AMERICAN SCIENTIFIC PUBLISHERS


Health Informatics
Vol. 4, 705–711, 2014

# Assessment of Left Atrial Reservoir Function in Mitral Valve Disease by Tissue Doppler, Strain and Strain Rate Imaging

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*Introduction:* Mitral valve stenosis and mitral valve regurgitation still result in significant morbidity and mortality. It has been shown that atrial remodeling and atrial fibrillation may occur in these patients. We sought to investigate how pressure or volume overload in the left atrium could impact atrial deformation properties obtained via Doppler-derived velocity and strain/strain rate imaging. *Methods:* Thirty-six patients, comprising 17 patients with a diagnosis of moderate to severe mitral stenosis and 19 patients with a diagnosis of moderate to severe mitral regurgitation, were compared with 16 healthy subjects. Two-dimensional, pulse Doppler, and tissue Doppler transthoracic echocardiographic study was performed. Measurement of regional velocity, strain and SR profiles, peak systolic velocity, peak strain, and strain rate was performed in two segments of the four left atrial walls. *Results:* There was a significant decline in peak systolic velocity in the mitral stenosis patients in both annular and roof segments, but the difference was not statistically significant between the mitral regurgitation patients and the healthy subjects. Total velocity was significantly lower in the mitral stenosis patients than in the healthy subjects, but the difference was not statistically significant between the healthy subjects and the mitral regurgitation patients. Comparison of total strain showed significant differences between the three groups mainly due to a decline in strain in the mitral stenosis patients in comparison with the other two groups. Comparison of total peak systolic strain rate between the groups showed significant differences due to a significant decline in the mitral stenosis group and a non-significant decline in the mitral regurgitation group by comparison with the healthy group. *Conclusion:* This reduction, especially in strain and strain rate, shows that the reservoir function of the left atrium could be compromised more severely in asymptomatic mitral stenosis patients.



**Keywords:** Echocardiography, Left Atrial, Mitral Stenosis, Mitral Regurgitation, Strain.

## 1. INTRODUCTION

Mitral valve stenosis (MS) and mitral valve regurgitation (MR) still lead to significant morbidity and mortality. It has been demonstrated that atrial remodeling may occur in these patients; accordingly, the replacement of the normal atrial tissue with fibrosis at the structural level gives rise to the development of atrial fibrillation (AF) rhythm.[1]

Recently, the regional assessment of atrial motion and deformation properties obtained via Doppler-derived velocity and strain/strain rate (SR) imaging has been proposed as a new method for the exploration of atrial regional function.[2–8] The left atrium (LA) has three components of function:[9–11] (1) During left ventricular (LV) systole, the LA acts as a reservoir, allowing the blood to be collected proximal to the closed mitral valve. This results in longitudinal lengthening and positive strain and SR values. (2) During LV diastole, the LA has conduit function and results in shortening and negative SR values. (3) During late diastole, the LA acts as a booster pump and results in a second nadir in strain and SR values. Strain and SR imaging permit us to regionally evaluate the three components of LA function, resulting in the early detection of LA dysfunction.[12,13]

Different loading conditions could have different consequences on atrial morphology and function. It may be possible that MS

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 2156-7018/2014/4/705/007 doi:10.1166/jmihi.2014.1309 

and MR had different effects on the LA by inducing pressure and volume load, respectively. The importance of reservoir function is emphasized by the fact that 42% of LV stroke volume is stored in the LA during LV systole.[14–16] It has been demonstrated that the best predictor of cardiac events in patients with MS is LA systolic deformation properties[11] and these properties are more sensitive indicators of atrial dysfunction than are atrial diameter and volume.[17] Conversely, myocardial deformation properties, measured during early and late diastole, are thought to have lower reproducibility.[11]

Tissue Doppler-based techniques provide additional information on atrial function, complementary to a conventional two-dimensional and Doppler flow echocardiography;[18, 19] nonetheless, further research is needed to explore the clinical utilities of these advanced techniques in a variety of cardiac diseases. The existing literature contains only a few studies on the assessment of LA regional myocardial properties in mitral valve diseases. In this study, we aimed to describe the effects of two different abnormal loading conditions on the different parts of LA function by tissue Doppler and SR studies.

