Strain rate imaging for functional quantification of the left atrium: atrial deformation predicts the maintenance of sinus rhythm after catheter ablation of atrial fibrillation

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Aims
The aim of the study was to investigate the atrial myocardial deformation properties using ultrasound strain rate (SR) imaging in patients after catheter ablation of atrial fibrillation (AF) and to compare its prognostic value in maintaining sinus rhythm.

Methods and results
A total of 118 patients with AF (74 paroxysmal AF, 44 persistent AF) underwent transthoracic echocardiography with Doppler-derived SR examinations before and after ablation as well as during 3 months of follow-up (FU). Peak SR and strain (S) were measured at each left atrium (LA) segment (septal, lateral, anterior, inferior) during systole (LAs) and at early (LAe) and late diastole (LAa). Clinical and echocardiographic parameters of patients with maintained sinus rhythm during FU were compared with those with recurrent AF and controls (n = 25 patients). Of 118 patients 82 (69%) showed stable sinus rhythm during FU. Atrial myocardial properties after catheter ablation differed significantly in patients with paroxysmal AF (SR-LAs 2.5 s⁻¹, S-LAs 30%, SR-LAa 2.2 s⁻¹) from patients with persistent AF (SR-LAs 2.3 s⁻¹, S-LAs 25%, SR-LAa 1.9 s⁻¹) and controls (SR-LAs 4.1 s⁻¹, S-LAs 88%, SR-LAa 2.9 s⁻¹) (P = 0.011). Best individual predictors of sinus rhythm maintenance were cut-off values of >2.25 s⁻¹ for septal and inferior SR-LAs and of >19.5% for inferior S-LAs (P < 0.001). LA deformation properties increased in patients with maintained sinus rhythm during FU in contrast to patients with recurrent AF (P = 0.001).

Conclusion
SR imaging enables the quantitative assessment of the LA function and can be considered as a potential marker of atrial reverse remodelling. Patients with higher atrial S and SR after catheter ablation appear to have a greater likelihood of maintenance of sinus rhythm. This may have further implications for the anticoagulation regime and the risk of cardioembolic complications.

Keywords
Strain rate imaging • Left atrial function • Atrial fibrillation • Catheter ablation

Introduction
Atrial fibrillation (AF) is the most common cardiac arrhythmia.1,2 It increases cardiovascular morbidity, especially embolic stroke and mortality.1,2 Catheter ablation, eliminating the initiating foci of AF, has been demonstrated to be an effective and potentially curative treatment in patients with paroxysmal and persistent AF. Structural and functional changes in the left atrial myocardium contribute to local impairment of electrical conduction and to AF recurrences.3,4 Ultrasound strain rate (SR) imaging allows the non-invasive functional quantification of the LA function analysing the deformation properties independent of cardiac rotational motion and the tethering effect.5–7 The purpose of this study was to assess Doppler-derived S and SR parameters in patients with AF before and after catheter ablation therapy and to compare their prognostic value regarding the maintenance of sinus rhythm during follow-up (FU).
Methods

Patient population

Of a total of 2500 patients undergoing ablation of AF (03/2003 to 10/2006) 118 patients (86 males, 60 ± 9 years) were included in the observational study. These patients were selected using the following major criteria: main FU period 2006; complete datasets of baseline and FU data; and first catheter ablation procedure during the above-mentioned observation period. The patients were investigated by transthoracic echocardiography 1 day before and within 24 h after catheter ablation and after 3 months of FU. Pre-ablation treatment included digitals (8%), ß-blocker (42%), amiodarone (37%), class 1 anti-arrhythmics (38%) and sotalol (24%). Patients with paroxysmal AF were more often treated with class 1 anti-arrhythmics and more rarely with digitals in comparison with patients with persistent AF. After ablation the medication including the anti-arrhythmic drug regime was unchanged up to 3 months of FU. All patients received anticoagulant therapy. Exclusion criteria were valvular stenosis or significant valvular insufficiency, valvular prosthesis, known severe coronary artery disease or significantly decreased left ventricular (LV) function (ejection fraction ≤50%).

