Atrial Myocardial Deformation Properties Predict Maintenance of Sinus Rhythm After External Cardioversion of Recent-Onset Lone Atrial Fibrillation

A Color Doppler Myocardial Imaging and Transthoracic and Transesophageal Echocardiographic Study

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Background—Accurate echocardiographic parameters to predict maintenance of sinus rhythm in patients with atrial fibrillation (AF) are poorly defined. This study was conducted to assess the atrial myocardial properties during AF through myocardial velocity, strain rate, and strain and to compare their prognostic value in maintaining sinus rhythm in patients with lone AF with standard transthoracic (TTE) and transesophageal echocardiography (TEE).

Methods and Results—Sixty-five consecutive patients with lone AF for ≤3 months underwent TTE, TEE, and myocardial velocity and strain rate imaging examinations before successful external cardioversion. Maintenance of sinus rhythm was assessed during a 9-month follow-up. Atrial myocardial velocity, strain, and strain rate values in AF patients were compared with those of age- and sex-matched referents. Moreover, clinical and echocardiographic parameters of patients with maintenance of sinus rhythm (MSR patients) over the 9-month follow-up period (n=25) were compared with those from patients with AF recurrence (AFR patients; n=40). Atrial myocardial properties assessed by myocardial velocity, strain rate, and strain were significantly reduced (P<0.0001) in patients (velocity, 3.2±1.4 cm/s; strain, 23.3±19%; strain rate, 2±0.9 seconds⁻¹) compared with referents (velocity, 5.7±1.3 cm/s; strain, 92±26%; strain rate, 4.2±1.8 seconds⁻¹). The individual predictors of sinus rhythm maintenance were atrial appendage flow velocity (MSR patients, 39±12 cm/s; AFR patients, 32±15 cm/s; P<0.01) assessed by TEE and atrial strain (MSR patients, 33±27%; AFR patients, 17±9%; P=0.0007) and strain rate (MSR patients, 2.7±1 seconds⁻¹; AFR patients, 1.6±0.6 seconds⁻¹; P<0.0001) peak systolic values. Atrial strain (P<0.0001; coefficient, 0.015; SE, 0.003) and strain rate (P<0.0001; coefficient, 0.372; SE, 0.075) parameters alone were confirmed as independent predictors of sinus rhythm maintenance by multivariable analysis.

Conclusions—Patients with higher atrial strain and strain rate appear to have a greater likelihood of staying in sinus rhythm. If the current data are verified in future studies, then additional pharmacological therapy and maintenance of anticoagulants for a longer period may need to be considered in those with lower atrial strain and strain rate measurements. (Circulation. 2005;112:387-395.)

Key Words: atrium ■ echocardiography ■ fibrillation

Atrial fibrillation (AF) is the most frequent arrhythmia in clinical practice. Its incidence is increasing with the aging population.1 Transthoracic DC cardioversion of AF is one of the most widely used and effective treatments to restore sinus rhythm; however, it has a high recurrence rate, which is only partially affected by antiarrhythmic treatment.2 Criteria used to select AF patients for DC cardioversion include origin and duration of AF, age, functional class, and transthoracic (TTE) and transesophageal (TEE) echocardiographic variables, but all have shown a limited predictive value.4,5
imaging has enhanced our ability to assess myocardial properties noninvasively.\textsuperscript{11} To date, few data are available on atrial myocardial velocities,\textsuperscript{12} and preliminary reports have validated strain and strain rate as a measure of atrial function.\textsuperscript{13-15}

Thus, we used myocardial velocities and strain and strain rate imaging in healthy subjects and in patients with AF immediately before DC cardioversion to study the atrial myocardial properties during arrhythmia and to compare their prognostic value with standard TTE and TEE.