## 2. METHODS

### 2.1. Study Population

This study recruited 36 patients: 17 patients with moderate to severe MS (2 men and 15 women) and 19 patients with moderate to severe MR (11 men and 8 women). All the patients were in New York Heart Association (NYHA) functional class I. The exclusion criteria were AF rhythm, previous cardiac surgery, LV systolic dysfunction [LV ejection fraction (LVEF) $< 55\%$], ischemic heart disease, and diabetes. The control group was comprised of 16 healthy subjects, by taking into account their past medical history, physical examination, electrocardiography (ECG), echocardiography, and negative recent noninvasive or invasive tests for cardiovascular diseases in men over 45 and women over 55 years of age.

The study was approved by the Ethics Committee of Rajaie Cardiovascular, Medical and Research Center, and informed consent was obtained from all the subjects.

### 2.2. Echocardiography

Two-dimensional, pulse Doppler, and tissue Doppler transthoracic echocardiographic study was performed using a commercial GE Vivid 7 system (Horten, Norway) with an M3S multi-frequency (1.5–4 MHz) harmonic-phased array transducer. Maximal LA volume was measured just before the opening of the mitral valve using the apical four and two-chamber views and was calculated via the biplane method of disk. Subsequently, LA volume was indexed to the body surface area (BSA), and LA volume index was calculated. Mitral valve area was calculated by direct planimetry and pressure half time (PHT) method. MR severity was measured in accordance with the recommendations of the American Society of Echocardiography (ASE) using quantitative parameters such as vena contracta, effective regurgitant orifice area, and regurgitant volume when all of these parameters were in accordance with one another.[20] Additionally, LV global systolic function was evaluated with the modified biplane Simpson method using the apical four and two-chamber views for calculating LV volumes and EF, so that patients with normal EF could be selected.

### 2.3. Doppler Myocardial Imaging and Off-Line Analysis

Via standard two and four-chamber views, color Doppler myocardial imaging (CDMI) was recorded throughout three cardiac cycles according to the guidelines of the ASE. The imaging sector angle was adjusted to achieve a parallel alignment of the sampling area with the myocardial segment of interest ($> 150$ frames/sec), and an appropriate velocity scale was chosen to avoid CDMI data aliasing. Gain settings, filters, pulse repetitive frequency, and depth of view were adjusted to optimize color saturation, and the images were stored digitally in cine-loop format in the memory of the scanner. The digitally stored CDMI data sets were processed off-line using the EchoPac quantitative analysis software, equipped to obtain regional myocardial velocity, strain, and SR. Two $4 \times 3$ mm sample volumes were placed in the annular and roof segments of the LA lateral, anterior, inferior, and inter-atrial septum (IAS) walls. For recording the profiles of the annular segments, the sample volume was placed midway between the mitral valve annulus and the mid portion of each LA wall and for the recording of the roof segments, the sample volume was placed between the LA roof and the mid portion of that wall (Fig. 1).

Via regional velocity, strain, and SR profiles, peak systolic velocity, peak strain, and SR values were averaged over three consecutive cardiac cycles. The echocardiographic analyses were performed by an experienced observer, and all the Doppler data were measured at end-expiration. The reproducibility was assessed separately for the analysis of peak systolic velocity, strain, and SR values, which were calculated from 15 randomly chosen subjects by 2 independent observers and by repeated measurement of these parameters on another occasion.



### 2.4. Statistical Analysis

All the continuous variables are expressed as mean ± standard deviation (SD). The data were tested for normal distribution using the Kolmogorov-Smirnov (K-S) test. The annular and roof segments were compared with the independent samples $t$-test, and the Analysis of Variance (ANOVA) and the post-hoc least significant differences (LSD) test were used for multiple comparisons. Statistical relations were assessed using the Pearson correlation. $P$-values $\leq 0.05$ were considered statistically significant. The intraobserver and interobserver variabilities were differences between the measurements expressed as a percentage of the error

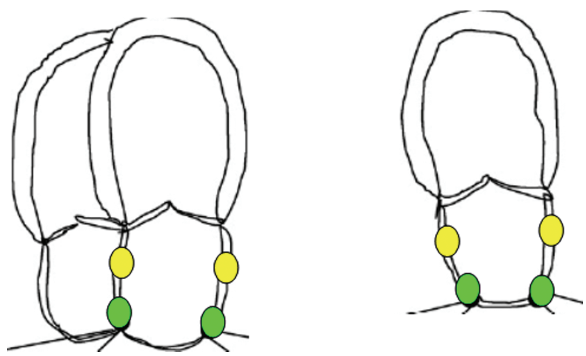

**Fig. 1.** Left: Sample volume was placed at the roof (green) and annulus (yellow) segments of the inter-atrial septum and the left atrial free wall from the apical four-chamber view. Right: Roof and annulus segments of the inferior and anterior walls of the left atrium are depicted from the apical two-chamber view.