At baseline before catheter ablation, patients with persistent AF (n = 44; defined as sustained AF between 7 days and 1 year) were differentiated from patients with paroxysmal AF (n = 74; spontaneous AF termination within 7 days). Patients were divided into two groups: (1) maintenance of sinus rhythm and (2) AF recurrence over a 3-month FU period (Figure 1). In addition, 25 persons without cardiovascular disease were selected as controls (58 ± 13 years, 18 men). These persons were referred from the department of neurology (n = 20) or recruited from healthy staff (n = 5) of the hospital and were investigated by transthoracic echocardiography for a comparative LA S and SR analysis. These 25 patients of the control group were selected on the basis of the known properties and characteristics of the study group. The aim was to create a comparable control group with similar characteristics regarding sex and age to the study group. The echocardiographic studies were performed by two experienced cardiologists who had no knowledge of the FU results.

Echocardiographic study

Each patient had a complete two-dimensional echocardiography study using a commercially available ultrasound scanner (Vivid 7, General Electric Medical Health) with a 2.5-MHz phased-array transducer. Standard echocardiographic views, including apical four- and two-chamber views, with the patient in the left lateral decubitus position, were obtained in two-dimensional and colour tissue Doppler imaging modes.

Mitral inflow velocities were recorded by standard pulsed-wave Doppler at the tips of the mitral valve leaflets in an apical four-chamber view. LA volumes were calculated from apical four- and two-chamber views, with the patient in the left lateral decubitus position, were obtained in two-dimensional and colour tissue Doppler imaging modes. Pulmonary venous flow velocities were measured from the apical four-chamber view by sampling the right upper pulmonary vein (PV).
and placing a sample volume of 1 cm into the PV. Pulsed-wave Doppler signals were obtained at a sweep speed of 100 mm/s. In addition, average septal and lateral peak mitral annular velocities (TVI VAan) were measured at late diastole.

**Left atrial strain rate data processing and analysis**

Three cine loops from apical four- and two-chamber views were digitized and stored on a magnetic optical disc for further offline analysis using a commercial software (Echopac version PC; General Electric Medical Health). The mean frame rate was 133 ± 25 frames/s (range 105–155) depending on the sector width. The image angle was adjusted to ensure that the sampling window was aligned parallel to the myocardial wall of interest. The pulse repetition frequency was 1000 Hz, resulting in an aliasing velocity of 16 cm/s. For analysis of the LA Doppler-derived SR data, a 6 × 6 mm² region of interest was positioned on each mid-segment of the LA wall in four- and two-chamber views and was manually tracked frame by frame to maintain its position within the LA wall (Figure 2). Peak SR and strain (S) were measured at each mid-LA segment (septal, lateral, anterior, inferior) during ventricular systole (LAs) and at early (LAe) and late diastole (LAa). The different cardiac phases of systole and of early and late diastole were discriminated by use of the transmitral Doppler profile of the aortic and the mitral valve. Myocardial atrial S determines regional lengthening expressed as a positive value or shortening expressed as a negative value.

**Catheter ablation procedure and follow-up**

Details of the electrophysiological study and radiofrequency catheter ablation have been reported previously.10 PV isolation was performed using a ‘double Lasso’ approach encircling and isolating the ipsilateral PVs by a long circular radiofrequency lesion in the LA antrum. After the catheter ablation procedure all patients were monitored by 24 h Holter recording until discharge as well as during 1 and 3 months of FU. Depending on the heart rhythm within the 3-month FU, patients were classified into the groups of maintained sinus rhythm (group 1) or recurrent AF (group 2). At each examination, a standard 12-lead ECG, a 24 h Holter recording and a TTE were performed, and an inquiry was made about any recurrence of palpitations.

**Statistical analysis**

Exploratory data analysis was performed and no adjustment was made for multiple tests. Two-tailed P-values were calculated and if <0.05 they were considered to be significant findings. Continuous data were expressed as mean values ± standard deviation or as median and percentile 25 and 75.

Comparisons between two groups were performed with the Mann–Whitney U-test and pairwise comparisons with the paired
Wilcoxon test. Changes in echocardiographic parameters during FU were analysed with the Friedman test. For categorical data 2 × 2 cross-tabulations and Fisher’s exact test were calculated. Area under the receiver operating characteristic (ROC) curve and univariate logistic regression analysis were used to describe the prognostic value of SR parameters for the prediction of sinus rhythm maintenance after catheter ablation. Sensitivity, specificity, and positive and negative predictive values were calculated. Optimal cut-off values were determined by the analysis of the sensitivity and specificity values derived from the ROC curve data. Bootstrapping was performed for the assessment of the reproducibility and the correctness of the ROC analysis. In addition, Spearman’s rho was determined for selected echocardiographic parameters (age, LA size, ejection fraction) correlated with SR data of controls and patients with AF.

