Evolving Changes in Doppler Mitral Flow Velocity Pattern in Rats With Hypertensive Hypertrophy

Tohru Masuyama, MD, FACC*, Kazuhiro Yamamoto, MD, PhD, FACC,† Yasushi Sakata, MD,* Reiko Doi, MD, PhD,* Nagahiro Nishikawa, MD,* Hiroya Kondo, MD, PhD,* Keiko Ono, MD,* Tsunehiko Kuzuya, MD, PhD,* Motoaki Sugawara, MD, PhD,† Masatsugu Hori, MD, PhD, FACC*

Suita and Tokyo, Japan

OBJECTIVES

The aim of our study was to explore evolving changes in a mitral flow velocity pattern (MFVP) and its hemodynamic and pathological correlates in hypertensive rats in an isolated diastolic heart failure model.

BACKGROUND

Development of left ventricular (LV) hypertrophy and concomitant diastolic dysfunction cause heart failure in hypertensive hearts even with normal systolic function; however, associated evolving change in MFVP is still unclear.

METHODS

Mitrail flow velocity pattern was recorded every 2 weeks from 7 to 19 weeks in six hypertensive rats. Hemodynamic and pathological correlates of Doppler mitral flow indexes were examined as an additional part of the study using the hypertensive rats at the age of 13 weeks (compensatory stage, n = 7) and at 19 weeks (heart failure stage, n = 8).

RESULTS

Initial development of pressure overload LV hypertrophy resulted in a decrease in early diastolic filling wave (E), a reciprocal increase in the filling wave due to atrial contraction (A) and prolongation of deceleration time of E wave (relaxation abnormality pattern). These changes were associated with an increase in tau, an index of LV relaxation, but without a change in LV end-diastolic pressure. Transition to congestive heart failure caused an increase in E, a decrease in A and shortening of deceleration time. These changes were not associated with further increase in tau but with elevation of LV end-diastolic pressure, reflecting marked LV hypertrophy and myocardial fibrosis.

CONCLUSIONS

Development of pressure overload LV hypertrophy is associated with evolving changes in MFVP from normal to relaxation abnormality pattern and, in turn, to pseudonormalized to restrictive pattern. Analysis of MFVP may be useful to follow not only functional but also constitutional changes of the myocardium in hypertensive hearts. (J Am Coll Cardiol 2000; 36:2333–8) © 2000 by the American College of Cardiology

Progressive left ventricular (LV) hypertrophy (LVH) and associated diastolic dysfunction are considered to alter Doppler mitral flow velocity pattern (MFVP) from a normal to a relaxation abnormality pattern and, in turn, to a pseudonormalized pattern and finally to a restrictive pattern (1–4). This idea is mainly based on the data of a number of clinical comparative studies in which MFVP was correlated to symptomatic or hemodynamic severity of the disease among patients. Longitudinal studies over the natural course have not been done so far in patients with hypertension because the disease process usually requires decades. Some longitudinal experimental works exist in which developmental LVH caused alteration in the LV filling pattern from normal to a relaxation abnormality pattern (5,6), but any of these works only observed initial changes and failed to observe the later change, i.e., alteration to a pseudonormalized or a restrictive pattern. Litwin et al. (7) performed longitudinal studies in rats with pressure-overload LVH till heart failure occurs; however, the relaxation abnormality pattern was not detected, probably because progressive LV systolic dysfunction was concomitant in their model. In human patients with hypertension, LV dysfunction is limited in diastole, at least in the initial stage, and the difference in the type of evolving LV dysfunction may account for the difference in the evolving changes in the MFVP. Thus, it would be interesting if we could study the evolving change in MFVP in a model of isolated diastolic heart failure.