Methods

This study was approved by the local ethics committee for human research. We studied 105 subjects, all AF patients who were candidates for elective DC cardioversion with an arrhythmia duration of \( \leq 3 \) months (estimated from the initial onset of symptoms until the time of the in-hospital conversion) with left atrium (LA) width \( \leq 4.5 \) cm at standard echocardiography and heart rate \( \leq 100 \) bpm. Exclusion criteria were atrial flutter, valvular stenosis, valvular prosthesis, significant valvular insufficiency, atrial and/or ventricular thrombosis, spontaneous contrast, patent foramen ovale or atrial septal defect, history of ischemic heart disease or decreased left ventricular (LV) function, arrhythmia, spontaneous contrast, patent foramen ovale or atrial septal defect, history of ischemic heart disease or decreased left ventricular (LV) function (ejection fraction \( < 50\% \)), New York Heart Association functional class III to IV, peripheral vascular disease, cerebrovascular disease, diabetes, hypertension, AF with identified reversible causes, and unsuccessful DC cardioversion. Because antiarrhythmic therapy may have a negative inotropic effect on the atrium, we also excluded patients under antiarrhythmic treatment.

As a referent group, we studied 40 healthy adult visitors (no history of cardiovascular disease, diabetes, and dyslipidemia and normal resting ECG, blood pressure, and echocardiographic study) of the same age and sex (mean age, 56.6 \pm 3\; years; age range, 48 to 60 years; 32 men).

Patients

Of 77 patients fulfilling our clinical and echographic selection criteria, 65 patients (mean age, 58.2 \pm 10\; years; age range, 44 to 63 years; 49 men) underwent successful DC cardioversion and were included in our study. Patients were divided into 2 groups based on AF recurrence (AFR group; \( n = 40 \) patients) and maintenance of sinus rhythm (MSR group; \( n = 25 \)) over a 9-month follow-up period. Clinical and echocardiographic characteristics of the 2 groups were compared.

Precardioversion treatment included digoxin (46\%), B-blocker (45\%), and verapamil (9\%). At the time of the study, all patients were receiving anticoagulant therapy.

All the echocardiographic studies were performed \( < 3 \) hours before DC cardioversion and were evaluated by 2 independent observers (G. D. S. and R. L. P.) who had no knowledge of the follow-up results.

TTE Study

Each subject had a complete echo mono and 2D color Doppler echocardiogram using a commercial GE Vingmed System V (Horten, Norway) with a 3.5-MHz variable-frequency harmonic phased-array transducer.

LA width was measured during systole along the parasternal long-axis view from the 2D guided M-mode tracing; LA length was measured from the apical 4-chamber view during systole. The maximum LA volume and minimum LA volume were calculated from apical 4- and apical 2-chamber zoomed views of the LA using the biplane method of disks.\textsuperscript{16,17} The difference between maximum LA volume and minimum LA volume divided by the minimum LA volume was used as the LA reservoir index.

LV global systolic function was evaluated by LV ejection fraction.\textsuperscript{18} To assess the longitudinal function of both ventricles, AV ring displacement was measured by conventional M mode for the lateral and septal points on the mitral ring and the lateral point on the tricuspid ring.

Mitrail flow velocity was assessed by pulsed-wave Doppler from the apical 4-chamber view by placing a 3-mm sample volume between the tips of the mitral leaflets in diastole and recording at a sweep velocity of 100 mm/s. Pulmonary venous flow velocity was obtained by positioning a 3- to 5-mm sample volume in the right upper pulmonary vein \( \sim 1 \) cm from the atrial cavity. From 10 consecutive cycles, peak flow velocities were measured and averaged.

A noninvasive estimate of LA pressure was obtained using the Doppler echocardiographic methods previously proposed by Temporelli et al\textsuperscript{19}: pulmonary artery wedge pressure = \( 0.26 \times \text{deceleration time of transmitral flow wave} + 5 \).

Color Doppler Myocardial Imaging

All echocardiographic studies were performed with the subject lying in the lateral decubitus position.

Real-time 2D color Doppler myocardial imaging data were recorded from the LA, right atrium, and basal segment of the LV using standard apical views at a high frame rate (\( \geq 180 \) frames per second, GE Vingmed System V, 3.5 MHz). An appropriate velocity scale was chosen to avoid data aliasing. The narrowest image sector angle possible (usually 30 degrees) was used to achieve the maximum color Doppler frame rate possible. Careful attention was paid to keep the region of interest at the center of the ultrasound sector to ensure an alignment as close to 0 degrees as possible to long-axis motion. In all the samples studied, we always selected 5 consecutive cardiac cycles (to be used for subsequent analysis) with an interbeat variability \( < 10\% \) to be recorded and used for subsequent analysis.

