curves of longitudinal mitral annular displacement and volume changes in the respective chambers [13]. Similarly, it would also be expected that pathological processes that are associated with changes of LV S and SR, would also generate similar changes of LA S and SR. Therefore, some authors have expressed concerns regarding the ability of echocardiography (and STE in particular) to evaluate intrinsic LA function, i.e. to discriminate it from the influence of LV systolic and diastolic properties, especially when the LA is the passive chamber [1, 3].

LA strain and strain rate in pathological processes

Many recent studies have described LA longitudinal S and SR alterations, including during reservoir and conduit phases, associated with sporting activities, cardiovascular risk factors, and cardiac pathology. In athletes, supranormal LA 'function' has been documented [14]. Subjects with cardiovascular risk factors [15], ageing [16], hypertension [17, 18], and diabetes [19] have been shown to have reduced LA S and SR when compared with normal controls. Other studies suggested that LA S and SR have diagnostic and prognostic value in patients

S_a — peak strain during left atrial contraction; S_s — peak strain during left ventricular contraction; SR_a — peak strain rate during left atrial contraction; SR_s — peak strain rate during left ventricular contraction; SR_e — peak strain rate during left ventricular early relaxation; CL — chamber lenght; EF — ejection fraction; EDV — end-diastolic volume; ESV — end-systolic volume; LA — left atrium; LV — left ventricle; Vp — flow propagation velocity

Table 3. Group 1: univariate correlations and multiple stepwise regression analyses for left atrial strain (S) and strain rate (SR)

Dependent variable	Independent variable	Correlation		Multiple stepwise regression analysis		
		R (Pearson)	P	Beta	R^2	P
S_a LA	S_a LV	0.347	0.013	0.347	0.121	0.013
S_s LA	S_s LV	0.541	< 0.001	0.477	0.436	0.001
	LA EDV	–0.513	< 0.001	–0.384		
	LA ESV	–0.515	< 0.001	–	–	–
SR_a LA	SR_a LV	0.288	0.043	0.288	0.083	0.043
SR_e LA	SR_e LV	0.52	< 0.001	0.399	0.434	0.001
	LA EDV	–0.537	< 0.001	–0.422		
	LA ESV	–0.356	0.011	–	–	–
SR_s LA	SR_s LV	0.52	< 0.001	0.429	0.433	0.001
	LA EDV	–0.508	< 0.001	–0.413		
	LA ESV	–0.307	0.03	–	–	–
	LV EDV	–0.342	0.015	–	–	–
	LV ESV	–0.339	0.016	–	–	–

Abbreviations as in Table 2.

Table 4. Group 2: univariate correlations and multiple stepwise regression analyses for left atrial strain (S) and strain rate (SR)

Dependent variable	Independent variable	Correlation		Multiple stepwise regression analysis		
		R (Pearson)	P	Beta	R^2	P
S_a LA	S_a LV	0.762	< 0.001	0.618	0.694	< 0.001
	LA EDV	–0.626	0.003	–0.408		
	LA volume at P wave onset	–0.489	0.029	–	–	–
	E/E'	0.522	0.018	–	–	–
S_s LA	S_s LV	0.836	< 0.001	0.836	0.683	< 0.001
	LV ESV	–0.512	0.021	–	–	–
	LV EDV	–0.468	0.038	–	–	–
	LV EF	0.555	0.011	–	–	–
SR_a LA	SR_a LV	0.851	<0.001	0.730	0.758	< 0.001
	E/E'	–0.598	0.005	–0.271		
	LA EDV	–0.609	0.004	–	–	–
	LA volume at P wave onset	–0.503	0.024	–	–	–
SR_e LA	SR_e LV	0.375	0.10	–	–	–
SR_s LA	SR_s LV	0.841	<0.001	0.721	0.777	< 0.001
	LA EDV	–0.593	0.006	–0.328		
	LA ESV	–0.545	0.013	–	–	–
	LA volume at P wave onset	–0.619	0.004	–	–	–
	LV volume at P wave onset	–0.452	0.045	–	–	–
	LV EF	0.483	0.033	–	–	–