For interobserver variability, Bland–Altman plots and 95% limits of the intraobserver variability, more than 4 weeks elapsed between the two readings. The standard deviation of differences (s) was calculated and a repeatability coefficient for 95% of patients (2.77s) presented. For the assessment of intraobserver variability, 11 randomly chosen patients were analysed by the same investigator twice. For the analysis of inter- and intraobserver variability the patients were randomly selected as representative samples (about 15 and 10%, respectively) from the main patient group. For the assessment of the intraobserver variability, more than 4 weeks elapsed between the two readings. The standard deviation of differences (s) was calculated and a repeatability coefficient for 95% of patients (2.77s) presented. Statistics were performed using SPSS for Windows 11.5.2.1., SPSS Inc., 1989–2002.

Results

Clinical characteristics and echocardiographic findings

The general characteristics and echocardiographic parameters of the studied patients are summarized in Table 1. Of a total of 118 included patients, 74 had paroxysmal and 44 persistent AF before

<table>
<thead>
<tr>
<th>Table I</th>
<th>Demographic and echocardiographic characteristics at the inclusion of atrial fibrillation (AF) patients and controls</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Controls (n = 25)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>58 ± 13</td>
</tr>
<tr>
<td>Male sex (%)</td>
<td>72</td>
</tr>
<tr>
<td>BSA (m²)</td>
<td>131 ± 9</td>
</tr>
<tr>
<td>Systolic blood pressure (mmHg)</td>
<td>80 ± 7</td>
</tr>
<tr>
<td>Diastolic blood pressure (mmHg)</td>
<td>66 ± 10⁠⁻ᵃᵇ</td>
</tr>
<tr>
<td>HR (b.p.m.)</td>
<td>9.6 ± 1.0⁠⁻ᵃᵇ</td>
</tr>
<tr>
<td>PW end diastole (mm)</td>
<td>9.6 ± 0.7⁠⁻ᵃᵇ</td>
</tr>
<tr>
<td>LV end diastole (mm)</td>
<td>50 ± 3</td>
</tr>
<tr>
<td>LV end systole (mm)</td>
<td>29 ± 3⁠⁻ᵇ</td>
</tr>
<tr>
<td>LV ejection fraction (%)</td>
<td>68 ± 5 ⁠⁻ᵇ</td>
</tr>
<tr>
<td>LA diameter (mm)</td>
<td>39 ± 4⁠⁻ᵇ</td>
</tr>
<tr>
<td>LAEF (%)</td>
<td>49 ± 5⁠⁻ᵇ</td>
</tr>
<tr>
<td>Mitral peak E wave (cm/s)</td>
<td>76 ± 22⁠⁻ᵇ</td>
</tr>
<tr>
<td>Mitral peak A wave (cm/s)</td>
<td>66 ± 16⁠⁻ᵇ</td>
</tr>
<tr>
<td>TVI LA Vₐₓ (cm/s)</td>
<td>–9.5 (⁠⁻¹₂, –7.5)ᵇ</td>
</tr>
<tr>
<td>Deceleration time of E (ms)</td>
<td>192 ± 24</td>
</tr>
<tr>
<td>Pulmonary vein S (cm/s)</td>
<td>55 ± 17⁠⁻ᵇ</td>
</tr>
<tr>
<td>Pulmonary vein E (cm/s)</td>
<td>48 ± 12⁠⁻ᵇ</td>
</tr>
<tr>
<td>Pulmonary vein A (cm/s)</td>
<td>31 ± 4</td>
</tr>
<tr>
<td>Mean strain LAs (%)</td>
<td>88 ± 23⁠⁻ᵇ</td>
</tr>
<tr>
<td>Mean strain LAc (%)</td>
<td>22 ± 6⁠⁻ᵇ</td>
</tr>
<tr>
<td>Mean strain LAs (%)</td>
<td>7.5 (⁠₆₃₉,₉)ᵇ</td>
</tr>
<tr>
<td>Mean strain rate LAs (s⁻¹)</td>
<td>4.₁ ± 0.₈ᵇ</td>
</tr>
<tr>
<td>Mean strain rate LAc (s⁻¹)</td>
<td>–3.₆ ± 0.₆⁠⁻ᵇ</td>
</tr>
<tr>
<td>Mean strain rate LAc (s⁻¹)</td>
<td>–2.₉ (⁠⁻₃.₃, –₂.₆)ᵇ</td>
</tr>
</tbody>
</table>