We have recently established an isolated diastolic heart failure model using Dahl salt-sensitive hypertensive rats, in which hypertension develops with LVH and diastolic dysfunction but without LV systolic dysfunction throughout the natural course (8). With normal LV systolic function, the rats fall into congestive heart failure due to isolated diastolic dysfunction. In the previous models of pressure overload LVH ultimately becoming congestive heart failure marked systolic dysfunction was concomitant (7,9–11). Compared with these models our model is considered more adequate to study the chronic effects of the development of LVH and the concomitant diastolic dysfunction on MFVP because no, or only minimal, systolic dysfunction is observed even in the failing stage. This model was used in this study to explore evolving changes in MFVP associated with the development of LVH and concomitant diastolic dysfunction until isolated diastolic heart failure occurs. Hemodynamic and pathological correlates of evolving changes in MFVP were also studied in the subgroup.
Abbreviations and Acronyms

- A = filling wave due to atrial contraction
- dP/dt = first derivatives of left ventricular value of systolic and end-diastolic pressure
- DT = deceleration time of early diastolic filling wave
- E = early diastolic filling wave
- E/A ratio = the ratio of peak early diastolic filling velocity and peak filling velocity at atrial contraction
- LV = left ventricular
- LVEDP = left ventricular end-diastolic pressure
- LVH = left ventricular hypertrophy
- MFVP = mitral flow velocity pattern
- MSC = myocardial stiffness constant

METHODS

This study conforms to the guiding principles of the Osaka University Graduate School of Medicine with regard to animal care and to the position of the American Heart Association on research animal use.

Subjects. This study consists of two parts, but both parts were performed using our recently developed rat models of isolated diastolic heart failure (8). Laboratory chow containing 0.3% NaCl was continuously fed to the male Dahl-Iwai salt-sensitive (Dahl S) rats (DIS/Eis, Eisai, Tokyo, Japan) (control rats). If the diet is switched to laboratory chow containing 8% NaCl at 7 weeks old, the rats die at 19 weeks or so with marked concentric LVH, severe pulmonary edema and elevated LV end-diastolic pressure (LVEDP) but with normal or minimally impaired LV systolic function (diastolic failure model).

The first part of the study (evolution study) was done in six rats of diastolic failure model and six control rats. In these rats echocardiographic Doppler studies were repeated at the ages of 7, 9, 11, 13, 15, 17, 19 weeks, and no other study was done. The second part of the study (hemodynamic and pathological study) was done in 16 control rats at the ages of 7, 9, 11, 13, 15, 17, 19 weeks, and no other study was done. The second part of the study was done in 16 control rats at the ages of 7, 9, 11, 13, 15, 17, 19 weeks, and no other study was done.

Echocardiographic Doppler studies. Transthoracic of M-mode LV echogram and MFVP were obtained with an echocardiograph equipped with a 7.5 MHz transducer (SONOS 2000, Hewlett-Packard, Andover, Massachusetts) after anesthetization with intraperitoneal administration of ketamine HCl (50 mg/kg) and xylazine HCl (10 mg/kg) using the method previously described (8). Anterior and posterior wall thickness and LV internal dimension were measured at end-diastole and at end-systole using a modification of the American Society for Echocardiography leading edge method (12). Midwall fractional shortenings and LV mass were calculated as previously described (8,13). Left ventricular mass was presented as the ratio to body weight (mg/g). Mitral flow velocity pattern was provided for determination of peak early diastolic filling velocity (E velocity), peak filling velocity at atrial contraction (A velocity), their ratio (E/A ratio) and the deceleration time (DT) of early diastolic filling wave (Fig. 1).

Hemodynamic studies. A high-fidelity LV pressure curve was obtained and analyzed using a previously described method (8,13). The data were digitized at a rate of 2,000 samples per second for the determination of systolic and end-diastolic pressure, peak positive and negative value of its first derivatives (dP/dt) and an index of LV relaxation, tau, using a nonzero asymptote method.

Left ventricular pressure and LV M-mode echogram were simultaneously recorded in all rats except 13-week-old control rats to determine myocardial stiffness constant (MSC) as previously described (14). In this analysis, the σ-ln (1/H) relation of the LV regional wall was evaluated with a spherical model of the ventricle to calculate mean wall stress (σ) using the equation: σ = PD/4H, where P is LV pressure, D is LV short axis diameter and H is wall thickness of the region of interest. Specifically, hand-traced lines of LV pressure and M-mode echograms were scanned into a computer system (Power Macintosh 7600/120, Apple, California), and the lines were digitized at a rate of 40 samples per cardiac cycle to obtain the curves of LV pressure, internal diameter and wall thickness. The diastolic σ-ln (1/H) data points from the point of minimal wall stress to the point at end-diastole were fitted to a single exponential curve with zero asymptote: σ = C exp [K ln (1/H)], where K was determined as an MSC in the anterior and posterior walls.