Offline Analysis

Color Doppler myocardial imaging data were stored in digital format and analyzed offline with dedicated software (Echopac, GE Vingmed). This method allowed us to calculate regional myocardial velocities, strain rate, and strain values. From this 1D ultrasound data set, 3 parameters were calculated: local velocity, local strain rate, and its integral, local strain (Figures 1 through 3). Myocardial velocity measures the local motion of a tissue; strain rate, the local rate of deformation; and strain, the total amount of local deformation of a tissue.

Longitudinal direction changes (measured from apical views) for atria are better described by the terms “rate of lengthening” in systole (positive strain rate value) and “rate of shortening” in diastole (negative strain rate value) (Figures 2 and 3).

Myocardial atrial strain determines regional lengthening expressed as a positive value or shortening expressed as a negative
LV and right ventricular myocardial deformation properties were studied from the basal segments of the septal, lateral, inferior, anterior, and right ventricular free wall using the methodology previously described.21

**TEE Study**

TEE was performed with Acuson Sequoia ultrasonograph with a 5-MHz phased-array transducer. All examinations were performed with a multiplane transducer. We evaluated LA appendage flow because in previous studies this parameter has been reported to be the strongest predictor of sinus rhythm maintenance. LA appendage flow was obtained by placing the pulsed Doppler sample volume at the orifice of the LA appendage, after which peak flow velocities were measured and averaged within an RR interval of 10 consecutive cardiac cycles. LA appendage flow was defined as the peak forward or emptying flow velocity.

**Electrical Cardioversion and Follow-Up**

After echocardiographic studies, patients underwent electrical cardioversion that started with 50 J and, when necessary, was followed by 100, 200, and 360 J until cardioversion was accomplished or until failure to convert with 360 J. Continuous ECG monitoring was performed during the 24 hours after the procedure. Cardioversion was considered successful when patients were in sinus rhythm at the time they left our department, which happened to be the day after the cardioversion was performed. After the electric cardioversion, all patients were seen once a week at an outpatient clinic during the first month, then monthly thereafter and at any time the patient complained of palpitations or other symptoms. At each examination, a standard 12-lead ECG was used, and an inquiry was made about any recurrence of palpitations. A 24-hour Holter recording was performed at 1, 6, and 9 months and at any time the patient had any symptoms suggesting recurrence of AF.

**Statistical Analysis**

All the analyses were performed with a commercially available package (SPSS, release 11.0, SPSS Inc). Power calculations were performed, and achieving 80% statistical power at a significance level of 0.05 required a standardized difference of 0.71 and an odds ratio of 0.208.

To compare AF and referents or AFR and MSR, the unpaired Student’s t test was performed for continuous variables; for categorical variables, Fisher’s exact test was used. Quantitative values are presented as mean ± SD. In addition, a multivariable analysis was performed using a forward stepwise logistic regression using likelihood ratio test, with values of $P<0.10$ as the threshold for entering or removing variables. The multivariable analysis was elaborated from variables identified as statistically significant by individual analyses.

To find a diagnostic cutoff value for maintenance of sinus rhythm, a nonparametric receiver-operating characteristics (ROC) curve analysis was constructed, and the area under the curve, which shows the discriminatory ability of the variable cutoff, was reported. Sensitivity, specificity, and positive and negative predictive values of the best cutoff variable were calculated. A value of $P<0.01$ was considered statistically significant.

Interobserver variability, expressed as a coefficient of variation, was assessed by analyzing 10 longitudinal regions in different, randomly chosen subjects by 2 independent investigators. For intraobserver variability, 10 longitudinal regions were analyzed by one investigator twice within 4 weeks. The second round of intraobserver measures was blinded to results from initial measures.

**Results**

General characteristics of the studied sample are presented in Table 1.

