Cardiac Mechanics in Mild Hypertensive Heart Disease
A Speckle-Strain Imaging Study

Arumugam Narayan, MD; Gerard P. Aurigemma, MD; Marcello Chinali, MD, PhD; Jeffrey C. Hill, RDCS; Theo E. Meyer, MD, PhD; Dennis A. Tighe, MD

Background—We hypothesized that abnormalities in regional systolic strain ($\varepsilon$) might be present among hypertensive subjects with normal ejection fraction, and, if present, could be used to identify patients at high risk for heart failure. The aim of the current case-control study was to use speckle tracking imaging to identify subclinical global and regional systolic function abnormalities in hypertensive subjects with normal ejection fraction.

Methods and Results—Standard 2D Doppler echocardiography, tissue Doppler imaging, and 2D speckle strain imaging were performed in 52 hypertensive subjects with normal ejection fraction and 52 control subjects of similar age. Peak systolic ($S'$), and diastolic ($E'$) annular velocities were obtained by tissue Doppler imaging, whereas longitudinal myocardial systolic velocity ($V_l$) and circumferential, longitudinal, and radial strains ($\varepsilon_c$, $\varepsilon_l$, $\varepsilon_r$) were obtained by speckle tracking. Midwall shortening and peak basal longitudinal strain ($\varepsilon_l$) were used as indices of regional function. Hypertensive subjects had lower velocities—tissue Doppler imaging $E'$ and $S'$, and $V_l$—and evidence of reduced regional function. Surprisingly, however, global $\varepsilon$ values did not differentiate hypertensive subjects from control subjects. Among hypertensive patients, significant inverse associations were found between left ventricular mass and global longitudinal and circumferential $\varepsilon$ (both $P<0.05$).

Conclusions—Hypertensive heart disease with normal ejection fraction is associated with reduced myocardial velocities and reduced regional function but normal global $\varepsilon$. Our data suggest that velocity abnormalities occur early in hypertension and may be an appropriate target for preventive strategies because they occur before abnormalities in global $\varepsilon$. (Circ Cardiovasc Imaging. 2009;2:382-390.)

Key Words: mechanics ■ systole ■ hypertension ■ left ventricular mass ■ echocardiography

Hypertension and heart failure are intimately related. Most patients with heart failure have antecedent hypertension, and clinical trials show that the incidence of heart failure among hypertensive subjects is between 1% and 2% per year.$^{1,2}$ Identifying subclinical left ventricular (LV) systolic dysfunction among hypertensive subjects might be helpful in identifying patients at higher risk for heart failure. Also, given the prevalence of hypertension in the population, identifying patients at high risk for heart failure might permit targeted preventive strategies.

Clinical Perspective on p 390

We and others have previously demonstrated that M-mode echocardiography can be used to measure circumferential shortening at the midwall ($FS_{mw}$, %)$^{3,4}$ a measure of regional circumferential strain. Reduced $FS_{mw}$ is prevalent among hypertensive subjects with hypertrophic remodeling. $^{3}$ and de Simone et al$^{4}$ have shown that low $FS_{mw}$ in relation to stress is a marker of poor outcome. However, $FS_{mw}$ is related to ventricular geometry, that is, the relative wall thickness (RWT).$^{3}$ Newer methods, such as 2D speckle imaging, appear to provide a direct, angle- and geometry-independent measure of circumferential strain ($\varepsilon_c$).$^5$

The aim of the current case-control study was to use speckle tracking imaging as well as standard echocardiographic techniques to identify subclinical abnormalities in LV function among hypertensive subjects as compared with normal control subjects. Accordingly, we studied (1) measures of systolic and diastolic function; (2) the relationship between measures of circumferential shortening and measures of LV remodeling, that is, LV mass index and RWT; and (3) the relationship between indices of myocardial function with measures of remodeling in hypertensive patients as compared with normal control subjects.

