Doppler Assessment of Right Ventricular Filling in a Normal Population
Comparison With Left Ventricular Filling Dynamics

William A. Zoghbi, MD, Gabriel B. Habib, MD, and Miguel A. Quinones, MD

To examine whether alterations in right ventricular filling dynamics occur with increasing age and to compare right and left ventricular filling in normal subjects, pulsed Doppler echocardiographic studies were performed at the tricuspid and mitral anuli in 50 normal volunteers (23 males and 27 females) with an age range of 5–66 years. An age-related decrease in peak early filling velocity, increase in peak late velocity, and augmentation in the late/early ratio of peak velocities at the tricuspid anulus were observed ($r = -0.68$, 0.63, and 0.84, respectively). Significant correlations were also found between age and first third, first half, and atrial filling fractions ($r = -0.60$, -0.72, and 0.69, respectively). Weaker relations were observed between heart rate and Doppler-derived diastolic parameters ($r = 0.18$–0.54). Right ventricular filling indexes related significantly to those of the left ventricle ($r = 0.58$–0.88), the best being for the late/early ratio of peak velocities. With inspiration, an increase in early and right ventricular filling occurred, whereas a reduction in filling occurred in the left ventricle. Thus, careful consideration for age, heart rate, and respiration is necessary in examining the effect of disease states or therapeutics on the filling dynamics of either the right or left ventricle. (Circulation 1990;82:1316–1324)

Doppler echocardiography has recently allowed a noninvasive assessment of ventricular filling dynamics. The Doppler technique has been used to assess left and right ventricular filling in a variety of conditions, including coronary artery disease, hypertension, and hypertrophic cardiomyopathy. In normal individuals, an age-related increase in isovolumic relaxation time and a decline in the rate of early left ventricular filling have been observed using M-mode and Doppler echocardiography and radionuclide angiography. It is not presently known whether similar age-related changes occur in the right ventricle. Therefore, this study was designed to examine the determinants of right ventricular filling and the relation between right and left ventricular filling in a normal population by using Doppler echocardiography.

Methods

Subject Population

The population consisted of 50 normal volunteers (23 males and 27 females) with an age range of 5–66 years (mean, 37±15 years) who met all the following criteria: the individuals were asymptomatic, had no risk factors for coronary artery disease, and had neither history nor evidence of systemic hypertension or cardiovascular, pulmonary, or systemic disease. All subjects had a supine blood pressure below 150/90 mm Hg and normal physical examination, electrocardiogram, and two-dimensional and Doppler echocardiographic studies.

Echocardiographic and Doppler Studies

Two-dimensional and Doppler echocardiographic studies were performed by using an ultrasound system (model 77020AC, Hewlett-Packard Co., Palo Alto, Calif., or Ultramark 8, Advanced Technology Laboratories, Bothell, Wash.) equipped with 3.5-, 2.5-, or 2.25-MHz transducers and recorded on 1/2-in. videotape. Echocardiographic images were obtained from the parasternal and apical windows, with the patient in the left lateral recumbent position. Pulsed Doppler studies were performed by using the parasternal and apical windows. For determination of right and left ventricular filling dynamics, pulsed Doppler recordings of inflow velocity were...
Doppler-Derived Parameters of Ventricular Filling

Echocardiographic and Doppler measurements were performed with the use of an off-line computer analysis station (model EC-500, Digisons, Houston) equipped with a digitizing pad and internal calipers and interfaced with the video signal. For the determination of right ventricular filling dynamics, measurements were taken from the window providing the highest velocity recordings at the tricuspid anulus, thus implying the least Doppler angle with flow. This echocardiographic window was the low parasternal view in 75% of the cases. The apical approach was used for mitral inflow measurements.

The Doppler velocity tracings at the tricuspid and mitral valve anulus were digitized by following the contour of the darkest portion of the spectral display. The following parameters were derived by the computer (Figure 2): peak early inflow velocity (peak E) (in centimeters per second) and peak late inflow velocity (peak A) (in centimeters per second), from which the ratio of peak A/peak E was derived; diastolic filling period, defined as the interval between the onset and termination of diastolic inflow velocity; the acceleration time, defined as the interval between the onset of diastolic flow and peak E; and the time-velocity integral (TVI) (in centimeters) of diastolic inflow velocity.

By use of TVI measurements, three other indexes of diastolic filling were derived by digitizing various portions of the Doppler velocity tracings (Figure 2): 1) first third filling fraction, as TVI during the first third of the diastolic filling period divided by the total TVI during diastole; 2) first half filling fraction, as TVI during the first half of the diastolic filling period divided by the total TVI; and 3) atrial filling fraction, as TVI of the A wave divided by the total TVI during diastole. As previously described, TVI of the A wave was determined as the area under the A wave, above a line extending from the velocity just before the

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**Figure 1.** Left panels: Two-dimensional echocardiographic frames in diastole showing the position of the Doppler sample volume at the level of the tricuspid and mitral anuli. Middle and right panels: Examples of blood velocity recordings by Doppler at the tricuspid and mitral anuli in two men, aged 28 and 66 years, with similar heart rates. Compared with the younger individual, the 66-year-old man has reduced early filling and a more prominent atrial contribution to filling of both right and left ventricles. Peak early filling velocity (E) and peak late velocity (A) are shown. LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.