**Table I. Clinical characteristics of the study population.**

| Variable | MS ($n = 17$) | MR ($n = 19$) | Healthy ($n = 16$) | $P$-value |
|---|---|---|---|---|
| BSA ($m^2$) | 1.6 ± 0.1 | 1.7 ± 0.1 | 1.7 ± 0.1 | NS |
| Age (years) | 42 ± 12 | 49 ± 13 | 41 ± 13 | NS |
| Heart rate (beats/min) | 79.8 ± 13.5 | 77.1 ± 15.4 | 83.8 ± 11.8 | NS |
| SBP (mm Hg) | 120.4 ± 15.7 | 124.9 ± 15.6 | 131.1 ± 19.0 | NS |
| DBP (mm Hg) | 84.2 ± 15.8 | 89.3 ± 27.3 | 78.9 ± 14.1 | NS |

*Notes*: MS = Mitral valve stenosis; MR = Mitral valve regurgitation; BSA = Body surface area; SBP = Systolic blood pressure; DBP = Diastolic blood pressure; NS = Non-significant.

of the mean values. All the statistical analyses were performed using the SPSS (version 16.0) statistical package (SPSS Inc. Chicago, IL, USA).

## 3. RESULTS

### 3.1. Clinical Characteristics

The clinical and echocardiographic characteristics of the three groups are summarized in Tables I and II, respectively. The mean age, mean heart rate, systolic blood pressure, diastolic blood pressure, and BSA of the three groups were comparable.

Maximal LA volume and also volume index were greater in the MS and MR patients ($P < 0.001$) but were not significantly different between the patients with MS and MR (NS). Also, left ventricular end-diastolic diameter (LVEDD) and EDD index were greater in the patients with MR ($P < 0.001$) but were comparable in the patients with MS and the healthy subjects (NS). Left ventricular end-systolic diameter (LVESD) and ESD index of the three groups were comparable (NS).



### 3.2. Left Atrial Systolic Velocity Comparison Between the Three Study Groups

Systolic velocity of each LA wall (measured at the annular and roof segments), mean values of each wall, mean values of the annular and roof segments separately, and finally their average (total values) for the three study groups are summarized in Table III.

### 3.3. Left Atrial Systolic Strain and Strain Rate Comparison Between the Three Study Groups

Similar to velocity assessment, the systolic strain and SR of each LA wall, measured at the annular and roof segments, mean values of each wall, mean values of the annular and roof segments separately, and finally their average (total values) for the three study groups are summarized in Table IV.

**Table III. Segmental peak systolic velocity of the different left atrial walls evaluated by color Doppler myocardial imaging (CDMI) study in the mitral stenosis and mitral patients compared with the healthy subjects.**