Methods

Study Population

Adult subjects of either sex (age, 18 to 90 years) attending the outpatient clinics at UMassMemorial Medical Center were recruited to participate in this study. The study was approved by the Human Subjects Committee of UMass Memorial. At the time of the
echocardiographic study, height, weight, and blood pressure were recorded. The exclusion criteria included a history of diabetes, coronary artery disease, myocardial infarction, stroke, valvular heart disease, atrial fibrillation, and congestive heart failure. After applying exclusion criteria, the study population consisted of 104 participants (52 hypertensive subjects and 52 clinically normal control subjects). The majority of hypertensive subjects were being treated with antihypertensive agents, including 23% who were taking β-blockers.

### Echocardiography

Standard echocardiographic images were obtained, including M-mode and 2D imaging, color-coded tissue Doppler, as well as mitral annular pulsed wave Tissue Doppler imaging. Circumferential, longitudinal, and radial strains ($e_c$, $e_l$, $e_r$) and longitudinal myocardial velocity ($V_l$) were obtained using speckle tracking software, as detailed below. Standard LV chamber and wall thickness measurements were made using American Society of Echocardiography standards; these included septal thickness, posterior wall thickness, LV end-systolic wall thickness, LV end-diastolic dimension, and LV end-systolic dimension. End-diastolic relative wall thickness was calculated as twice the posterior wall thickness divided by the end-diastolic dimension; LV mass was calculated using the conventional cube formula. Assignment of patients into categories of hypertrophy was made by reference to the American Society of Echocardiography chamber quantitation guidelines. Hypertrophy was diagnosed if the LV mass index (LVMi) was abnormal (>95 g/m² for women, >115 g/m² for men). Concentric geometry was diagnosed if the RWT exceeded 0.42 for both men and women. Concentric remodeling was diagnosed if LVMi was normal but RWT was high.

### Speckle Tracking Analysis by 2D Echocardiography

The 2D images acquired in the short- and long-axis planes were analyzed using the custom acoustic tracking software that allowed a semiautomated analysis of ventricular dynamics (EchoPAC Advanced Analysis Technologies, version 5.5, General Electric, Milwaukee, Wis.). Because reliable operation of this software required a minimum frame rate of 30 Hz, frame rates of 40 to 90 Hz were used in this study. Data were obtained from the apical 4-chamber and short-axis views (papillary muscle level). Three sets of images were analyzed and averaged to improve accuracy. We used this analysis to obtain data on global $e$ as well as regional $e_l$ (obtained in the basal segments; see below).

### Regional Function

We computed FSmw using previously published methodology. FSmw was considered to be an index of regional circumferential function. We averaged values from all 6 segments for LV $e_l$ for comparison with FSmw measurements. We report basal $e_l$, the mean value for the 2 basal segments, that is, the basal septal and the basal lateral walls, as an index of regional longitudinal function. Circumferential and meridional end-systolic stress, indices of afterload, were computed using previously described methodology.

### Statistical Analysis

Continuous variables are reported as mean values ± standard deviation; categorical variables are reported as percentages. Analyses were performed with SPSS version 15.0 (SPSS Inc, Chicago, Ill.). Normal distribution of variables was assessed by Kolmogorov-Smirnov test. Comparison of categorical variables (eg, sex) was performed by χ² test. Comparison of continuous anthropometric data (including age and body size and blood pressure parameters) of hypertensive and normal participants was carried out by Student t test. Comparison of echocardiographic characteristics (including LV mass and geometry, left atrial geometry and parameters of diastolic function, systolic function, and speckle tracking) was carried out by analysis of covariance, with probability values adjusted for differences among groups in age, sex, distribution, and body surface area. An additional post hoc comparison of echocardiographic characteristics (by age- and sex-corrected analysis of covariance) was performed based on the presence of normal or depressed FSmw in relation to circumferential stress in hypertensive subjects. A probability value <0.05 was considered statistically significant.

### Results

#### Clinical and Demographic Data

Clinical characteristics of the study population are found in Table 1. By definition, hypertensive subjects had higher blood pressure; hypertensive subjects were also more likely to be men ($P=0.06$). This nonsignificant sex difference partially accounts for the higher weight, body surface area, and body mass index in this group.