AF patients had significantly larger LA dimensions and a significantly lower LA reservoir index than referents. LV ejection fraction was also significantly lower in AF patients.
TABLE 1. General Characteristics of the Studied Sample

<table>
<thead>
<tr>
<th></th>
<th>AF Patients (n=65)</th>
<th>Referents (n=40)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>58±10</td>
<td>56±3</td>
<td>0.2</td>
</tr>
<tr>
<td>Male sex, %</td>
<td>75</td>
<td>80</td>
<td>0.8</td>
</tr>
<tr>
<td>BSA, m²</td>
<td>1.8±0.2</td>
<td>1.9±0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Systolic blood pressure, mm Hg</td>
<td>133±10</td>
<td>131±12</td>
<td>0.3</td>
</tr>
<tr>
<td>Diastolic blood pressure, mm Hg</td>
<td>78±7</td>
<td>77±11</td>
<td>0.6</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>83±18</td>
<td>72±10</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Range</td>
<td>60–95</td>
<td>62–75</td>
<td></td>
</tr>
<tr>
<td>LA, cm</td>
<td>4.4±0.3</td>
<td>3.7±0.4</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Range</td>
<td>4–4.5</td>
<td>3.4–3.9</td>
<td></td>
</tr>
<tr>
<td>IVS end-diastole, cm</td>
<td>1.1±0.1</td>
<td>1±0.1</td>
<td>0.09</td>
</tr>
<tr>
<td>LV end-diastole, cm</td>
<td>5.0±0.4</td>
<td>4.8±0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>PW end-diastole, cm</td>
<td>1.1±0.1</td>
<td>1±0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>LV ejection fraction, %</td>
<td>54±3</td>
<td>58±4</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>LA, cm</td>
<td>4.4±0.3</td>
<td>3.7±0.4</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Range</td>
<td>4–4.5</td>
<td>3.4–3.9</td>
<td></td>
</tr>
<tr>
<td>LV septal ring displacement, cm</td>
<td>1.1±0.2</td>
<td>1±0.1</td>
<td>&gt;0.9</td>
</tr>
<tr>
<td>LV lateral ring displacement, cm</td>
<td>1.3±0.3</td>
<td>1.3±0.2</td>
<td>&gt;0.9</td>
</tr>
<tr>
<td>RV free wall ring displacement, cm</td>
<td>1.7±0.4</td>
<td>1.6±0.2</td>
<td>0.1</td>
</tr>
</tbody>
</table>

BSA indicates body surface area; IVS, interventricular septum; PW, posterior wall; and RV, right ventricle.

Color Doppler Myocardial Imaging Study: Atrial Function

Peak systolic and early diastolic (Table 2) myocardial atrial velocities, strain rate, and strain were significantly compromised in AF patients compared with referents (Figures 1 through 3).

Comparing standard Doppler indexes with strain and strain rate values, we found a significant correlation between peak systolic myocardial atrial strain and peak systolic pulmonary vein flow ($r=0.65$, $P=0.001$). Peak systolic strain correlated ($P<0.01$) to the atrial volume–derived LA reservoir index but not to peak systolic AV ring displacement.

Peak early diastolic myocardial atrial strain/strain rate correlated to mitral peak early diastolic wave ($r=0.71$, $P=0.001$; $r=-0.68$, $P=0.002$, respectively) and mitral early diastolic wave deceleration time ($r=0.77$, $P=0.0001$; $r=-0.69$, $P=0.01$, respectively). Peak systolic and early diastolic myocardial right atrial strain and strain rate were correlated to tricuspid peak early diastolic wave (strain: $r=0.73$, $P=0.0001$; $r=-0.77$, $P=0.0001$, respectively; strain rate: $r=0.63$, $P=0.01$; $r=-0.68$, $P=0.001$, respectively). Peak early diastolic strain of both left and right atria correlated to peak systolic AV ring displacement ($P<0.01$).

Color Doppler Myocardial Imaging Study: Ventricular Function

LV myocardial peak systolic deformation properties were also significantly lower in AF patients in each studied segment (basal septum: $-1.5±0.7$ seconds $-1$ for AF versus $-1.8±0.3$ seconds $-1$ for referents; $P=0.01$).

There was a significant correlation between atrial and LV myocardial systolic strain ($r=0.57$, $P<0.01$).