BSA indicates body surface area; HR, heart rate; LA, left atrium; LAEF, left atrial ejection fraction; TVI LA Vₐₓ, mean of TVI annulus medial and lateral. Pulmonary vein S, E, and A indicate systolic, early and late diastolic values. Mean LA strain and strain rate values were measured during ventricular systole (LAs) and at early (LAc) and late diastole (LAc). Significance (marked if P < 0.05): ¹paroxymal AF patients vs. controls, ²persistent AF patients vs. controls.
Figure 3 Segmental myocardial strain rate data of the left atrium in controls and in patients with paroxysmal and persistent atrial fibrillation within 24 h after catheter ablation measured during ventricular systole (Sys), early (VE) and late diastole (VA). Green boxplots represent strain rate data of the septal atrial wall, yellow boxplots represent data of the lateral wall, red boxplots represent data of the anterior wall and blue boxplots represent data of the inferior atrial wall. The bold line shows the median value. Values more than three box-lengths from 25/75th percentile (extremes) were marked by an asterisk, values more than 1.5 box-lengths (outliers) by an open circle.
Figure 4 Segmental left atrial myocardial strain rate data differentiated in patients with paroxysmal and persistent atrial fibrillation (AF) dependent on heart rhythm during 3 months of follow-up (sinus rhythm vs. recurrent AF) obtained the day after catheter ablation. Parox-Sinus rh indicates patients with paroxysmal AF before ablation and sinus rhythm during follow-up (FU), Per-Sinus rh indicates patients with persistent AF before ablation and sinus rhythm during FU, Parox-AFib indicates patients with paroxysmal AF before ablation and recurrent AF during FU, Per-AFib indicates patients with persistent AF before ablation and recurrent AF during FU. The bold line shows the median value. Values more than three box-lengths from 25/75th percentile (extremes) were marked by an asterisk, values more than 1.5 box-lengths (outliers) by an open circle. Sys, VE and VA indicate measurements at ventricular systole and at early and late diastole.
catheter ablation. At the time of inclusion, 81% of the patients with paroxysmal AF showed sinus rhythm (Figure 1). Patients with persistent AF had significantly larger LA dimensions than patients with paroxysmal AF and controls ($P < 0.001$). In addition, typical parameters of atrial function such as the transmitral late diastolic velocity, LAEF and peak systolic venous flow were significantly higher in controls than in the AF group at baseline. Peak systolic and diastolic myocardial atrial SR and S values were significantly reduced in AF patients compared with controls ($P = 0.001$).

Significantly larger percentages of both paroxysmal and persistent AF patients than controls were taking calcium antagonists (60 and 25%, respectively), sodium channel blocker antagonists (50 and 25%, respectively), ß-blockers (50 and 35%, respectively), and angiotensin-converting enzyme inhibitors (50 and 25%, respectively). There were no differences in gender, age, body surface area and LV dimensions among the three groups.

**Comparison of Doppler-derived strain rate data in controls and atrial fibrillation patients right after catheter ablation**

In all patients sinus rhythm was noted right after catheter ablation procedure. In the controls, mean SR-LAs and SR-LAa did not correlate with age and LA dimension. In the patients with AF SR-LAa correlated slightly with LA dimension ($r = -0.302$, $P = 0.001$). Mean SR-LAs correlated slightly inversely with mean SR-LAe ($r = -0.274$, $P = 0.003$) and mean SR-LAa ($r = -0.356$, $P = 0.0001$). With the exception of SR-LAe significant differences were noted between the deformation properties of LA segments of patients with paroxysmal and persistent AF and controls ($P < 0.05$) (Figure 3). Patients with paroxysmal AF showed higher systolic S values ($P = 0.008$) and lower SR values in the late diastole ($P = 0.01$) septal and inferior than patients with persistent AF. Lateral and anterior systolic S and SR were significantly lower than basal and septal ($P < 0.05$).