| Velocity (cm/s): | Healthy ($n = 16$) | MS ($n = 17$) | MR ($n = 19$) | $P$-value |
|---|---|---|---|---|
| *IAS wall*: | | | | |
| Annulus | 5.1 ± 1.1 | 3.5 ± 1.1 | 5.7 ± 1.2 | 0.000 |
| Roof | 3.0 ± 1.1 | 2.6 ± 1.3 | 3.9 ± 1.2 | 0.009 |
| Mean | 4.0 ± 1.6 | 3.1 ± 1.3 | 4.8 ± 1.5 | 0.000 |
| *Lateral wall*: | | | | |
| Annulus | 6.5 ± 1.8 | 4.1 ± 1.8 | 6.3 ± 1.9 | 0.000 |
| Roof | 3.4 ± 1.2 | 1.6 ± 0.7 | 2.6 ± 1.0 | 0.000 |
| Mean | 4.9 ± 2.2 | 2.8 ± 1.8 | 4.5 ± 2.4 | 0.000 |
| *Anterior wall*: | | | | |
| Annulus | 6.0 ± 1.1 | 3.8 ± 0.8 | 5.8 ± 1.9 | 0.000 |
| Roof | 3.4 ± 1.1 | 1.9 ± 0.5 | 3.3 ± 1.1 | 0.000 |
| Mean | 4.7 ± 1.7 | 2.9 ± 1.2 | 4.6 ± 2.0 | 0.000 |
| *Inferior wall*: | | | | |
| Annulus | 5.4 ± 1.0 | 2.9 ± 0.9 | 5.3 ± 1.5 | 0.000 |
| Roof | 2.9 ± 1.5 | 1.6 ± 0.8 | 2.1 ± 1.2 | 0.000 |
| Mean | 4.1 ± 1.8 | 2.3 ± 1.1 | 3.8 ± 2.1 | 0.000 |
| Mean annular | 5.8 ± 1.4 | 3.6 ± 1.3 | 5.8 ± 1.7 | 0.000 |
| Mean roof | 3.1 ± 1.2 | 1.9 ± 0.9 | 3.0 ± 1.3 | 0.000 |
| $P$-value | $p < 0.001$ | $p < 0.001$ | $p < 0.001$ | |
| *Total* | 4.5 ± 1.8 | 2.8 ± 1.4 | 4.4 ± 2.0 | 0.000 |

*Notes*: MS = Mitral valve stenosis; MR = Mitral valve regurgitation; IAS = Inter-atrial septum.

Comparison of LA peak systolic strain values in the roof and annular segments (Table IV) showed significant differences between the study groups, except for the annular segments in the IAS and the roof segments in the lateral wall. The dissimilarities were mainly owing to the differences between the MS patients and the MR patients or the healthy subjects; these results were particularly due to significant declines in the peak strain of the annular and roof segments in the MS patients. However, comparison between the MR patients and the healthy subjects demonstrated significant differences in the mean strain of

**Table II. Echocardiographic characteristics of the study population.**

| Variable | MS ($n = 17$) | MR ($n = 19$) | Healthy ($n = 16$) | $P$-value |
|---|---|---|---|---|
| LA volume (ml) | 105.7 ± 28.4 | 111.1 ± 34.0 | 45.0 ± 7.7 | 0.000 |
| LA volume index (ml/$m^2$) | 63.4 ± 18.8 | 60.9 ± 20.9 | 25.5 ± 4.1 | 0.001 |
| LVEDD(cm) | 4.6 ± 0.1 | 5.7 ± 0.1 | 4.6 ± 0.1 | 0.049 |
| LVEDD index (cm/$m^2$) | 1.9 ± 0.1 | 3.2 ± 0.1 | 1.8 ± 0.1 | 0.050 |
| LVESD (cm) | 3.2 ± 0.1 | 3.7 ± 0.1 | 3.1 ± 0.1 | NS |
| LVESD index (cm/$m^2$) | 2.7 ± 0.1 | 2.0 ± 0.1 | 2.6 ± 0.1 | NS |
| LVEF (%) | 58.4 ± 3.1 | 69.0 ± 3.0 | 59.3 ± 2.9 | 000 |
| Mitral valve area ($cm^2$) | 0.8 ± 0.2 | – | – | – |

*Notes*: MS = Mitral valve stenosis; MR = Mitral valve regurgitation; LVEF = Left ventricular ejection fraction; LA = Left atrium; BSA = Body surface area; LVEDD = Left ventricular end-diastolic diameter; LVESD = Left ventricular end-systolic diameter.

J. Med. Imaging Health Inf. 4, 705–711, 2014

**Table IV.** Segmental peak systolic strain of the different left atrial walls evaluated by color Doppler myocardial imaging (CDMI) study in the mitral stenosis and mitral regurgitation patients compared with the healthy subjects.