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obtained at the level of the tricuspid and mitral anuli during undisturbed normal respiration (Figure 1). Right ventricular inflow velocity was recorded from the short-axis, low parasternal, and apical four-chamber views. Left ventricular inflow velocity was recorded from the apical four-chamber view as previously described. No angle correction between the Doppler ultrasound beam and presumed flow direction was performed. To examine the effect of respiration on filling dynamics, a subgroup of 17 adult individuals (9 men and 8 women; mean age, 33±8 years; range, 21–48 years) underwent a simultaneous recording of respiration with the Doppler study; a nasal thermistor probe (Interspec, Inc., Ambler, Pa.) interfaced with the ultrasound equipment was used. In this subgroup, recordings were obtained during normal breathing followed by a short period of end-tidal volume apnea. All Doppler recordings were performed at a sweep speed of 100 mm/sec.
onset of the A wave to the end of diastolic flow (Figure 2).

All individuals were in normal sinus rhythm. To minimize the effect of respiration on the variability in ventricular filling, Doppler measurements were obtained from five to seven consecutive cardiac cycles and averaged. Results with this approach were similar to those obtained during apnea (see below). In the subgroup with monitored respiration, measurements were also performed during apnea and on the first beat after the onset of inspiration and expiration. An average of five measurements during each phase of respiration and apnea was determined.

Reproducibility and Beat-to-Beat Variability

To determine the intraindividual, interobserver, and beat-to-beat variability in the Doppler-derived parameters of diastolic filling, Doppler measurements from 10 randomly selected studies, with an average of five to seven consecutive beats, were repeated by the same observer and another independent observer. Intraobserver and interobserver variability was determined as mean percent error, derived as the absolute difference between two observations divided by the mean of the two observations and expressed in percent. Beat-to-beat variability was determined using the coefficient of variation, as standard deviation divided by the mean and expressed in percent. These methods allow comparison of variability among various parameters of ventricular filling.

Statistical Analysis

Results are expressed as mean±SD. Correlations between parameters of ventricular filling, age, heart rate, and blood pressure as well as correlations between right and left ventricular filling parameters were performed by univariate linear regression analysis. Multiple linear regression analysis was performed when a given parameter was found to relate to more than one variable. Correlation coefficients were judged statistically significant at p<0.05. The quality of the fit of the multiple regression equation to the data was assessed by the multiple correlation coefficient r. The square of r (r²) is also a useful measure because it gives the fraction of the total variance in the dependent variable (diastolic filling parameters) that is explained by the regression equation. Comparison of Doppler parameters between the phases of respiration, ventricles, and gender groups was performed by paired or unpaired Student’s t test, where appropriate. Statistical significance was again defined as p<0.05.

Results

Comparison of Right and Left Ventricular Filling

The range, mean, and standard deviations of the Doppler filling parameters in the 50 volunteers are shown in Table 1. The heart rate during recording of right and left ventricular inflow velocities was nearly identical. However, the diastolic filling period of the right ventricle was significantly longer than that of the left ventricle. At the tricuspid anulus, the total

Table 1. Doppler-Derived Parameters of Diastolic Filling From Tricuspid and Mitral Inflow Velocity

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tricuspid inflow</th>
<th>Mitral inflow</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR (beats/min)</td>
<td>69±10 (52–87)</td>
<td>69±10 (52–90)</td>
<td>NS</td>
</tr>
<tr>
<td>DFP (msec)</td>
<td>480±11 (298–690)</td>
<td>457±109 (243–681)</td>
<td>0.003</td>
</tr>
<tr>
<td>TVI (cm)</td>
<td>11.7±2.0 (7.3–15.5)</td>
<td>14.1±1.8 (8.9–19.9)</td>
<td>0.0001</td>
</tr>
<tr>
<td>Peak E (cm/sec)</td>
<td>47±9 (27–64)</td>
<td>60±12 (35–83)</td>
<td>0.0001</td>
</tr>
<tr>
<td>Peak A (cm/sec)</td>
<td>35±12 (18–67)</td>
<td>48±12 (30–90)</td>
<td>0.0001</td>
</tr>
<tr>
<td>Peak A/peak E</td>
<td>0.79±0.34 (0.34–1.54)</td>
<td>0.86±0.35 (0.37–1.92)</td>
<td>0.005</td>
</tr>
<tr>
<td>Acc time (msec)</td>
<td>112±21 (74–163)</td>
<td>103±15 (74–144)</td>
<td>0.01</td>
</tr>
<tr>
<td>1/3 FF (%)</td>
<td>54±11 (32–76)</td>
<td>58±10 (32–83)</td>
<td>0.02</td>
</tr>
<tr>
<td>1/2 FF (%)</td>
<td>66±11 (40–83)</td>
<td>66±9 (42–84)</td>
<td>NS</td>
</tr>
<tr>
<td>AFF (%)</td>
<td>21±10 (3–41)</td>
<td>22±10 (3–42)</td>
<td>NS</td>
</tr>
</tbody>
</table>

Values are mean±SD; range is shown in parentheses.