Abbreviations as in Table 2.

with overt cardiac disease, ranging from ischaemic heart disease to atrial fibrillation, cardiomyopathies (hypertrophic, dilated), valvular heart disease, and congenital heart disease [20–26]. However, these results mirror the already known alterations of STE-derived LV S and SR in athletes, subclinical disease, and overt cardiac pathology [27, 28]. Moreover, when LV S and SR parameters were assessed together with LA function in the same study, the LA S/SR parameters cor-

Table 5. Intra-observer reproducibility for left atrial and left ventricular strain and strain rate, expressed as coefficients of variation (CV).

CV [%]	Group 1		Group 2	
	Left atrium	Left ventricle	Left atrium	Left ventricle
S_a	11.8	7.2	17.2	11.7
S_s	9.7	6.5	21.1	19.4
SR_s	11.7	9.9	14.3	17.7
SR_e	10.2	8.8	22.6	27.6
SR_a	10.2	5.0	17.6	21.7
Time to S_a	8.6	8.3	15.4	18.8
Time to S_s	3.3	1.7	7.8	4.9
Time to SR_s	11.7	5.9	17.5	15.9
Time to SR_e	1.4	1.2	9.3	6.2
Time to SR_a	3.5	3.1	14.5	11.4

Abbreviations as in Table 2.

related closely and mirrored LV S/SR changes [15, 18, 21], or alterations of LV function [23].

In our study we showed that in asymptomatic subjects up to 30% of the variability of LA S and SR during systole and early diastole can be accounted for by LV S and SR variability, while this interdependence was as high as 72% in heart failure patients. We also found that in patients with LV dysfunction (Group 2) reduction of S and SR is equally reflected in the LV and the LA, when the LA is the passive chamber. Moreover, virtually all timings of S and SR indices (except for S during LA contraction in asymptomatic subjects) occurred simultaneously in both LA and LV, regardless of the group studied. Thus, our results suggest that the finding of decreased LA S and SR parameters in different cardiac pathologies can be explained by similar changes in LV S and SR and not necessarily by alterations of intrinsic LA compliance and chamber stiffness. Our results are in keeping with a recent study performed in 843 patients with acute myocardial infarction in which peak longitudinal LA S was not associated with outcome, after adjustment for LV longitudinal S and LA volume. These authors concluded that "peak atrial longitudinal strain provides a composite measure of LV longitudinal systolic function and maximum LA volume before mitral valve opening, and as such contains no added information when these readily obtained measures are known" [5]. Similarly, in hypertensive patients, Miyoshi et al. [18] showed that STE-derived LA S and SR parameters are mainly associated with alteration in LV systolic and diastolic parameters.

The possible exception may be the evaluation of LA contraction by LA S and SR. In asymptomatic subjects, we have shown that the correlation of LA S and SR during LA contraction with corresponding LV S and SR is marginally less than for systole and early diastole, probably because of the differences of the impact of LV chamber stiffness and chamber pressures on the LA systolic function vs. LV late diastolic function. In addition, also in asymptomatic subjects, LA S during LA contraction occurs slightly earlier when compared with LV S, which is also explainable by the normal compliance of the chamber in (near) normal hearts. In heart failure patients, we have shown that LA S and SR is higher than LV S and SR and that the E/E' ratio (a surrogate measurement of LV end-diastolic filing pressure, which represents LA afterload) is an independent predictor of LA SR during LA contraction. This is in keeping with previous studies that showed that LA S and SR during LA contraction may be increased in hypertension, as a compensatory mechanism for LV diastolic dysfunction [17].