TABLE 2. Color Doppler Myocardial Study in AF Patients Compared With Referents

<table>
<thead>
<tr>
<th></th>
<th>AF Patients (n=65)</th>
<th>Referents (n=40)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrial septum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity, cm/s</td>
<td>3.6±1.6</td>
<td>6.3±1</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>S, %</td>
<td>26.2±18</td>
<td>97.8±31</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SR, s⁻¹</td>
<td>1.9±0.9</td>
<td>4.2±1.1</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>LA lateral wall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity, cm/s</td>
<td>2.9±0.6</td>
<td>6.9±2.25</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>S, %</td>
<td>26.5±21</td>
<td>79±16</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SR, s⁻¹</td>
<td>1.96±0.9</td>
<td>4.1±1.8</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>RA free wall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity, cm/s</td>
<td>4.46±1.8</td>
<td>9.2±1.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>S, %</td>
<td>43.7±29.6</td>
<td>165±71</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SR, s⁻¹</td>
<td>2.9±1.7</td>
<td>6.1±2.1</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>LA inferior wall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity, cm/s</td>
<td>3.2±1.4</td>
<td>5.7±1.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>S, %</td>
<td>23.3±19</td>
<td>92±26</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SR, s⁻¹</td>
<td>2±0.9</td>
<td>4.2±1.8</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>LA anterior wall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity, cm/s</td>
<td>3.2±1.7</td>
<td>7.2±1.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>S, %</td>
<td>17±13</td>
<td>79±16</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SR, s⁻¹</td>
<td>1.7±0.8</td>
<td>4.9±2.6</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

RA indicates right atrium; S, strain; and SR, strain rate.
Clinical, TTE, and TEE Variables and Outcome

All 65 AF patients were followed up for a 9-month period; 25 (38%) of them maintained sinus rhythm (MSR group). The remaining 40 patients (62%) had ≥1 AF recurrence (AFR group), all within the first 6 months of cardioversion.

Comparing clinical and standard echocardiographic data between the MSR and AFR group patients showed that there was no significant difference (Table 3). Mitral and tricuspid ring displacement was also similar between groups. LA appendage flow velocities recorded by multiplane TEE were significantly different between groups (P<0.01) (Table 3). There was no difference in drug treatment after cardioversion between those groups (digoxin, 10 of 25 versus 19 of 40; regular β-blocker, 13 of 25 versus 18 of 40; verapamil or diltiazem, 2 of 25 versus 3 of 40; P=NS).

Color Doppler Myocardial Imaging Variables and Outcome

Peak systolic atrial myocardial velocities were lower in the AFR group, but this difference was not significant. Conversely, the peak systolic atrial myocardial strain and strain rate values in each studied atrial wall were significantly lower in the AFR group (Table 4). Early diastolic atrial myocardial velocity, strain, and strain rate were not significantly different between groups. LV myocardial deformation properties were also unable to significantly differentiate AFR from MSR patients (−1.4±0.7 versus −1.6±0.8 seconds⁻¹; P=0.25).

In multivariable analysis, the best predictors of sinus rhythm maintenance were atrial inferior wall peak systolic strain rate (P<0.0001; coefficient, 0.372; SE, 0.075) and atrial septal peak systolic strain (P<0.0001; coefficient, 0.015; SE, 0.003), whereas LA appendage flow velocity was not significant.

In ROC analysis, in predicting sinus rhythm maintenance, a cutoff value of 1.8 seconds⁻¹ for atrial inferior wall peak systolic strain rate was associated with a sensitivity of 92%, specificity of 79%, positive predictive value of 77%, and negative predictive value of 86% (area under the ROC curve, 0.878; SE, 0.047; 95% CI, 0.77 to 0.94). For atrial septal peak systolic strain, a cutoff value of 22% was associated with a sensitivity of 77%, specificity of 86%, positive predictive value of 73%, and negative predictive value of 94% (area under the ROC curve, 0.852; SE, 0.05; 95% CI, 0.76 to 0.93) (Figures 4 through 7).

The intraobserver and interobserver variabilities were good for peak systolic velocities (4% and 5.5%, respectively) and strain values (7% and 10%, respectively) but worse for strain rate (11% and 15%, respectively). The intraobserver and interobserver variabilities for early diastolic atrial deformation indexes were 12% and 18% for strain and 13% and 18% for strain rate.