#### Cardiac Structure

Echocardiographic assessment of cardiac structure is found in Table 2 and Table 3. As expected, the hypertensive subjects had a higher LV mass (both unindexed and indexed) and RWT than normal control subjects. One fourth of the hyper-
tensive subjects had LV hypertrophy, using the American Society of Echocardiography partition values. Most hypertensive subjects had evidence of hypertrophic remodeling, with 69% having concentric geometry, and 21% having concentric hypertrophy. As expected, most control subjects had normal LV mass index and geometry.

### Systolic Function Analysis

EF and endocardial shortening were similar between the groups (Table 4). As expected, FS\text{mw} was significantly lower among hypertensive subjects. Similarly, basal $e_c$ was significantly lower in hypertensive subjects. In addition, mean values for both circumferential and meridional stress were significantly lower in the hypertensive subjects, reflecting hypertrophic remodeling. Surprisingly, there was no demonstrable difference between hypertensive subjects and normal control subjects with regard to any of the 3 measured global strain parameters: $e_c$, $e_l$, and $e_c$. Of the Doppler variables, only peak longitudinal velocity by speckle tracking ($V_l$) (3.9 versus 4.4 cm/s, $P<0.001$) and peak tissue Doppler systolic velocity ($S'$) (9 versus 10 cm/s, $P<0.01$) were significantly lower among hypertensive subjects than normal control subjects.

### Stress-Shortening and Stress-Strain Relations

Figures 1 and 2 show the relationship between shortening parameters and stress and between shortening/strain parameters and RWT. There was a weak, nonsignificant correlation between FS\text{mw} and $e_c$ in both normal and hypertensive subjects ($r=0.05, P=NS$). When we examined the stress-shortening relationships, we observed that approximately one fourth of hypertensive subjects fell below the 95% confidence limits of the normal stress-FS\text{mw} relationship (Figure 1, left panel). Examination of the relationship between $e_c$ and circumferential stress showed the expected inverse relationship ($r=-0.28, P<0.01$).

As has been shown previously, FS\text{mw} was closely related to RWT ($r=-0.62, P<0.001$), whereas there was no relationship between $e_c$ and RWT ($r=0.05, P=NS$) (Figure 2). Although there was a weak inverse correlation between longitudinal strain and/or regional longitudinal strain (basal $e_l$) versus meridional stress, these relationships were not statistically significant (not shown).

### Global and Regional Systolic Parameters in Hypertensive Patients

As shown in Figure 3 (upper left panel), in the hypertensive subjects we found a significant inverse relation between LV mass and indices of global LV systolic function, including both longitudinal $e$ ($r=-0.51; P<0.001$) and circumferential $e$ ($r=0.28; P<0.05$). In a separate analysis of the population by tertiles of LV mass, significantly lower $e_l$ was observed in patients with LV mass > 190 g ($P<0.01$). A similar but nonsignificant result was observed for $e_c$.

By contrast, indices of regional systolic function (FS\text{mw} and basal $e_l$) were strongly associated with RWT. Figure 3 (left panel) shows the significant association between FS\text{mw} ($r=-0.78; P<0.001$) and basal $e_l$ ($r=-0.36; P<0.01$, respectively) and RWT. In an additional analysis separating hypertensive patients into tertiles of RWT, significantly lower FS\text{mw} and basal $e_l$ was observed in patients with RWT > 0.49 ($P<0.001$ for both).

### Depressed Midwall Shortening in Relation to Stress

To further explore the association between cardiac strain parameters and traditional echocardiographic indices of LV structure and function, we performed a post hoc analysis to investigate characteristics of patients whose FS\text{mw} in relation to circumferential stress fell below 95% confidence limits of the normal relationship (Figure 1). There were 14 such individuals. As shown in Table 5, patients with depressed FS\text{mw} in relation to stress were slightly (although not significantly) older, had higher wall thickness and RWT, and a lower LV diastolic diameter, E', and E/A ratio. Although systolic velocity indices were similarly reduced in hyperten-