| Strain (%): | Healthy ($n = 16$) | MS ($n = 17$) | MR ($n = 19$) | $P$-value |
|---|---|---|---|---|
| *IAS wall*: | | | | |
| Annulus | 32.2 ± 24.8 | 19.5 ± 20.3 | 25.7 ± 9.6 | 0.176 |
| Roof | 133.4 ± 102.4 | 48.7 ± 37.3 | 105.1 ± 55.1 | 0.005 |
| Mean | 82.8 ± 89.6 | 34.1 ± 33.1 | 65.4 ± 56.0 | 0.010 |
| *Lateral wall*: | | | | |
| Annulus | 42.5 ± 25.3 | 21.1 ± 9.6 | 25.5 ± 21.6 | 0.007 |
| Roof | 64.6 ± 54.4 | 35.2 ± 24.8 | 55.0 ± 31.7 | 0.105 |
| Mean | 53.3 ± 43.0 | 28.2 ± 19.8 | 40.3 ± 30.6 | 0.009 |
| *Anterior wall*: | | | | |
| Annulus | 26.6 ± 12.3 | 16.5 ± 8.5 | 17.3 ± 9.0 | 0.009 |
| Roof | 47.4 ± 29.0 | 19.8 ± 9.0 | 56.2 ± 28.0 | 0.000 |
| Mean | 36.7 ± 24.1 | 18.2 ± 8.8 | 36.8 ± 28.4 | 0.001 |
| *Inferior wall*: | | | | |
| Annulus | 44.8 ± 21.3 | 19.7 ± 15.8 | 35.6 ± 18.5 | 0.002 |
| Roof | 44.1 ± 25.9 | 23.0 ± 10.7 | 65.9 ± 37.8 | 0.000 |
| Mean | 44.5 ± 23.3 | 21.4 ± 13.4 | 50.8 ± 33.0 | 0.000 |
| Mean annular | 36.6 ± 22.5 | 19.3 ± 14.2 | 26.0 ± 16.6 | 0.000 |
| Mean roof | 74.0 ± 71.0 | 32.4 ± 25.2 | 70.5 ± 43.7 | 0.000 |
| $P$-value | 0.000 | 0.001 | 0.000 | |
| *Total* | 55.2 ± 55.8 | 25.7 ± 21.8 | 48.3 ± 39.8 | 0.000 |

*Notes*: MR = Mitral valve regurgitation; MS = Mitral valve stenosis; IAS = Inter-atrial septum.

the annular segments ($P = 0.001$) but not in the roof segments (P = NS).

Comparison of total strain showed significant differences between the three groups, mainly due to a decline in strain in the MS patients in comparison with that in the other two groups. The mean of total strain in the MR patients was lower than that in the control group; the difference, however, did not constitute statistical significance.



Comparison of peak systolic SR (Table V) showed significant differences in all the segments between the three study groups, leading to significant differences in the mean of the annular and roof segments between the study groups as well. In the assessment of the SR of the mean roof segments, although there was a significant difference between the MS and MR patients, there were no differences between the MR patients and the healthy subjects and also between the MS patients and the healthy subjects.

Finally, comparison of the total peak systolic SR of the groups showed significant differences, which were secondary to a significant decline in the MS group and an insignificant decline in the MR group by comparison with the healthy group. It is deserving of note that, especially in total SR that calculated from more segments, led to statistically significant differences between the MR and normal groups with small differences.

The results demonstrated that in the MS and MR patients, similar to the healthy subjects, the inferior wall had the lowest systolic velocity and the septum had larger longitudinal strain values. The annular and roof segments of atrial deformation indices were studied separately through a comparison of the mean systolic velocity, strain, and SR values of the annular and roof segments. The mean of each variable in the annular segments was calculated by summing annular value in the mentioned segments of all the LA walls and then averaging them. In addition, these values in the roof segments were recorded by summing all the values in the four LA walls and subsequently averaging them.

Total mean strain and SR values were significantly lower in the MS patients than those in the healthy subjects ($P = 0.03$ and $P = 0.01$, respectively). Nevertheless, although strain and SR values were lower in the MR group, the difference between the MR group and the healthy group was not statistically significant (P = NS).

This study also showed that the MS patients had lower velocity, strain, and SR values in the anterior and inferior walls rather than in the IAS. The MR patients had significantly lower strain and SR in the anterior wall.

### 3.4. Assessment of the Correlation Between Velocity, Strain, and Strain Rate and Maximal Left Atrial Volume

Assessment of the correlation between theses parameters in the annular and roof segments in the healthy group showed a significant negative correlation between peak systolic velocity and maximal LA volume in the roof segment of the lateral ($r = -0.42$; $P = 0.002$), anterior ($r = -0.31$; $P = 0.032$), and posterior ($r = -0.39$; $P = 0.006$) walls. Peak systolic velocity of the annular segment of the anterior wall exhibited a significant correlation ($r = 0.34$; $P = 0.016$). Assessment of the correlation between strain and SR with maximal LA volume in this group showed only a negative correlation in the roof segment of the anterior segment in the anterior wall ($r = -0.33$; $P = 0.019$); the evaluation of the correlation in the other segments demonstrated no significant correlation (P = NS). There was a significant correlation between the peak systolic velocity of the IAS and LA volume index in the MS group ($r = 0.54$; $P = 0.030$) and between the peak systolic SR of the IAS and LA volume index in the MR group ($r = 0.47$; $P = 0.049$) (Figs. 2 and 3, respectively).