Randomly selected, 10 recordings were used to assess reproducibility of the measurements of MSC. Two observers independently analyzed the same recording to determine MSC (interobserver variability). Intraobserver variability was determined by one observer repeating the analysis process a second time for comparison with his first measurements. Mean differences between observations were 0.00 ± 0.25 (interobserver) and 0.01 ± 0.14 (intraobserver), and absolute differences between observations were 0.19 ± 0.13 (interobserver) and 0.11 ± 0.08 (intraobserver).
**Pathological studies.** Hemodynamic studies were followed by adequate additional anesthesia; an incision was made in the chest, and the LV was harvested and weighed. Specimens of the LV were provided to determine myocyte diameter and the percent area of fibrosis as previously described (8,13).

**Statistical analysis.** Results are expressed as mean values ± standard deviation. Data were analyzed using a statistical software (STATVIEW II, Abacus Concepts, Berkeley, California). Differences between stages were assessed using one-factor analysis of variance and Scheffe’s test for factorial analysis. Differences between two groups were assessed using Student t test. A p value of less than 0.01 was considered statistically significant.

**RESULTS**

**Echocardiographic Doppler parameters.** Blood pressure increased from 7 to 13 weeks; thereafter, it was constant, and LV mass gradually increased from 7 to 19 weeks in hypertensive rats (Table 1). Left ventricular end-diastolic dimension was smaller in hypertensive rats than it was in control rats between 9 and 17 weeks, but midwall fractional shortening was not different between hypertensive and controls rats throughout the experiment. Early diastolic filling wave and E/A ratio slightly and progressively decreased from 7 to 11 weeks and were almost constant between 11 and 15 weeks, followed by an abrupt increase at 15 or 17 weeks (Fig. 2). Deceleration time was prolonged from 7 to 11 weeks, and, thereafter, it was gradually shortened (Fig. 3).

**Hemodynamic and pathological correlates.** Elevation of LVEDP was observed at 19 weeks in hypertensive rats (Table 2, Fig. 4). Tau was increased at 13 weeks in hypertensive rats, but there was no further increase in tau after that. Myocardial stiffness constant did not change at 13 weeks but significantly increased at 19 weeks at the anterior and posterior walls. There was a progressive increase in myocyte diameter in hypertensive rats, but significant myocardial fibrosis was evident only at 19 weeks in hypertensive rats.

**DISCUSSION**

Mitral flow velocity pattern changed from normal to relaxation abnormality pattern with initial development of LVH and associated diastolic dysfunction. This change was associated with myocardial hypertrophy but not with myocardial fibrosis, and LV functional alteration was exclusively observed in the LV relaxation phase. Advanced development

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**Table 1. Serial Changes in Echocardiographic Parameters in Control and Hypertensive Rats**