Other potential limitations of STE-derived longitudinal LA deformation

Current speckle tracking algorithms are usually unable to limit the region of interest that can be selected for STE such as to include only the LA myocardium, because of the poor lateral resolution of far-field echo signals, which is in the range of the LA wall thickness (i.e. 2–3 mm) [29]. Therefore, with the current technology, tracking only the LA myocardium is not feasible and extracardiac structures are also included in the analysis. Also, determination of LA S and SR as indices of intrinsic LA function does not take into account the fact that the pulmonary veins provide stiff, immobile anchoring points to the LA, and it entirely excludes the LA appendage from the analysis.

Limitations of the study

The stored echocardiographic images did not allow us to assess the impact of the differences in chamber geometry between the LA and the LV, the impact of the anchoring points provided by the pulmonary veins on the deformation of the LA, and the impact of the non-inclusion of the LA appendage on the results, in particular on the regression analysis. However, these limitations are inherent to all current 2D speckle tracking echocardiographic protocols.

We did not assess if the influence of LV deformation on LA deformation indices would also be strong in patients with primarily LA dysfunction (e.g. "stiff LA") [30] because of the difficulty in making such a diagnosis non-invasively. In addition, we did not use techniques for quantitative assessment of LA fibrosis (such as cardiac magnetic resonance imaging) as an independent predictor of LA S/SR [31]. Future studies should assess this issue.

The lack of predictive value of other indices of LV systolic (stroke work, EF) and diastolic (E, A, EDT, E/E', Vp) function on LA S and SR may be explained by the poor correlation of these indices with invasive measures of LV contractility [32], relaxation, and filling pressures [33], respectively.

Our study included a limited number of patients in Group 2. Thus, interpretation of the results reported for this group should be cautious and the study should be replicated

in larger groups. Also, our study included mostly women, but there are no reasons to suspect that the findings of our study would be different in men compared with women.

The results reported in our study for mean LV S_s in Group 1 are artificially low compared with the "normal" values reported in a recent meta-analysis (13.6% vs. 19.7%) because we measured peak S parameters starting with the P wave (which gives biphasic strain curves), not starting with the R wave (which gives monophasic strain curves); adding LV S_a to LV S_s in our study would correct this apparent difference [34].

CONCLUSIONS

Left atrial deformation strongly reflects LV deformation both in asymptomatic subjects and in patients with LV dysfunction. With the possible exception of LA contraction in asymptomatic individuals, discriminating intrinsic LA function from LV influence is difficult using deformation analysis.