### 3.5. Reproducibility

The mean values of the intraobserver variabilities for peak systolic velocities, strain, and SR values were 4%, 7%, and 8%, respectively. The mean values of the interobserver variabilities for peak systolic velocities, strain, and SR values were 6%, 8%, and 10%, respectively.

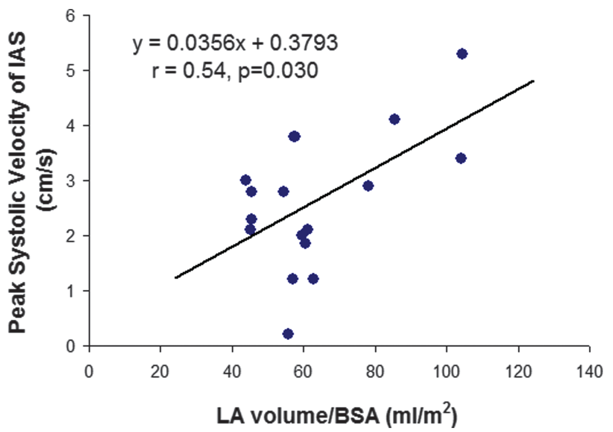


**Fig. 2.** Maximal left atrial (LA) volume index had a positive correlation with the longitudinal peak systolic velocity of the roof segment of the inter-atrial septum (IAS) wall in the mitral stenosis group.

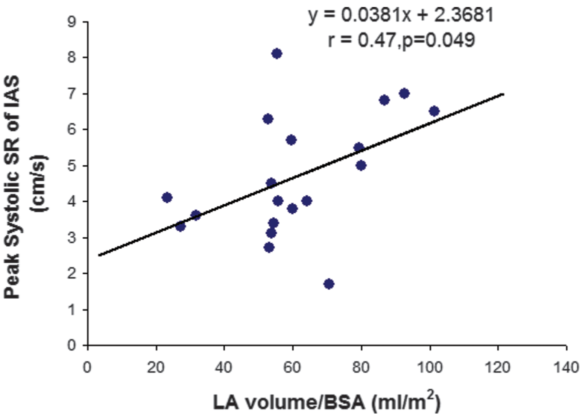


**Fig. 3.** Maximal left atrial (LA) volume index had a positive correlation with the longitudinal peak systolic strain rate of the roof segment of the inter-atrial septum (IAS) wall in the mitral regurgitation group.

## 4. DISCUSSION

In the current study, we investigated difference in the LA physiology in LA pressure and volume overload. Advanced echocardiographic technology has now made it possible to assess regional atrial function with new noninvasive and objective measures, in particular by tissue Doppler-derived velocity and strain/SR imaging.[21] In a study, Sirbu et al.[22] assessed the feasibility of measuring regional longitudinal strain/SR profiles in the LA wall and validated these measurements by correlating them with the standard indicators for LA function derived from volumetric measurements in healthy young subjects. They concluded that strain and SR imaging could be considered a robust technique for the noninvasive assessment of LA deformation and the understanding of LA pathophysiology. The three components of atrial function are reservoir function, conduit function, and booster pump function. According to the previous studies on the deformational properties of the LA, systolic strain and SR represent atrial reservoir function and early and late diastolic SRs show conduit and booster functions, respectively.



In the present study, we aimed to compare LA reservoir function by strain imaging study in MS and MR as LA pressure and volume overload, respectively. According to previous studies, strain and SR can predict symptoms in MS patients[11] and they are relatively independent of preload and afterload[14] as well as translational motion.[7] Moreover, among the other parameters for the evaluation of LA physiology such as E/A ratio,[14,23] LA fractional area change,[12,14] and LAEF,[10,14] these parameters are more sensitive.