<table>
<thead>
<tr>
<th>Group</th>
<th>7 Weeks</th>
<th>9 Weeks</th>
<th>11 Weeks</th>
<th>13 Weeks</th>
<th>15 Weeks</th>
<th>17 Weeks</th>
<th>19 Weeks</th>
</tr>
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<tbody>
<tr>
<td>Systolic blood pressure (mm Hg)</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>123 ± 6</td>
<td>121 ± 6</td>
<td>132 ± 10</td>
<td>144 ± 9</td>
<td>129 ± 8</td>
<td>146 ± 8</td>
<td>146 ± 8</td>
</tr>
<tr>
<td>Hypertension</td>
<td>120 ± 7</td>
<td>166 ± 15*</td>
<td>197 ± 13*</td>
<td>235 ± 5*</td>
<td>233 ± 7*</td>
<td>236 ± 6*</td>
<td>231 ± 7*</td>
</tr>
<tr>
<td>Heart rate (beats per minute)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>238 ± 15</td>
<td>217 ± 12</td>
<td>239 ± 20</td>
<td>226 ± 11</td>
<td>228 ± 13</td>
<td>215 ± 11</td>
<td>235 ± 22</td>
</tr>
<tr>
<td>Hypertension</td>
<td>229 ± 14</td>
<td>241 ± 17</td>
<td>229 ± 10</td>
<td>231 ± 21</td>
<td>227 ± 18</td>
<td>240 ± 14</td>
<td>241 ± 21</td>
</tr>
<tr>
<td>End-diastolic dimension (mm)</td>
<td></td>
<td></td>
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<tr>
<td>Control</td>
<td>7.2 ± 0.5</td>
<td>9.0 ± 0.3</td>
<td>8.7 ± 0.4</td>
<td>8.8 ± 0.3</td>
<td>8.8 ± 0.5</td>
<td>8.9 ± 0.3</td>
<td>8.7 ± 0.4</td>
</tr>
<tr>
<td>Hypertension</td>
<td>7.3 ± 0.4</td>
<td>7.3 ± 0.8*</td>
<td>7.8 ± 0.3*</td>
<td>7.2 ± 1.0*</td>
<td>7.2 ± 0.4*</td>
<td>7.8 ± 0.2*</td>
<td>8.7 ± 0.5</td>
</tr>
<tr>
<td>Midwall fractional shortening (%)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Control</td>
<td>25 ± 2</td>
<td>20 ± 2</td>
<td>19 ± 4</td>
<td>16 ± 4</td>
<td>19 ± 4</td>
<td>14 ± 3</td>
<td>14 ± 3</td>
</tr>
<tr>
<td>Hypertension</td>
<td>24 ± 2</td>
<td>18 ± 1</td>
<td>15 ± 5</td>
<td>13 ± 2</td>
<td>17 ± 4</td>
<td>17 ± 3</td>
<td>15 ± 2</td>
</tr>
<tr>
<td>LV mass (mg/g)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Control</td>
<td>2.53 ± 0.31</td>
<td>2.47 ± 0.15</td>
<td>2.18 ± 0.29</td>
<td>2.17 ± 0.18</td>
<td>2.00 ± 0.17</td>
<td>2.28 ± 0.15</td>
<td>2.20 ± 0.22</td>
</tr>
<tr>
<td>Hypertension</td>
<td>2.51 ± 0.28</td>
<td>2.90 ± 0.25</td>
<td>3.09 ± 0.22*</td>
<td>3.22 ± 0.35*</td>
<td>3.83 ± 0.53*</td>
<td>3.92 ± 0.22*</td>
<td>4.29 ± 0.33*</td>
</tr>
</tbody>
</table>

Values are expressed as mean ± standard deviation. *p < 0.01 vs. control group at the same age. Heart rate was measured on the echo-Doppler recordings. LV = left ventricular.
of LVH and associated diastolic dysfunction lead to the transition to congestive heart failure, when MFVP changed from relaxation abnormality to a pseudonormalized or restrictive pattern. This change was not associated with further impairment of LV relaxation but with stiffening of the myocardium due to myocardial fibrosis and marked LVH.

**Diastolic filling abnormality in the initial stage.** Initial changes in MFVP included decreases in E and E/A ratio, an increase in A and a prolongation of DT. These changes are exactly the same as we predicted from the clinical comparative studies in patients with hypertension. However, E/A ratio dropped below 1.0 only in one-third of our rats studied, and there was no rat with an E/A ratio of <0.75, while E/A ratio is frequently <1.0 in patients with hypertension, and E/A ratio of <1.0 is a common definition of relaxation abnormality pattern in patients. Normal value of E/A ratio is about 2.0 in rats, while it is about 1.0 in humans in their fifties and about 1.3 in humans in their forties (15). Thus, the difference in the normal value of the E/A ratio is a likely explanation for the result that we did not see MFVP with an E/A ratio of 1.0 in hypertensive rats as often as this is seen in patients with hypertension.

Slowed LV relaxation as assessed with an increase in tau appeared to be a major contributor to the initial change in MFVP. Although the change in another index of LV relaxation, peak negative dP/dt, was different from that in tau, the difference should be explained by the fact that peak negative dP/dt is much more load-dependent that tau (16).

It is well known that diastolic filling is determined by atrioventricular pressure gradient (17,18) and, therefore, is regulated not only by LV relaxation but also by driving pressure and LV operating stiffness or compliance (1–4). For example, a decrease in driving pressure also causes the similar change in MFVP, i.e., a relaxation abnormality pattern. However, LVEDP was not altered at this stage in our rats, and, therefore, this is an improbable mechanism.