### Table 3. LV Remodeling in the Study Population

<table>
<thead>
<tr>
<th></th>
<th>Normal (n=52, %)</th>
<th>HTN (n=52, %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVH</td>
<td>0</td>
<td>25*</td>
</tr>
<tr>
<td>Abnormal RWT</td>
<td>13</td>
<td>69*</td>
</tr>
<tr>
<td>Normal geometry</td>
<td>87</td>
<td>27*</td>
</tr>
<tr>
<td>Concentric remodeling</td>
<td>13</td>
<td>48*</td>
</tr>
<tr>
<td>Concentric LVH</td>
<td>0</td>
<td>21*</td>
</tr>
<tr>
<td>Eccentric LVH</td>
<td>0</td>
<td>4*</td>
</tr>
</tbody>
</table>

HTN indicates subjects with hypertension; LVH, LV hypertrophy.

*Unadjusted $P<0.05$ versus normal.

### Table 4. Systolic Function in the Study Population

<table>
<thead>
<tr>
<th></th>
<th>Normal (n=52)</th>
<th>HTN (n=52)</th>
<th>$P$ Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>EF and shortening</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EF, %</td>
<td>66±7</td>
<td>68±6</td>
<td>NS</td>
</tr>
<tr>
<td>FS\text{endo}, %</td>
<td>36±7</td>
<td>38±6</td>
<td>NS</td>
</tr>
<tr>
<td>FS\text{mw}, %</td>
<td>18±3</td>
<td>16±3</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Stress</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma_c$, g/cm²</td>
<td>98±24</td>
<td>78±23</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>$\sigma_m$, g/cm²</td>
<td>51±14</td>
<td>39±12</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Strain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$e_c$, %</td>
<td>22±3</td>
<td>22±4</td>
<td>NS</td>
</tr>
<tr>
<td>$e_l$, %</td>
<td>22±3</td>
<td>20±3</td>
<td>NS</td>
</tr>
<tr>
<td>$e_r$, %</td>
<td>44±11</td>
<td>42±12</td>
<td>NS</td>
</tr>
<tr>
<td>Basal $e_c$, %</td>
<td>20±3</td>
<td>18±3</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Velocity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_l$, cm/s</td>
<td>4.4±0.9</td>
<td>3.9±0.7</td>
<td>≤0.005</td>
</tr>
<tr>
<td>$S'$, cm/s</td>
<td>10±2</td>
<td>9±2</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

HTN indicates subjects with hypertension; FS\text{endo}, fractional shortening measured at the endocardium; c, circumferential; m, meridional; l, longitudinal; r, radial.

*P values adjusted for differences among groups in age, sex, and body surface area.

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sive patients with normal and reduced midwall mechanics, a significant reduction in longitudinal global strain could be observed only in hypertensive patients with depressed stress-corrected FSmw. By contrast, compared with normal control subjects, a stepwise decrease in basal longitudinal strain was observed in hypertensive patients with normal and impaired midwall mechanics ($P<0.05$ for both).

**Figure 1.** Left panel shows the correlation between FSmw and circumferential stress; right panel shows the correlation between mean circumferential strain by speckle tracking and circumferential stress. The fit line and 95% confidence limits shown are derived from the normal subjects. For this and the other graphics, hypertensive subjects are shown in black triangles and normal control subjects in open circles. Approximately one fourth of hypertensive patients fall below the confidence limits for FSmw-stress relationship.

**Diastolic Function**

When we examined the relationships between diastolic function parameters and LV structure variables, we found that both E' and E/E' correlated with RWT ($r=-0.34$, $r=-0.21$, $P<0.05$) (Figure 4). In addition, E-wave deceleration time ($r=0.37$, $P<0.001$), and A' were positively correlated with RWT ($r=0.31$, $P<0.001$) (data not shown graphically).

**Figure 2.** Left panel shows the correlation between FSmw and RWT, a descriptor of LV geometry; right panel shows the correlation between mean circumferential strain and RWT. A significant correlation between FSmw and RWT was observed. By contrast (right panel), there was no correlation between circumferential strain and RWT.
Correlation Between Shortening and Lengthening Velocities

$S'$ and $E'$ were correlated both in hypertensive and normal subjects ($r=0.56$, $P<0.001$). A similar relationship was observed between $V_l$ versus $E'$ ($r=0.53$, $P<0.001$) (data not shown graphically).