### 4.1. Velocity Assessment

Comparison of the annular and roof segments of the different LA walls and their mean in our healthy subjects showed that longitudinal systolic velocity was larger in the annular segments than in the roof segments. This means that there was velocity gradient and inhomogeneity in velocity from annulus to roof in the normal, MR, and MS groups. Our results showed that, although there was a larger decline in velocity in the MS patients, the percentage of changes in velocity gradient was the same in the three groups (about 47%). In the healthy subjects, the LA inferior wall and the IAS had lower systolic velocity. In the MS and MR patients, the inferior wall had the lowest systolic velocity (Table III). This fact is perhaps due to the insertion of four pulmonary veins to the inferior wall, which causes limited motion, as was described in a previous study.[14]

Assessment of the correlation in the healthy subjects showed a significant correlation between systolic velocity and maximal LA volume in both roof and annular segments in the anterior wall, but only in the roof segments in the IAS and the lateral and inferior walls. There was a different result in the MS group insofar as there was a correlation in the roof segments. Whereas this correlation was positive in the MS group, the correlation was negative in the healthy group: this may show the significance of the assessment of the roof segments in comparison with the annular segments, which are influenced more by tethering.[24] There was no significant correlation in the MR group.

### 4.2. Strain and Strain Rate Assessment

Comparison of the annular and roof segments of the different LA walls in our healthy subjects showed that longitudinal systolic strain and SR were larger in the roof segments than in the annular ones. These data show that myocardial motion does not follow the same pattern as does myocardial deformation.[15] This means that, similar to systolic velocity, there is gradient and inhomogeneity in strain and SR values from annulus to roof, but in a reverse direction. This gradient was noted in our MS and MR patients as well. In the MS patients, besides the decline in strain and SR, strain gradient (40% in the MS group vs. 63% in the control group). In the MR patients, there was no significant decline in strain and SR value and strain gradient. The strain and SR of the IAS was the largest between the four LA walls in the patient groups and the healthy subjects. This may be due to the fact that the septum lies between the LA and the right atrium and its deformation is, thus, influenced by both atria.

**Table V. Segmental peak systolic strain rate of the different left atrial walls evaluated by color Doppler myocardial imaging (CDMI) study in the mitral stenosis and mitral regurgitation patients compared with the healthy subjects.**

| *SR* (1/s): | Healthy ($n = 16$) | MS ($n = 17$) | MR ($n = 19$) | *P*-value |
|---|---|---|---|---|
| *IAS wall*: | | | | |
| Annulus | 2.7 ± 1.8 | 1.4 ± 1.0 | 1.9 ± 1.7 | 0.046 |
| Roof | 4.6 ± 1.7 | 2.3 ± 1.1 | 3.6 ± 1.8 | 0.000 |
| Mean | 3.7 ± 1.9 | 1.8 ± 1.1 | 2.7 ± 1.9 | 0.000 |
| *Lateral wall*: | | | | |
| Annulus | 2.5 ± 1.5 | 1.4 ± 0.7 | 1.6 ± 1.1 | 0.018 |
| Roof | 2.4 ± 1.4 | 1.8 ± 1.0 | 2.6 ± 0.8 | 0.102 |
| Mean | 2.4 ± 1.4 | 1.6 ± 0.9 | 2.1 ± 1.1 | 0.015 |
| *Anterior wall*: | | | | |
| Annulus | 1.8 ± 1.0 | 1.1 ± 0.5 | 1.5 ± 0.9 | 0.048 |
| Roof | 2.1 ± 1.0 | 1.5 ± 0.7 | 2.6 ± 1.0 | 0.008 |
| Mean | 2.0 ± 1.1 | 1.3 ± 0.6 | 2.0 ± 1.0 | 0.002 |
| *Inferior wall*: | | | | |
| Annulus | 2.3 ± 1.0 | 1.4 ± 0.8 | 2.0 ± 0.9 | 0.015 |
| Roof | 2.7 ± 1.9 | 1.4 ± 0.6 | 2.6 ± 1.6 | 0.022 |
| Mean | 2.5 ± 1.5 | 1.4 ± 0.7 | 2.3 ± 1.1 | 0.001 |
| Mean annular | 2.3 ± 1.4 | 1.3 ± 0.8 | 1.6 ± 1.2 | 0.000 |
| Mean roof | 2.9 ± 1.3 | 1.8 ± 0.9 | 3.0 ± 1.8 | 0.000 |
| *P*-value | 0.016 | 0.003 | 0.000 | |
| Total | 2.6 ± 1.6 | 1.5 ± 0.9 | 2.3 ± 1.4 | 0.000 |

*Notes*: MR = Mitral valve regurgitation; MS = Mitral valve stenosis; IAS = Inter-atrial septum.