### Table 2. Hemodynamic and Pathological Parameters at the Ages of 7, 13 and 19 Weeks in Control and Hypertensive Rats

<table>
<thead>
<tr>
<th>Group</th>
<th>7 Weeks Control</th>
<th>7 Weeks Hypertension</th>
<th>13 Weeks Control</th>
<th>13 Weeks Hypertension</th>
<th>19 Weeks Control</th>
<th>19 Weeks Hypertension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>4</td>
<td>7</td>
<td>5</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic AoP (mm Hg)</td>
<td>114 ± 5</td>
<td>117 ± 5</td>
<td>223 ± 12†</td>
<td>134 ± 9†</td>
<td>210 ± 15†</td>
<td></td>
</tr>
<tr>
<td>LVEDP (mm Hg)</td>
<td>6 ± 3</td>
<td>6 ± 2</td>
<td>8 ± 1</td>
<td>7 ± 2</td>
<td>21 ± 4††</td>
<td></td>
</tr>
<tr>
<td>Tau (ms)</td>
<td>18 ± 3</td>
<td>19 ± 3</td>
<td>25 ± 4†</td>
<td>20 ± 3</td>
<td>26 ± 3††</td>
<td></td>
</tr>
<tr>
<td>+dP/dt&lt;sub&gt;max&lt;/sub&gt; (mm Hg/s)</td>
<td>7,196 ± 290</td>
<td>6,797 ± 698</td>
<td>8,002 ± 1,182†</td>
<td>7,828 ± 716</td>
<td>6,261 ± 1,539</td>
<td></td>
</tr>
<tr>
<td>−dP/dt&lt;sub&gt;max&lt;/sub&gt; (mm Hg/s)</td>
<td>7,677 ± 1,408</td>
<td>8,872 ± 1,508</td>
<td>8,640 ± 1,238†</td>
<td>9,785 ± 1,277</td>
<td>7,122 ± 1,623</td>
<td></td>
</tr>
<tr>
<td>Myocardial stiffness constant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior wall</td>
<td>1.91 ± 0.15</td>
<td>NA</td>
<td>1.98 ± 0.08</td>
<td>1.77 ± 0.19</td>
<td>2.55 ± 0.30††</td>
<td></td>
</tr>
<tr>
<td>Posterior wall</td>
<td>1.68 ± 0.08</td>
<td>NA</td>
<td>1.89 ± 0.13</td>
<td>1.75 ± 0.15</td>
<td>2.41 ± 0.20††</td>
<td></td>
</tr>
<tr>
<td>Myocyte diameter (μm)</td>
<td>14.0 ± 0.4</td>
<td>14.2 ± 0.4</td>
<td>17.0 ± 0.7†</td>
<td>14.2 ± 0.2</td>
<td>19.0 ± 1.3††</td>
<td></td>
</tr>
<tr>
<td>Area of fibrosis (%)</td>
<td>1.3 ± 0.1</td>
<td>1.0 ± 0.3</td>
<td>1.1 ± 0.2</td>
<td>1.4 ± 0.4</td>
<td>5.8 ± 2.1††</td>
<td></td>
</tr>
</tbody>
</table>

Values are expressed as mean ± standard deviation. *p < 0.01 vs. control group at the same age; †p < 0.01 vs. data at 7 weeks; ††p < 0.01 vs. data of hypertensive rats at 13 weeks.

−dP/dt<sub>max</sub> = peak negative value of the first derivative of LV pressure; +dP/dt<sub>max</sub> = peak positive value of the first derivative of LV pressure; LV = left ventricular; LVEDP = LV end-diastolic pressure; NA = no measurement; Systolic AoP = systolic aortic pressure; Tau = time constant of LV relaxation.
An increase in afterload also works toward causing the similar change in MFVP; however, because the changes in afterload and in MFVP did not parallel each other in this study, its contribution should be partial if present. In terms of a passive component of LV diastolic property, we only measured MSC. This index did not seem to be elevated at this stage. It has been previously shown that the MSC, end-diastolic elastic stiffness or both are not altered in gradually developing experimental LVH (5,6,19). We certainly failed to assess LV compliance or stiffness at the chamber level; however, chamber stiffness cannot have been altered if we consider unchanged LVEDP and LV end-diastolic diameter at this stage. An increase in tau was observed at this stage even in the absence of myocardial fibrosis in this study, which is consistent with the previous study (5). Thus, LVH is only a possible constitutional or pathological change of the myocardium at this stage.