Discussion

We undertook this study to determine whether speckle tracking imaging could provide novel insights into systolic function among hypertensive subjects. A principal advantage of speckle tracking imaging is that it offers measurements of strain that, unlike tissue Doppler, are not dependent on insonation angle and compare closely with those obtained by MRI tagging. Thus, for the first time, a noninvasive method is available for widespread use that would permit measurement of the 3 principal systolic strains: circumferential, longitudinal, and radial. We hypothesized that this method would identify subclinical abnormalities in systolic function, which might eventually be used to target hypertensive patients who might be at increased risk for heart failure. We studied unselected patients whose hypertensive heart disease was uncomplicated by coronary heart disease, heart failure, or severe valvular disease. Thus, we believe that our results are potentially applicable to a large percentage of hypertensive subjects seen in daily practice.

Principal Findings

Hypertensive subjects had, on average, mean strain values that were similar to those found in normal control subjects. Depressed global strain was seen only in those patients with more extreme LV hypertrophic remodeling, also characterized by depressed midwall shortening in relation to circumferential stress. Second, whereas the extent of shortening by strain analysis was not significantly reduced (except for patients with more advanced hypertensive heart disease),
velocity of shortening was reduced: Both tissue Doppler longitudinal velocity (peak S’) and peak longitudinal velocity by speckle tracking (V_L) were lower among hypertensive subjects. Third, as expected from our prior work, regional function was abnormal. Mean midwall shortening, which we used as an index of regional circumferential function, was reduced in hypertensive subjects, and a sizable group of hypertensive subjects had reduced FSmw in relation to stress (Figure 1). In the current population of patients, with a 25% prevalence of LV hypertrophy, approximately one fourth fell below confidence limits of the normal stress-shortening relationship. In parallel, regional longitudinal function, as assessed by basal longitudinal strain, was also reduced. Both of these indices of regional systolic function, FSmw and basal longitudinal strain, were related to LV geometry (RWT), whereas global indices of strain were mostly related to LV mass. Finally, diastolic filling variables were abnormal in direct relation to hypertrophic remodeling.

### Regional Dysfunction in Hypertensive Heart Disease

We used FSmw as an index of regional circumferential function because the current speckle tracking software does not permit assessment of transmural strains. Our data corroborate prior work with hypertensive subjects by our group and others, which has consistently demonstrated that midwall shortening is inversely related to stress and, when stress-shortening plots are constructed, approximately one fourth of individuals have low midwall shortening in relation to stress. We observed similar data in the current population. This depression of myocardial function is not apparent when endocardial indices, for example, endocardial fractional shortening or ejection fraction, are used to gauge systolic function. We have usually interpreted these data to mean that concentric hypertrophy allows for normal chamber function despite reduced shortening at the midwall. Similar results have been found in patients with aortic stenosis, in hypertensive men with concentric remodeling, and in patients with diastolic heart failure. These results have been corroborated by others. Stated otherwise, endocardial indices of function may conceal systolic dysfunction when relative wall thickness is high. Basal ε_l was used as a measure of regional longitudinal function and was reduced in hypertensive heart disease. To our knowledge, this depression of regional function using speckle strain technology has not been previously demonstrated.

### Velocity Is Reduced in Patients With Hypertension and Remodeling

We also found that the velocity of longitudinal shortening was reduced among hypertensive subjects; V_L, S’, and E’ were all lower among hypertensive subjects than among normal control subjects. That velocity of shortening in the longitudinal plane is reduced has been shown by Yip et al, who observed that the peak systolic mitral annular velocity by Tissue Doppler imaging (TDI) was lower in patients with LV hypertrophy and diastolic heart failure as compared with age-matched normal subjects. Bruch et al studied patients with acromegaly and found that the E, E/A ratio, and E’ were lower in patients with active acromegaly as compared with age-matched normal subjects and well-controlled acromegaly, whereas S’ and E/E’ ratio did not differ. Nikitin et al evaluated patients with heart failure and normal global systolic function. They observed that E’ and S’ were lower in this group, whereas E/E’ ratio was higher as compared with normal subjects. Vinereau et al demonstrated similar findings among hypertensive subjects and patients with hypertrophic cardiomyopathy with significant hypertrophic remodeling. These data confirm observations that we made in