**Comparison between patients with maintained strain rate and recurrent atrial fibrillation during follow-up**

Of the 118 patients followed up for a 3-month period after catheter ablation, a total of 82 patients (69%) remained in sinus rhythm. Of those a total of 52 (63%) had initially paroxysmal and 30 (37%) persistent AF. There were no significant differences of clinical and standard echocardiographic data between the two groups of maintained sinus rhythm and recurrent AF. However, peak systolic atrial S and SR as well as early and end-diastolic atrial SR were

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**Figure 5** Representative left atrial (LA) myocardial velocity, strain rate and strain curves in a patient with paroxysmal atrial fibrillation (AF) and maintained sinus rhythm during follow-up (A, at the top) and in a patient with paroxysmal AF and recurrent AF (B, at the bottom) within 24 h after catheter ablation; the sample volume was placed in the mid-segment of the LA septal wall. AVC indicates aortic valve closure.
Figure 6  Time course of echocardiographic parameters (median) after catheter ablation in patients with maintained sinus rhythm during follow-up (FU) and patients with recurrent atrial fibrillation. Strain rate data of the left atrium (LA) were measured at ventricular systole, early and late diastole. The asterisks mark significant within-group comparisons. Between-group analysis revealed significant differences of all presented parameters with the exception of early diastolic strain rate.
significantly lower in the recurrent AF group ($P < 0.001$) (Figures 4 and 5). LV myocardial SR data were also not able to differentiate patients with recurrent AF from patients with remaining sinus rhythm (data not shown).

Three months after catheter ablation of AF, patients with maintained sinus rhythm showed significantly higher peak systolic atrial $S$ and end-diastolic atrial SR values than patients with recurrent AF (Figure 6). While an increase of LAa $S$ values and a reduction of the LA diameter were noted in patients with maintained sinus rhythm, patients with recurrent AF showed significantly lower SR data and increased LA diameter during FU. The between-group analysis revealed significant differences in all presented parameters (Figure 6) with the exception of mean SR-LAe.

**Prediction of sinus rhythm during follow-up on the basis of echocardiographic data after catheter ablation procedure**

In univariate logistic regression analysis, the best predictors of sinus rhythm maintenance were atrial septal systolic SR ($P < 0.0001$) and atrial inferior systolic $S$ ($P < 0.0001$). For predicting sinus rhythm
Table 2  

<table>
<thead>
<tr>
<th></th>
<th>Area bootstrapping</th>
<th>SE</th>
<th>95% CI – lower, upper value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTE 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR sept sys</td>
<td>0.6642</td>
<td>0.0729</td>
<td>0.5115, 0.8169</td>
</tr>
<tr>
<td>SR inf sys</td>
<td>0.6434</td>
<td>0.0784</td>
<td>0.4898, 0.7970</td>
</tr>
<tr>
<td>Strain sept</td>
<td>0.6436</td>
<td>0.0659</td>
<td>0.5145, 0.7726</td>
</tr>
<tr>
<td>Strain inf</td>
<td>0.6347</td>
<td>0.0666</td>
<td>0.5041, 0.7653</td>
</tr>
<tr>
<td>TTE 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR sept sys</td>
<td>0.9551</td>
<td>0.0747</td>
<td>0.8088, 1.1015</td>
</tr>
<tr>
<td>SR inf sys</td>
<td>0.9628</td>
<td>0.0603</td>
<td>0.8447, 1.0809</td>
</tr>
<tr>
<td>Strain sept</td>
<td>0.9883</td>
<td>0.0156</td>
<td>0.9577, 1.0189</td>
</tr>
<tr>
<td>Strain inf</td>
<td>0.9676</td>
<td>0.0368</td>
<td>0.8954, 1.0398</td>
</tr>
</tbody>
</table>

SR indicates strain rate; sept, septal; inf, inferior; SE, standard error; 95% CI, confidence interval.

maintenance, a cut-off value of ≥20.5% for atrial septal systolic S was associated with a sensitivity of 99%, specificity of 78%, positive predictive value of 88%, and negative predictive value of 96% [area under the ROC curve, 0.988; standard error (SE), 0.007; 95% confidence interval (CI), 0.975–1.001] (Figure 7). Septal late diastolic SR correlated with the maintenance of sinus rhythm (ROC 0.933; SE 0.031; 95% CI, 0.895–1.0398; P < 0.0001). Additional ROC curves were used to describe the prognostic value of the LA size for the prediction of sinus rhythm maintenance after catheter ablation. Using an optimal cut-off value of 46.5 mm a sensitivity of 57% and a specificity of 61% were seen to predict sinus rhythm during FU (AUC 0.587; SE 0.059; CI 0.472–0.703; P = 0.132). Bootstrapping was performed for further validation showing the reproducibility and the correctness of the derived cut-off values (Table 2).