Conflict of interest: *none declared*

References

1. Appleton CP, Kovács SJ. The role of left atrial function in diastolic heart failure. Circ Cardiovasc Imag, 2009; 2: 6–9. doi: 10.1161/CIRCIMAGING.108.845503.
2. Barbier P, Solomon SB, Schiller NB et al. Left atrial relaxation and left ventricular systolic function determine left atrial reservoir function. Circulation, 1999; 100: 427–436.
3. Bowman AW, Kovács SJ. The left atrial conduit volume is generated by deviation from the constant-volume state of the left heart: a combined MRI-echocardiographic study. Am J Physiol Heart Circ Physiol, 2004; 286: H2416–H2424. doi: 10.1152/ajpheart.00969.2003
4. Waters EA, Bowman AW, Kovács SJ. MRI determined left ventricular "crescent effect": a consequence of the slight deviation of the contents of the pericardial sack from the constant-volume state. Am J Physiol Heart Circ Physiol, 2005; 288: H848–H853. doi: 10.1152/ajpheart.00744.2004
5. Ersbøll M, Andersen MJ, Valeur N et al. The prognostic value of left atrial peak reservoir strain in acute myocardial infarction is dependent on left ventricular longitudinal function and left atrial size. Circ Cardiovasc Imag, 2013; 6: 26–33. doi: 10.1161/CIRCIMAGING.112.978296.
6. Rees E, Coulson R, Dunstan F et al. Central arterial stiffness and diastolic dysfunction are associated with insulin resistance and abdominal obesity in young women but polycystic ovary syndrome does not confer additional risk. Hum Reprod, 2014; 29: 2041–2049. doi: 10.1093/humrep/deu180.
7. Mărgulescu AD, Rimbaş RC, Florescu M et al. Cardiac adaptation in acute hypertensive pulmonary edema. Am J Cardiol, 2012; 109: 1472–1481. doi: 10.1016/j.amjcard.2012.01.359.
8. Schramm W. The units of measurement of the ventricular stroke work: a review study. J Clin Monit Comput, 2010; 24: 213–217. doi: 10.1007/s10877-010-9234-4.
9. Kelly RP, Ting CT, Yang TM et al. Effective arterial elastance as index of arterial vascular load in humans. Circulation, 1992; 86: 513–521.
10. Saraiva RM, Demirkol S, Buakhamsri A et al. Left atrial strain measured by two-dimensional speckle tracking represents a new tool to evaluate left atrial function. J Am Soc Echocardiogr, 2010; 23: 172–180. doi: 10.1016/j.echo.2009.11.003.
11. Vianna-Pinton R, Moreno CA, Baxter CM et al. Two-dimensional speckle-tracking echocardiography of the left atrium: feasibility and regional contraction and relaxation differences in normal subjects. J Am Soc Echocardiogr, 2009; 22: 299–305. doi: 10.1016/j.echo.2008.12.017.
12. Zhang W, Kovács SJ. The diastatic pressure-volume relationship is not the same as the end-diastolic pressure-volume relationship. Am J Physiol Heart Circ Physiol, 2008; 294: H2750–H2760. doi: 10.1152/ajpheart.00200.2008.
13. To AC, Flamm SD, Marwick TH et al. Clinical utility of multimodality LA imaging. Assessment of size, function, and structure. J Am Coll Cardiol Cardiovasc Imag, 2011; 4: 788–798. doi: 10.1016/j.jcmg.2011.02.018.
14. D'Ascenzi F, Cameli M, Zacà V et al. Supernormal diastolic function and role of left atrial myocardial deformation analysis by 2D speckle tracking echocardiography in elite soccer players. Echocardiography, 2011; 28: 320–326. doi: 10.1111/j.1540-8175.2010.01338.x.
15. Miyoshi H, Mizuguchi Y, Oishi Y et al. Early detection of abnormal left atrial-left ventricular-arterial coupling in preclinical patients with cardiovascular risk factors: evaluation by two-dimensional speckle-tracking echocardiography. Eur J Echocardiogr, 2011; 12: 431–439. doi: 10.1093/ejechocard/jer052.
16. Sun JP, Yang Y, Guo R et al. Left atrial regional phasic strain, strain rate and velocity by speckle-tracking echocardiography: normal values and effects of aging in a large group of normal subjects. Int J Cardiol, 2013; 168: 3473–3479. doi: 10.1016/j.ijcard.2013.04.167.
17. Baltabaeva A, Marciniak M, Bijnens B et al. How to detect early left atrial remodelling and dysfunction in mild-to-moderate hypertension. J Hypertens, 2009; 27: 2086–2093. doi: 10.1097/HJH.0b013e32832f4f3d.
18. Miyoshi H, Oishi Y, Mizuguchi Y et al. Early predictors of alterations in left atrial structure and function related to left ventricular dysfunction in asymptomatic patients with hypertension. J Am Soc Hypertens, 2013; 7: 206–215. doi: 10.1016/j.jash.2013.02.001.
19. Mondillo S, Cameli M, Caputo ML et al. Early detection of left atrial strain abnormalities by speckle-tracking in hypertensive and diabetic patients with normal left atrial size. J Am Soc Echocardiogr, 2011; 24: 898–908. doi: 10.1016/j.echo.2011.04.014.
20. Antoni ML, ten Brinke EA, Atary JZ et al. Left atrial strain is related to adverse events in patients after acute myocardial infarction treated with primary percutaneous coronary intervention. Heart, 2011; 97: 1332–1337. doi: 10.1136/hrt.2011.227678.
21. Donal E, Ollivier R, Veillard D et al. Left atrial function assessed by trans-thoracic echocardiography in patients treated by ablation for a lone paroxysmal atrial fibrillation. Eur J Echocardiogr, 2010; 11: 845–852. doi: 10.1093/ejechocard/jeq074.
22. Rosca M, Popescu BA, Beladan CC et al. Left atrial sysfunction as a correlate of heart failure symptoms in hypertrophic cardiomyopathy. J Am Soc Echocardiogr, 2010; 23: 1090–1098. doi: 10.1016/j.echo.2010.07.016.
23. Barbosa MM, Rocha MO, Botoni FA et al. Is atrial function in Chagas dilated cardiomyopathy more impaired than in idiopathic dilated cardiomyopathy? Eur J Echocardiogr, 2011; 12: 643–647. doi: 10.1093/ejechocard/jer096.
24. Motoki H, Borowski AG, Shrestha K et al. Impact of left ventricular diastolic function on left atrial mechanics in systolic heart failure. Am J Cardiol, 2013; 112: 821–826. doi: 10.1016/j.amjcard.2013.05.007.
25. Spethmann S, Baldenhofer G, Dreger H et al. Recovery of left ventricular and left atrial mechanics in various entities of aortic stenosis 12 months after TAVI. Eur Heart J Cardiovasc Imag, 2014; 15: 389–398. doi: 10.1093/ehjci/jet166.