Discussion

To the best of our knowledge, this is the first attempt to study atrial myocardial deformation properties in AF patients and referents. The main results of our study are that the myocardial deformation properties of both atria during recent-onset lone AF are severely compromised and that atrial myocardial deformation properties are predictive of sinus rhythm maintenance over a 9-month follow-up period.

Atrial Deformation Properties During AF

During recent-onset lone AF, the myocardial atrial deformation properties are significantly impaired. The atrial lengthening that occurs during ventricular ejection is significantly reduced, and the atrial shortening that occurs during ventricular early filling is also reduced. No atrial deformation could be detected during late diastole. These findings are in agreement with several studies demonstrating that during AF the reservoir and conduit function are impaired and the booster pump is absent and confirm an increase in atrial stiffness during AF.

Maintenance of Sinus Rhythm and AF Duration: LA Size

The duration of AF and LA size derived by TTE are still taken into account as important determinants for restoration and maintenance of sinus rhythm in clinical practice. Several studies have demonstrated that duration of AF has only a certain predictive value. Moreover, accurate information on duration of AF is limited.

In our study, duration of arrhythmia was not predictive of maintenance of sinus rhythm at follow-up. This finding is in agreement with previous reports.

TTE is an excellent technique to assess LA size. M mode–derived LA size, shown to correlate well to angiographically derived LA areas and volumes, has been used to monitor changes in LA size in AF.

We also measured atrial volume by TTE in our patients with lone AF, but this was not predictive of maintenance of sinus rhythm. Our findings on atrial size and volume are in agreement with previous reports.
agreement with previous studies demonstrating conflicting
data on the relationship between mild or moderate LA
enlargement and prognostic importance with regard to long-
term maintenance of sinus rhythm.5,28

The LA reservoir index that we used was also unable to
significantly discriminate between MSR and AFR patients,
probably because this index is influenced by global heart
motion and does not exclusively reflect changes in atrial
compliance. Moreover, manually traced 2D echocardiographic
LA areas are limited by poor temporal resolution (typically
2 to 3 area values per cardiac cycle).

LA Appendage Velocities and Maintenance of
Sinus Rhythm
In our study, LA appendage velocities on TEE were able to
significantly differentiate the AFR group from the MSR