Prediction of sinus rhythm during follow-up on the basis of echocardiographic data before catheter ablation

For predicting sinus rhythm maintenance, a cut-off value of ≥20% for atrial septal systolic S was associated with a sensitivity of 57% and a specificity of 56% (area under the ROC curve, 0.644; SE, 0.047; 95% CI, 0.552–0.735; P = 0.003). Using the parameter of LA size pre-ablation (cut-off value of 50 mm) a sensitivity of 80% and specificity of 37% were seen to predict sinus rhythm during FU (AUC 0.597; SE 0.058; CI 0.483–0.71; P = 0.095). Patients with paroxysmal AF showed in 70% stable sinus rhythm during FU, patients with persistent AF showed sinus rhythm in 68% (Figure 1).

Observer variability and feasibility data

Of a total of 100 segments in the controls (n = 25 patients) and 472 analysed segments in AF patients (n = 118 patients), 98 (98%) and 459 (97%), respectively, had adequate waveforms for assessment of SR. Of the 13 LA segments in the AF patient cohort that could not be analysed, six were located anteriorly, three inferiorly, three laterally and one septally. Interobserver and intraobserver variability of the mean systolic, early and late diastolic SR and S values were examined in each randomized selected control. For the interobserver variability typical margins of tissue velocity imaging (TVI) and SR data were derived from Bland–Altman plots (TVI ± 0.3 cm/s, S ± 20%, SR ± 0.2 s⁻¹) (Figure 8).

The analysis of intraobserver measurements demonstrated a high congruence. For TVI the minimum and maximum of standard deviations were 0.11 and 1.04, respectively, and of the repeatability coefficient for 95% of patients were 0.3 and 2.87. For S analysis the minimum and maximum of standard deviations were 0.34 and 2.76, respectively, and of the repeatability coefficient for 95% of patients were 0.94 and 7.65, and for SR 0.10 and 0.36 (repeatability coefficient 0.28 and 1.01, respectively).

Bland–Altman analysis showed no evidence of any systematic difference regarding inter- and intraobserver variability.

Discussion

To our knowledge, this is the first study analysing LA deformation properties in patients before and after catheter ablation of AF. Major findings of our study are: first, Doppler-derived LA SR parameters reflect the atrial remodelling process depending on the type of AF (paroxysmal vs. persistent) and secondly the assessment of reverse remodelling is after maintenance of sinus rhythm. LA SR parameters are predictive of sinus rhythm maintenance over a 3-month FU period. LA deformation properties were significantly compromised in patients with persistent AF in comparison with patients with paroxysmal AF or controls.

Assessment of left atrial function by strain rate imaging

SR imaging has been proposed as a quantitative echocardiographic tool for assessing intrinsic myocardial function independent of tethering effects.7,14–16 The assessment of SR imaging as a feasible and useful method for the analysis of LA function was revealed by several previous studies.5,6,17,18 However, there is no widely accepted gold standard parameter reflecting LA contractility. Similar to the traditional parameters, such as peak A velocity, TVI VAE, fractional area change, LAEF LA S revealed the compromised atrial contractility in patients with AF in our study. During AF no atrial deformation could be detected in late diastole. Systolic and early diastolic SR parameters are reduced correlating to an impaired reservoir and conduit function and missing booster pump during AF.19 S and SR data of the septal atrial segments showed significantly higher values than lateral or anterior, due to the angle dependency in Doppler measurements.20,21

Recovery of left atrial function after catheter ablation and re-established sinus rhythm

In patients with re-established sinus rhythm during FU, a recovery of LA function was assessed reflecting functional reverse atrial
Figure 8 Bland–Altman plots with the estimated limits of agreement and their 95% confidence interval (CI) of different echocardiographic parameters. The numbers upon the plots refer to the patient identification. SR indicates strain rate, S indicates strain.
remodelling. Similar to previous studies, LA contractility improved after successful cardioversion or after linear ablation for AF in the case of maintained sinus rhythm, but did not reach normal values of controls. LA size decreased during the 3-month FU period in contrast to patients with recurrent AF. Recent experimental studies have demonstrated that AF causes changes in LA connexin density and distribution, cellular structural remodelling, myolysis, and glycogen accumulation.