26. Riesenkampff E, Mengelkamp L, Mueller M et al. Integrated analysis of atrioventricular interactions in tetralogy of Fallot. Am J Physiol Heart Circ Physiol, 2010; 299: H364–H371. doi: 10.1152/ajpheart.00264.2010.
27. Nakai H, Takeuchi M, Nishikage T et al. Subclinical left ventricular dysfunction in asymptomatic diabetic patients assessed by two-dimensional speckle tracking echocardiography: correlation with diabetic duration. Eur J Echocardiogr, 2009; 10: 926–932. doi: 10.1093/ejechocard/jep097.
28. Florescu M, Stoicescu C, Magda S et al. "Supranormal" cardiac function in athletes related to better arterial and endothelial function. Echocardiography, 2010; 27: 659–667. doi: 10.1111/j.1540-8175.2009.01121.x.
29. Clare GC, Margulescu AD, Leong FT. Stiff left atrial syndrome following left atrial appendage resection and multiple ablations for atrial fibrillation. Heart, 2013; 99: 508. doi: 10.1136/heartjnl-2012-303171.
30. Ho SY, Cabrera JA, Sanchez-Quintana D. Left atrial anatomy revisited. Circ Arrhythm Electrophysiol, 2012; 5: 220–228. doi: 10.1161/CIRCEP.111.962720.
31. Kuppahally SS, Akoum N, Burgon NS et al. Left atrial strain and strain rate in patients with paroxysmal and persistent atrial fibrillation: relationship to left atrial structural remodeling detected by delayed-enhancement MRI. Circ Cardiovasc Imag, 2010; 3: 231–239. doi: 10.1161/CIRCIMAGING.109.865683.
32. Uriel N, Torre-Amione G, Milo O et al. Echocardiographic ejection fraction in patients with acute heart failure: correlations with hemodynamic, clinical, and neurohormonal measures and short-term outcome. Eur J Heart Fail, 2005; 7: 815– 819. doi: 10.1016/j.ejheart.2004.10.013
33. Ommen SR, Nishimura RA, Appleton CP et al. Clinical utility of Doppler echocardiography and tissue Doppler imaging in the estimation of left ventricular filling pressures: a comparative simultaneous Doppler-catheterization study. Circulation, 2000; 102: 1788–1794.
34. Yingchoncharoen T, Agarwal S, Popović ZB et al. Normal ranges of left ventricular strain: a meta-analysis. J Am Soc Echocardiogr, 2013; 26: 185–191. doi: 10.1016/j.echo.2012.10.008.

Czy odkształcenie i prędkość odkształcenia lewego przedsionka odzwierciedlają wewnętrzną czynność serca, czy są zależne od czynności lewej komory?