### Table 5. Characteristics of Patients With Low Midwall Shortening in Relation to Stress

<table>
<thead>
<tr>
<th></th>
<th>Normal (n=52)</th>
<th>HTN Normal FSmw/CS (n=38)</th>
<th>HTN Abnormal FSmw/CS (n=14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>49±14</td>
<td>51±15</td>
<td>58±15</td>
</tr>
<tr>
<td>Cardiac structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Septal thickness, cm</td>
<td>0.8±0.1</td>
<td>1.0±0.1; † ‡¶</td>
<td>1.3±0.3¶</td>
</tr>
<tr>
<td>Posterior wall thickness, cm</td>
<td>0.8±0.1</td>
<td>1.0±0.1; † ‡¶</td>
<td>1.2±0.3¶</td>
</tr>
<tr>
<td>LVIDd, cm</td>
<td>4.5±0.5</td>
<td>4.6±0.5; *</td>
<td>4.2±0.5*</td>
</tr>
<tr>
<td>LVIDs, cm</td>
<td>2.9±0.4</td>
<td>2.8±0.4</td>
<td>2.7±0.5*</td>
</tr>
<tr>
<td>LA size, cm</td>
<td>3.2±0.4</td>
<td>3.6±0.4*</td>
<td>3.6±0.5*</td>
</tr>
<tr>
<td>LV mass, g</td>
<td>116±31</td>
<td>167±54‡</td>
<td>191±96‡</td>
</tr>
<tr>
<td>LV mass/BSA, g/m²</td>
<td>66±13</td>
<td>86±20‡</td>
<td>99±48‡</td>
</tr>
<tr>
<td>RWT</td>
<td>0.35±0.05</td>
<td>0.42±0.05; *</td>
<td>0.61±0.17¶</td>
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<tr>
<td>EF and shortening</td>
<td></td>
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<td></td>
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<tr>
<td>EF, %</td>
<td>66±9</td>
<td>69±6‡</td>
<td>65±10</td>
</tr>
<tr>
<td>FSendo, %</td>
<td>36±7</td>
<td>39±5‡</td>
<td>36±7</td>
</tr>
<tr>
<td>FSmw, %</td>
<td>21±3</td>
<td>21±2</td>
<td>15±3¶</td>
</tr>
<tr>
<td>Stress</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>σ_c, g/cm²</td>
<td>98±23</td>
<td>82±19</td>
<td>74±30‡</td>
</tr>
<tr>
<td>σ_m, g/cm²</td>
<td>51±13</td>
<td>41±10‡</td>
<td>30±17†</td>
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<tr>
<td>Strain</td>
<td></td>
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<tr>
<td>ε_l, %</td>
<td>22±3</td>
<td>22±4</td>
<td>22±5</td>
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<td>ε_t, %</td>
<td>22±3</td>
<td>21±3</td>
<td>19±4*</td>
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<td>ε_r, %</td>
<td>44±11</td>
<td>43±13</td>
<td>38±12</td>
</tr>
<tr>
<td>Basal ε_t, %</td>
<td>20±3</td>
<td>19±3</td>
<td>16±4¶</td>
</tr>
<tr>
<td>Velocity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V_L, cm/s</td>
<td>4.4±0.9</td>
<td>3.8±0.6τ</td>
<td>3.9±0.7*</td>
</tr>
<tr>
<td>S’, cm/s</td>
<td>10±2</td>
<td>9±2*</td>
<td>9±2*</td>
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<tr>
<td>Diastolic parameters</td>
<td></td>
<td></td>
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<tr>
<td>E, cm/s</td>
<td>84±20</td>
<td>84±20</td>
<td>77±20</td>
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<tr>
<td>A, cm/s</td>
<td>64±20</td>
<td>73±20*</td>
<td>88±30§</td>
</tr>
<tr>
<td>E/A</td>
<td>1.4±0.5</td>
<td>1.2±0.3*</td>
<td>0.9±0.3¶</td>
</tr>
<tr>
<td>DT, ms</td>
<td>201±25</td>
<td>238±35‡</td>
<td>247±65‡</td>
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<tr>
<td>E’, cm/s</td>
<td>15±4</td>
<td>12±3*</td>
<td>10±2§</td>
</tr>
<tr>
<td>E/E’</td>
<td>6.3±2</td>
<td>7.3±2*</td>
<td>7.9±4</td>
</tr>
</tbody>
</table>