**Prediction of the maintenance of sinus rhythm after catheter ablation**

Atrial deformation properties measured during systole and late diastole are able to discriminate patients with maintained sinus rhythm after the catheter ablation procedure from those with recurrent AF. During ventricular systole, LA serves as a reservoir to store blood when AV valves are closed. This reservoir function is influenced by atrial relaxation and atrial chamber stiffness. Similar to the findings of Di Salvo et al., the degree of the impairment in atrial compliance assessed by the systolic S and SR seems to be strongly correlated with the maintenance of sinus rhythm. The best predictive value for maintenance of sinus rhythm was obtained by systolic S of the septal LA wall. Early diastolic SR data failed to identify cut-off values for the prediction of the maintenance of sinus rhythm. This corresponds to the fact that the LA acts as conduit in the early diastole, passively emptying during ventricular relaxation and regarding its function strongly dependent on LV compliance. Late diastolic SR reflecting active atrial contraction correlated well but to a lesser extent with the maintenance of sinus rhythm. Because the SR analysis was performed up to a maximum of 24 h after catheter ablation the phenomenon of atrial stunning could explain this finding. Atrial stunning is a complex process of atrial remodelling occurring during and after AF. Atrial SR parameters correlated well with LA appendage function and were significantly compromised during atrial stunning. However, atrial stunning itself was identified as an independent predictor of an early relapse into AF and cannot be considered separately from the global atrial remodelling process.

**Pathophysiologic background for the recurrence of atrial fibrillation after catheter ablation**

AF is often initiated and maintained by ectopic foci localized in the PVs. During catheter ablation a complete electrophysiologic isolation of the PVs are intended by use of radiofrequency current applications. However, recurrent AF can occur in the case of incomplete lesions and following reconduction from the PVs to the LA. In addition, trigger within the LA can also initiate AF correlating to the electrophysiologic and structural remodelling. LA SR data after catheter ablation reflect the atrial remodelling process and were significantly different in patients with maintained sinus rhythm and recurrent AF. Impaired LA deformation properties correspond to lower success rates after catheter ablation in patients with persistent AF in comparison with those of paroxysmal AF.

**Study limitations**

One major limitation is the lack of gold standard measurement for the LA function. Invasive determination of the LA pressure was not considered feasible. Secondly, it cannot be excluded that the FU period of 3 months was too short to detect effects of morphologic reverse remodelling of the LA. In addition, in patients with paroxysmal AF >50% of all AF episodes occur without any symptoms. Because of logistic reasons, patients cannot continuously be monitored during the total FU resulting in an underestimation of the true recurrence rate of AF and leading to a potential falsifying effect on the SR data and their predictive value. A further limitation is that LA S and SR parameters might be influenced by preload and afterload conditions. Hence, it cannot be excluded that differences in medical therapy, especially for the comparison of AF patients and controls, have a potential influence on the atrial SR data. These aspects have to be further investigated, i.e. by a correlation of an invasively measured LA pressure and LA SR data. Finally, the usual limitations inherent in the angle dependency of Doppler techniques also apply to SR imaging. Due to the fact that the atrial walls are very thin and a sample volume of 6 x 6 mm² was used, it cannot be excluded that blood pool activity falsified the tissue Doppler signal.

**Clinical implications**

Analysis of the SR data of the LA enables non-invasive assessment of atrial reverse remodelling in patients with AF. Patients with higher atrial S and SR values seem to have a greater likelihood for sinus rhythm maintenance after catheter ablation. Patients with persistent AF showed significantly lower SR data than patients with paroxysmal AF, measured during sinus rhythm the day after ablation, correlating to a higher recurrence rate of AF during FU. In conclusion, patients with impaired LA deformation properties after catheter ablation should be followed up closely and over a longer period. In these patients anticoagulation therapy plays an important role and has to be strictly monitored to prevent cardioembolic events. However, further prospective studies will be required to confirm our findings.

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**Conflict of interest:** none declared.

**References**