Andrei Dumitru Margulescu[1], Emma Rees[2], Rose-Marie Coulson[3], Aled D. Rees[3], Dragos Vinereanu[1], Alan G. Fraser[4]

[1]Department of Cardiology, University and Emergency Hospital of Bucharest, University of Medicine and Pharmacy "Carol Davila", Bucharest, Rumunia

[2]College of Human and Health Sciences, Swansea University, Singleton Park, Swansea, Wielka Brytania

[3]Institute of Molecular and Experimental Medicine, School of Medicine, Cardiff University, Heath Park, Wielka Brytania

[4]Wales Heart Research Institute, School of Medicine, Cardiff University, Heath Park, Wielka Brytania

Streszczenie

Wstęp: Odkształcenie (S, *strain*) lewego przedsionka (LA) i prędkość odkształcenia (SR, *strain rate*) są opisywane jako miary wewnętrznej czynności serca.

Cel: Ze względu na fakt, że LA i lewa kamora (LV) łączą się poprzez pierścień mitralny zbadano: (1) czy wskaźniki LA można najlepiej prognozować na podstawie odkształcenia LV; (2) czy zdarzenia S i SR występują w podobnym czasie w przypadku LA i LV; (3) czy zmiany S i SR u chorych z dominującą dysfunkcją LV będą podobne w przypadku LA i LV.

Metody: W badaniu retrospektywnie oceniono 50 kobiet bez objawów (Grupa 1) i 20 chorych, u których w ostatnim czasie (< 96 h) wystąpił ostry obrzęk płuc (10 kobiet) (Grupa 2). Stosując metodę śledzenia markerów akustycznych, określono średnie wartości amplitudy i czasu dla S i SR z trzech projekcji koniuszkowych jednego cyklu serca, zaczynając od załamka P.

Wyniki: W Grupie 1 wszystkie wskaźniki odkształcenia LA były wyższe niż wskaźniki odkształcenia LV (dla wszystkich porównań $p < 0,001$). W Grupie 2 wartości S i SR podczas skurczu LA były wyższe dla LA niż LV (w obu przypadkach $p < 0,05$), lecz wszystkie inne wskaźniki odkształceń nie różniły się między LA a LV. Zdarzenia S i SR przebiegały symultanicznie w LA i LV w obu grupach, oprócz S w czasie skurczu LA w Grupie 1, które wystąpiło nieco wcześniej w LA niż w LV. W analizie wielozmiennowej najważniejszymi czynnikami predykcyjnymi wskaźników odkształcenia LA były odpowiednie wskaźniki odkształcenia LV, zwłaszcza u chorych z dysfunkcją LV (Grupa 1: $r = 0,35–0,52$; Grupa 2: $r = 0,76–0,85$; $p < 0,05$ w transformacji Fishera z wartości r do z).

Wnioski: Odkształcenie LA w znacznym stopniu odpowiada odkształceniom LV zarówno u osób bez objawów, jak i u chorych z dysfunkcją LV. Trudno oddzielić wewnętrzną czynność LA od wpływu LV na podstawie analizy odkształceń mięśnia sercowego; wyjątek może stanowić skurcz LA u pacjentów bez objawów.

Słowa kluczowe: czynność lewego przedsionka, echokardiografia, odkształcenie, prędkość odkształcenia, śledzenie markerów akustycznych

Kardiol Pol 2015; 73, 7: 539–548

Adres do korespondencji:
Andrei Dumitru Margulescu, MD, Department of Cardiology, University and Emergency Hospital of Bucharest, University of Medicine and Pharmacy "Carol Davila", Spl. Independentei 169, Sector 5, Bucharest, 050098, Romania, e-mail: andrei_marg@yahoo.com
Praca wpłynęła: 25.10.2014 r. **Zaakceptowana do druku:** 19.01.2015 r. **Data publikacji AoP:** 23.02.2015 r.