*P<0.05; †P<0.01; ‡P<0.001 compared with normal group.
§P<0.001 compared with Normal FSmw/CS group.

HTN indicates hypertension; LVIDd, LV diastolic dimension; LVIDs, LV systolic dimension; LA size, left atrial anteroposterior size; BSA, body surface area; EF, ejection fraction; FSendo, fractional shortening measured at the endocardium. 

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hypertensive subjects with concentric hypertrophy, using
M-mode mitral annular displacement.3 To reiterate, despite
this difference in velocities, average strains are no different in
hypertensive subjects than in normal individuals and support
the position that velocity abnormalities precede global strain
abnormalities in hypertensive subjects.

Regional Versus Global Function
Why is global circumferential strain normal in hypertensive
patients when FSmw is not, and why do our results differ
from those obtained by MRI tagging? We believe that there
are several potential explanations. First, FSmw estimates
circumferential strain at the midwall layer exclusively. By
contrast, in the current software configuration, \( e_c \) measures
the average strain throughout the region of interest, and
therefore the mean \( e_c \) value is an average of strains in the
epicardial, midwall, and subendocardial regions.18 It is well
known that there is a gradient of strains from the epicardium
to the subendocardium.19,20

A second explanation for our results is that the mean LV mass
of our patients was much less than what was reported in the 3
prior relevant studies. In fact, Palmon et al18 reported a mean
LVMI of 142 g/m² and a mean RWT of 0.49 in their study,
Aurigemma1 found a mean LVMI of 154 g/m² and a mean RWT
of 0.62, and Vinereanu17 described a population with mean
LVMI of 175 g/m² and mean RWT of 0.52, suggesting that
these investigations were studying patients with more advanced
disease. In support of this hypothesis is our finding of a
significant negative association between LV mass and \( e_c \).

Diastolic Function
There appeared to be an inverse relationship between LV
remodeling and longitudinal velocities. Hypertension was
associated with reduced longitudinal velocity abnormalities,
seen both with speckle tracking imaging and with TDI. That
longitudinal velocity is depressed in hypertensive subjects
with normal EF has been demonstrated previously, as noted
above.17 Our data support the notion that abnormalities in
diastolic filling (and filling pressure) (1) precede abnormali-
ties in global strain and LV systolic function (eg, EF) and (2)
are related to abnormalities in longitudinal lengthening and
LV geometry.19,20 As noted above, the statistically significant
close correlation between \( S' \) and \( E' \) suggests that initial
diastolic filling is closely related to longitudinal shortening.20

Limitations
Our \( e_c \) measurements were not directly validated by us using
MRI tagging. However, Amundsen et al9 showed a good
correlation between longitudinal 2D strain values and those
obtained by MRI tagging. In normal individuals, 2D \( e \) was
not feasible in approximately 6% of segments. We have
previously shown that the interobserver and intraobserver
variances for 2D speckle strain measurements were 12% and
11%, respectively.5 This variability, though comparable
to those shown by Serri et al21 and Korinek et al,22 is
substantial. However, we do not believe that the variability
data vitiate the results of this cross-sectional study because
there is no reason to believe that there is more variability in
hypertensive subjects than in control subjects. At the present
time, it is not possible to measure transmural values for
circumferential strain using speckle tracking technology;
such ability would certainly shed light on the meaning of
reduced midwall shortening in relation to stress, as was
observed in this population of hypertensive subjects.