<table>
<thead>
<tr>
<th>Atrial septum</th>
<th>MSR Patients (n=25)</th>
<th>AFR Patients (n=40)</th>
<th>P</th>
<th>MSR Patients (n=25)</th>
<th>AFR Patients (n=40)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity, cm/s</td>
<td>3.9±1.9</td>
<td>3.4±1.4</td>
<td>0.2</td>
<td>−3.3±1.1</td>
<td>−3.4±1.3</td>
<td>0.75</td>
</tr>
<tr>
<td>S, %</td>
<td>37±18</td>
<td>19±14</td>
<td>&lt;0.0001</td>
<td>18±10</td>
<td>12±11</td>
<td>0.75</td>
</tr>
<tr>
<td>SR, s⁻¹</td>
<td>2.7±0.7</td>
<td>1.4±0.8</td>
<td>&lt;0.0001</td>
<td>−2.3±0.6</td>
<td>−2.4±1.3</td>
<td>0.72</td>
</tr>
<tr>
<td>LA lateral wall</td>
<td>Velocity, cm/s</td>
<td>3.2±1.9</td>
<td>2.7±1.4</td>
<td>0.2</td>
<td>−2.4±0.8</td>
<td>−2.3±0.4</td>
</tr>
<tr>
<td>S, %</td>
<td>39±26</td>
<td>18±13</td>
<td>&lt;0.0001</td>
<td>18±12</td>
<td>14±5</td>
<td>0.07</td>
</tr>
<tr>
<td>SR, s⁻¹</td>
<td>3±1.7</td>
<td>1.3±0.9</td>
<td>&lt;0.0001</td>
<td>−2.5±0.9</td>
<td>−2.2±0.8</td>
<td>0.16</td>
</tr>
<tr>
<td>RA free wall</td>
<td>Velocity, cm/s</td>
<td>5±2.3</td>
<td>4.3±2</td>
<td>0.2</td>
<td>−5.5±1.9</td>
<td>−5.1±1.5</td>
</tr>
<tr>
<td>S, %</td>
<td>58±44</td>
<td>33±23</td>
<td>0.003</td>
<td>23±16</td>
<td>20±10</td>
<td>0.3</td>
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<td>SR, s⁻¹</td>
<td>3.8±1.6</td>
<td>2.3±1.6</td>
<td>&lt;0.0001</td>
<td>−2.8±1.5</td>
<td>−2.4±1.1</td>
<td>0.2</td>
</tr>
<tr>
<td>LA inferior wall</td>
<td>Velocity, cm/s</td>
<td>3.7±1.8</td>
<td>2.9±1.9</td>
<td>0.2</td>
<td>−3.5±1.6</td>
<td>−3.2±1.4</td>
</tr>
<tr>
<td>S, %</td>
<td>33±27</td>
<td>17±9</td>
<td>0.0007</td>
<td>12±8</td>
<td>11±9</td>
<td>0.65</td>
</tr>
<tr>
<td>SR, s⁻¹</td>
<td>2.7±1</td>
<td>1.6±0.6</td>
<td>&lt;0.0001</td>
<td>−2.4±0.9</td>
<td>−2.1±0.7</td>
<td>0.1</td>
</tr>
<tr>
<td>LA anterior wall</td>
<td>Velocity, cm/s</td>
<td>3.9±2</td>
<td>3±1.6</td>
<td>0.1</td>
<td>−3.2±1.5</td>
<td>−3.2±1.6</td>
</tr>
<tr>
<td>S, %</td>
<td>24±13</td>
<td>13±10</td>
<td>0.0002</td>
<td>8±6</td>
<td>7±6</td>
<td>0.5</td>
</tr>
<tr>
<td>SR, s⁻¹</td>
<td>2.1±0.6</td>
<td>1.4±0.8</td>
<td>0.0003</td>
<td>−2.4±1.2</td>
<td>−1.6±1.5</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Abbreviations as in Table 2.
group in individual analyses; however, this finding was not confirmed by multivariable analysis.

The predictive value of LA appendage velocities for maintenance of sinus rhythm is still debated. In contrast to other authors,17 Perez et al29 found no relation between LA appendage flow velocity, assessed by TEE, and maintenance of sinus rhythm. In addition, TEE, a moderately invasive technique, is not a recommended routine procedure before cardioversion.5,27

Atrial Deformation Properties and AF
Garrey30 described the central role of atrial tissue mass and histology in the pathogenesis of AF. Structural remodeling is a key feature in the persistence and recurrence of AF.31 During AF, there is an atrial remodeling, which leads to an increase in atrial stiffness.32 Several experimental studies have demonstrated that AF per se causes atrial electrophysiological remodeling, changes in connexin density and distribution, cellular structural remodeling, myolysis, and glyco
gen accumulation.6–9 Other studies have shown that a few weeks of rapid atrial pacing in the presence of normal ventricular rate response produce an isolated atrial cardiomyopathy characterized by impaired booster pump and reservoir functions and increased chamber stiffness.10 Recent studies have demonstrated that atrial compliance is altered by AF before structural remodeling occurs.33 Thus, our findings suggest the ability of the new myocardial deformation indexes, which are echocardiographically derived, to detect abnormalities in atrial compliance earlier than myocardial velocities, TEE, and conventional parameters, reflecting structural changes assessed by TTE.

The degree of the impairment in atrial compliance assessed by strain and strain rate in our study seems to be strongly predictive of maintenance of sinus rhythm.

The superior sensitivity of strain and strain rate imaging in detecting myocardial abnormalities compared with myocardial velocities, which detect only motion, has been confirmed in several studies34–36 and is related to their relative independence from the tethering effect and global cardiac motion.37,38

Our best predictive value for maintenance of sinus rhythm was obtained by peak systolic strain rate measured on an inferior atrial wall; however, we found that peak systolic strain rate measurements are less reproducible than strain measurement. Thus, despite its higher sensitivity and specificity, we suggest using peak systolic strain to study AF patients as candidates for electrical cardioversion.