Another fact that should be noted is that with respect to the results mentioned in Tables III–V, in most of the comparisons, there were significant differences between the annular and roof segments. Calculation of the mean of these values in the LA walls may be problematic inasmuch as in some of the mean values, there is a considerable standard deviation. However, it is noteworthy that these mean values were calculated in the same situation in the three groups in the present study.

### 4.3. Left Atrial Function in Mitral Stenosis Compared to Mitral Regurgitation

Our findings demonstrated a significant decrease in LA deformational indices in the MS patients by comparison with the MR patients and normal subjects. This reduction in LA strain and SR in our MS patients signifies that pressure overload could have more severe deleterious effects on the LA than could MR despite similar LA volume indices, which could be secondary to hemodynamic load and higher LA pressure in MS or the direct involvement of the LA myocardial fibers by pathological changes related to the rheumatic process. According to previous studies, as the atrium fills during the reservoir phase, the atrial myocardium (like the ventricle) stores elastic energy, which is released when the mitral valve opens to aid early ventricular filling.[25] Hoit et al.[12] examined LA mechanics during LV dysfunction and compared the compensatory response with a normal atrium versus a failing atrium (induced with rapid atrial pacing). With a normal atrium, reservoir function increased by 19% and booster pump function (atrial contraction) nearly doubled to maintain cardiac output despite a fall in LVEF from 57% to 32%. In contrast, with a failing atrium, reservoir function fell by 30%, conduit function increased by 33%, and atrial kick disappeared. Our results showed that in conditions with the same LA sizes, the reservoir function of the LA could be diminished more significantly in pressure overload than volume overload, which means that pressure overload may have more pathologic effects on the atrial wall and its function as assessed by strain imaging. The other components of atrial function (conduit and booster) and their changes following pressure or volume overload were not assessed in the present study and should be addressed in another research.

### 4.4. Clinical Implication

In this study, we showed that the tissue Doppler measurement of LA longitudinal strain can be used for the early detection of LA impairment in patients with asymptomatic MS and MR and that it may be useful for referring patients for surgical correction before the onset of irreversible atrial myocardial damage. Further studies should be performed to examine whether using other measures to define functional capacity more precisely might show any correlation between functional capacity and severity of LA dysfunction as assessed by strain imaging study.

### 4.5. Limitations

First and foremost among the limitations in the present study is that we used Doppler-based measurement of velocity, strain, and SR despite the dependence of these parameters on the angle of the beam direction.[26] We, however, took great care to ensure the alignment and the quality of the data collected. Another drawback of significance was the difference in the mechanism of pressure and volume overload: our MS patients had rheumatic involvement and MR in our patients was mostly due to myxomatous and flail mitral valve. We could not evaluate the effect of the rheumatic process on the LA wall or the mitral annulus properties. Furthermore, we did not know the time of MR development in our MR group, and in sub-acute forms (in flail mitral valve), the LA did not have enough time to remodel. Also, noise precluded us from evaluating some segments, and we did not include there segments in the calculation of the data ($\approx 10\%$ of the all segments). Our study populations were matched in terms of general characteristics, with the exception of gender, which may have influenced the results. Nikitin et al.[27] reported that the LA anteroposterior diameter is smaller in women than in men, but overall LA function is not influenced by sex.

Further studies with larger sample sizes and sex-matched groups are required to confirm more precisely the potential importance of atrial regional mechanical function. Magnetic resonance imaging (MRI) and three-dimensional echocardiography can improve the accuracy of the assessment of LA morphology and function, but they are not widely available.

## 5. CONCLUSION

Motion and deformation parameters were reduced in our asymptomatic MS (LA pressure overload) and MR (LA volume overload) groups compared with those in our normal subjects; the difference was more significant in pressure overload. This reduction, especially in strain and SR, shows that the reservoir function of the LA could be compromised more severely in asymptomatic MS patients. The prognostic significance of this finding should be addressed in future studies.



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Received: 31 December 2013. Accepted: 25 March 2014.