Although LV mass progressively increased in a linear fashion, MFVP did not change uniformly. The dissociation of LV mass and MFVP indexes indicates that development of LVH itself cannot be considered as a direct contributor to the abnormal MFVP. In other words, not LVH itself but an LVH-related change in diastolic function is a likely mechanism for the relaxation abnormality pattern in the initial stage. The mechanism by which LVH alters diastolic function is still unclear. Left ventricular hypertrophy is associated not only with changes in quantity, such as increases in LV mass and LV myocyte diameter, but also with changes in quality such as isoform switching of actin, myosin and other proteins. Left ventricular relaxation is affected by the factors affecting inactivation, i.e., reuptake of the myoplasmic activating calcium, which include metabolic control by the coronary circulation and neurohumoral control (16). Any of these may well alter LVH development and cause diastolic dysfunction without a constitutional change in the myocardium. A reduction in relative mitochondrial volume that occurs early after pressure overload may also be related (20).

**Diastolic filling abnormality in the failing stage.** Changes in MFVP in the failing stage, i.e., a marked increase in E, a decrease in A and a shortening of DT, cannot be explained by the further change in LV relaxation because tau did not change from 13 to 19 weeks. At this stage increased LV stiffness appeared to be a most important contributor to the abnormalities of MFVP. We certainly failed to obtain an index of LV stiffness at the chamber level; however, LV stiffness should be elevated at the failing stage in our rats if a markedly elevated LVEDP in the absence of LV enlargement is taken into consideration. Ohno et al. (21) clearly showed that the transition of MFVP from a relaxation abnormality to a restrictive pattern is closely related with changes in LV stiffness in a model of pacing induced heart failure. Their model is different from ours because LV systolic dysfunction progressively occurred along with diastolic dysfunction and because LV relaxation abnormality paralleled changes in LV stiffness in their model of dilated cardiomyopathy. In hearts with hypertension, however, LV systolic dysfunction is frequently minimal even at the failing stage, and an increase in tau usually precedes the changes in LV stiffness as observed in our model. In addition, while neither myocardial hypertrophy nor fibrosis is observed even at the failing stage in the pacing model (22,23), both myocardial hypertrophy and fibrosis were evident in our rats. The increase in LV stiffness, i.e., elevated LVEDP in the absence of LV enlargement, in our rats should be at least partially explained by the increased MSC due to myocardial fibrosis. Development of marked LVH should have also contributed to the increase in LV chamber stiffness independent of the change in MSC. Thus, the pseudonormalized to restrictive pattern in the hearts with hypertension should imply the presence of myocardial constitutional changes such as myocardial hypertrophy and fibrosis.

**Study limitations.** Two limitations are noted. First, our anesthesia decreased heart rate by about 40% because resting heart rate in rats is approximately 400 beats/min. Thus, the values of hemodynamic and echo-Doppler indexes might not reflect physiological conditions of the rat; however, MFVP is not analyzable without negative chronotropic anesthesia. Because the effects of anesthesia appeared homogeneous among the studied rats, we may safely use these indexes for the interindividual comparisons. Second, we did not measure left atrial function. Kono et al. (24) showed that an increased workload imposed on the left atrial myocardium and an eventual intrinsic left atrium dysfunction may account for the reduction of the left atrial contribution to LV filling at the failing stage in a model of heart failure, due to multiple sequential intracoronary embozations. The transition of MFVP from a relaxation abnormality to a pseudonormalized and restrictive pattern was so quick in our rats that intrinsic left atrium dysfunction was unlikely to occur; however, changes in left atrial function may have partially influenced the transition of MFVP at the failing stage.

**Conclusions.** Development of pressure overload LVH was associated with evolving changes in MFVP from normal to relaxation abnormality pattern and, in turn, to a pseudonormalized pattern and finally to a restrictive pattern. The evolving change was observed in a model of isolated diastolic dysfunction, and, therefore, contribution of LV systolic dysfunction to the evolving change should have been small. It is not myocardial constitutional changes such as myocardial hypertrophy or fibrosis themselves but LVH-related changes in the active component of LV diastolic function that directly contributed to the relaxation abnormality pattern. The pseudonormalized to restrictive pattern was associated with changes in LV stiffness due to LV constitutional change, i.e., myocardial hypertrophy and fibrosis. Analysis of the MFVP may be useful for following not only functional but also constitutional changes in hearts with hypertension.
Acknowledgments
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References