Atrial Deformation Properties and Atrial Phases
Atrial deformation properties measured during early diastole failed to discriminate MSR from AFR patients. This is not surprising because in early diastole the atria act as a conduit, passively emptying during ventricular relaxation when the blood is transferred from systemic and pulmonary veins to the ventricles.32 Thus, atrial function during early diastole is strongly influenced by LV compliance. This is demonstrated by the strong correlation between early diastolic strain and strain rate values and LV global diastolic function indexes and between peak early diastolic strain and peak systolic annular excursion.

However, the failure of peak early diastolic atrial myocardial strain and strain rate values could be explained at least in part by their lower reproducibility. Indeed, we found it easier to measure the peak systolic value because of the highest rate of change. During ventricular systole, the atria function as reservoirs to store blood when AV valves are closed, and reservoir function is influenced by atrial relaxation, ventricle contraction through the descent of the base, and atrial chamber stiffness.32

The significant correlation between systolic strain and strain rate and the pulmonary vein peak systolic flow may confirm preliminary findings suggesting that atrial peak systolic myocardial strain and strain rate are measures of atrial reservoir function.13–15 Conversely, only a low correlation has been found between peak systolic myocardial atrial strain and ventricular peak systolic strain, and no correlation at all has been found between the peak systolic AV ring displacement and atrial peak systolic deformation properties.

These findings confirm that the peak systolic atrial strain and strain rate are less influenced by tethering effects and...
global heart motion and suggest that the abnormal atrial deformation properties during this phase are due mainly to changes in atrial myocardial compliance. Moreover, the predictive value of peak systolic myocardial atrial strain is in agreement with a previous article demonstrating atrial pacing to compromise atrial booster pump and reservoir function.10

Study Limitations
This study carries several limitations. The first is patient sample. We included only patients with AF lasting ≤3 months to reduce the recurrence of arrhythmia. Thus, the conclusion we have drawn may be different for a longer duration of AF. Although our study sample may seem to be a relatively low-risk group, the recurrence rate of AF is 61%. Because 65% of our patients had a previous history of AF and our institution is a tertiary referral center, we cannot rule out that these patients are a subgroup of difficult cases with high recurrence rate. The second limitation is drug treatment. The studied sample may appear to be heterogeneous with regard to preconditioning and postconditioning treatment, but this corresponds to the usual clinical situation encountered in hospital practice, and there was no statistical difference between groups for the preconditioning and postconditioning medical treatment in our study. However, to reduce the influence of the treatment, we excluded patients on antiarrhythmic therapy. The comparison between AF patients and referents may also have been influenced by medical treatment. Third, the findings in the echocardiographic study were acquired with 2 different echo scanners. Patients were not moved between the examinations, however, so they were not studied in different conditions. The final limitation is the color Doppler myocardial imaging study. Atrial strain rate and, especially, strain are influenced by loading conditions; thus, the comparisons of atrial deformation properties between patients and referents and between AF group and AFR group may have been influenced by preload reduction and different atrial wall stress during AF. Although we selected 5 heart cycles with an interbeat variability <10%, this limitation should be considered when patients and referents who presented significant differences in heart rate and atrial dimensions are compared. Conversely, AFR patients and MSR patients present similar mean heart rates, LA maximal volumes, and LA pressures (Table 3), so this confounding factor should not detract from the predictive value of atrial strain and strain rate.

The usual limitations inherent in the angle dependency of all echocardiographic Doppler techniques also apply to ultrasound-derived strain rate imaging. In this study, care was taken to align the ultrasound beam with the direction of myocardial deformation to be studied.

Clinical Implications
Our results are in agreement with previous reports showing that the ability of TTE and TEE to predict the maintenance of sinus rhythm is limited. Patients with higher atrial strain and strain rate appear to have a greater likelihood of staying in sinus rhythm. If the current data are verified in future studies, then additional pharmacological therapy and maintenance of anticoagulants for a longer period may need to be considered in those with lower atrial strain and strain rate measurements.

References


Atrial Myocardial Deformation Properties Predict Maintenance of Sinus Rhythm After External Cardioversion of Recent-Onset Lone Atrial Fibrillation. A Color Doppler Myocardial Imaging and Transthoracic and Transesophageal Echocardiographic Study
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