Although not significantly different, the normal control
subjects were slightly younger and more often women than

Figure 4. Left panel shows the correlation between early diastolic mitral annular velocity (E') and RWT; right panel shows the correlation between E/E' ratio and RWT. There is an inverse correlation between early diastolic mitral annular velocity (E') and RWT and a modest direct correlation between E/E' ratio and RWT.
the hypertensive subjects. Despite our statistical correction by analysis of covariance, we cannot say for certain that the differences in velocities and filling abnormalities were not partially influenced by age and sex. However, as previously shown by Sun et al and recently confirmed by Marwick et al in nearly 250 normal volunteers, there does not appear to be a significant age or sex dependence of strain values.

Finally, the prevalence of hypertensive subjects with concentric remodeling is high (48%) compared with previous studies. This high prevalence is likely because most of our hypertensive subjects were treated and because we used a lower relative wall thickness and lower LVMI cutoff to define concentric geometry/ hypertrophy than previous studies.

Conclusion

In hypertensive subjects with LV remodeling, normal EF, and no history of heart failure, velocity of shortening and lengthening, midwall shortening, and diastolic filling variables are abnormal, whereas global systolic strains in all 3 planes are not significantly reduced. We conclude that reduced FS_mw in mild hypertensive heart disease may reflect, primarily, abnormal LV geometry and not reduced myocardial function. The velocity abnormalities observed in this series of patients with mild hypertensive heart disease with normal EF are associated with higher E/E' and left atrial pressure. Furthermore, velocity abnormalities occur in direct proportion to RWT. However, in contrast to velocity of shortening, the extent of circumferential and radial shortening is preserved, and only mild reduction in longitudinal strain can be found in hypertensive patients with high LV mass and reduced FS_mw. These data suggest that velocity abnormalities occur relatively early in hypertensive subjects, are associated with (or even responsible for) diastolic filling abnormalities, and thus may be a target for preventive strategies.

Acknowledgments

We thank Jacqueline Jolie for assistance in manuscript preparation and Allison McNamee, RN, for assistance in patient recruitment.

Disclosures

Dr Aurigemma received research grants from Philips Ultrasound and Toshiba America Medical Systems.

References


3. Narayanan et al Cardiac Mechanics in Hypertensive Heart Disease


Clinical identification of high-risk hypertensive patients is desirable for preventive strategies. We hypothesized that abnormalities in regional systolic strain ($\varepsilon$) may help identify such high-risk patients even when the ejection fraction is normal. Accordingly, the aim of the current study was to use echocardiographic speckle tracking imaging, a technique that is independent of ultrasound angle of interrogation, to identify subclinical global and regional systolic function abnormalities in hypertensive subjects with normal ejection fraction. Accordingly, 2D speckle strain imaging was performed in 104 subjects (52 hypertensive subjects, 53±12 years of age, and 52 control subjects, 49±13 years of age; $P=0.82$), all of whom had normal ejection fraction. We measured systolic velocities as well as systolic strains. Our principal findings were that when compared with control subjects, hypertensive subjects had lower myocardial systolic velocities but similar values for $\varepsilon$ in all 3 planes: longitudinal, radial, and circumferential. Among hypertensive subjects, significant inverse associations were found between left ventricular mass and global longitudinal ($r=-0.51$) and circumferential $\varepsilon$ ($r=-0.21$; both $P<0.05$). To summarize, mild hypertensive heart disease with normal ejection fraction was associated with reduced myocardial velocities but normal global $\varepsilon$. We interpret these data as showing that velocity abnormalities occur early in hypertension, are related to ventricular geometry, and thus may be an appropriate target for preventive strategies because they occur before detectable abnormalities in global strain.
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_Circ Cardiovasc Imaging_. 2009;2:382-390; originally published online July 21, 2009;
doi: 10.1161/CIRCIMAGING.108.811620
_Circulation: Cardiovascular Imaging_ is published by the American Heart Association, 7272 Greenville Avenue,
Dallas, TX 75231
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Print ISSN: 1941-9651. Online ISSN: 1942-0080

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