HR, heart rate; NS, not significant; DFP, diastolic filling period; TVI, time-velocity integral; Peak E, peak early velocity; Peak A, peak late velocity; Acc time, acceleration time; 1/3 FF, first third filling fraction; 1/2 FF, first half filling fraction; AFF, atrial filling fraction.
TABLE 2. Correlations Between Parameters of Right and Left Ventricular Filling Assessed by Doppler Echocardiography

<table>
<thead>
<tr>
<th>Parameter</th>
<th>r</th>
<th>Regression equation</th>
<th>SEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak E (cm/sec)</td>
<td>0.64</td>
<td>y=0.48x+18</td>
<td>7</td>
</tr>
<tr>
<td>Peak A (cm/sec)</td>
<td>0.66</td>
<td>y=0.68x+2</td>
<td>9</td>
</tr>
<tr>
<td>Peak A/peak E</td>
<td>0.88</td>
<td>y=0.86x+0.05</td>
<td>0.16</td>
</tr>
<tr>
<td>1/3 FF (%)</td>
<td>0.62</td>
<td>y=0.68x+15</td>
<td>9</td>
</tr>
<tr>
<td>1/2 FF (%)</td>
<td>0.58</td>
<td>y=0.69x+20</td>
<td>9</td>
</tr>
<tr>
<td>AFF (%)</td>
<td>0.71</td>
<td>y=0.74x+5</td>
<td>7</td>
</tr>
</tbody>
</table>

r, correlation coefficient; SEE, standard error of the estimate; Peak E, peak early velocity; Peak A, peak late velocity; 1/3 FF, first third filling fraction; 1/2 FF, first half filling fraction; AFF, atrial filling fraction; y, respective Doppler parameter of right ventricular filling; x, respective Doppler parameter of left ventricular filling.

TVI, peak E, peak A, and peak A/peak E ratio were significantly smaller than at the mitral anulus. First third filling fraction of the right ventricle was less than that of the left ventricle. In addition, acceleration time across the tricuspid valve was longer. However, the parameters of diastolic function tested during the later phase of diastole (first half and atrial filling fractions) were similar in the two ventricles.

Table 2 shows the correlations between right and left ventricular filling dynamics derived by the Doppler technique. Significant correlations were observed between filling dynamics of the two ventricles (r=0.58–0.88). The best correlation was obtained between the peak A/peak E ratio at the tricuspid and mitral anuli, with a regression equation close to the line of identity.

Effect of Respiration on Filling Parameters

The phases of respiration had different effects on right and left ventricular filling (Table 3). At the tricuspid inflow, a significant increase in total TVI (mean, 27%) was observed from early expiration to early inspiration with an increase in peak E (15%) and peak A (10%) and no change in the peak A/peak E ratio or filling fractions. In contrast, at the mitral inflow, a reduction from expiration to inspiration was observed in total TVI (16%), peak E (5%), and peak A (10%), with a relative enhancement, albeit small, of early filling demonstrated in an increase in first half (3%) and first third (8%) filling fraction and a reduction in the peak A/peak E ratio (6%). In this adult population, (aged 21–48 years), there was no relation between age and the changes in filling dynamics during inspiration for both tricuspid and mitral inflow. Measurements of Doppler parameters from the average of five to seven consecutive beats were nearly identical to those obtained during apnea (Table 3).

Effect of Gender and Blood Pressure

To examine the effect of gender on right ventricular filling, all Doppler parameters were compared in the two subgroups. The men and women had a similar distribution of age (38±17 and 36±15 years, respectively; p=NS). There was no significant difference between any Doppler-derived parameter of diastolic function in the two gender subgroups.

In the population studied, the systolic and diastolic blood pressures averaged 120±13 and 76±9 mm Hg, respectively. There was a weak relation between diastolic blood pressure and age (r=0.34; p=0.05); however, no relation between systolic pressure and age was observed in this population. No significant relation was found between either systolic or diastolic pressure and any parameter of diastolic function studied.

Relation of Filling Dynamics to Age and Heart Rate

Age and, to a lesser extent, heart rate were found to be important determinants of Doppler-derived parameters of diastolic filling. Table 4 shows the univariate linear correlations between age, heart rate, and the Doppler variables for both ventricles in the total population. Figures 3 and 4 illustrate the relation of the Doppler parameters of right and left ventricular filling with age. In this population, no relation was observed between age and heart rate. Overall, the Doppler filling parameters demonstrated a stronger relation with age (absolute

TABLE 3. Effect of Respiration on Doppler-Derived Parameters of Right and Left Ventricular Filling

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Inspiration</th>
<th>Expiration</th>
<th>Apnea</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVI (cm)</td>
<td>13.1±3.2*</td>
<td>10.3±2.7</td>
<td>11.7±2.2</td>
<td>11.4±2.6</td>
</tr>
<tr>
<td>DFP (msec)</td>
<td>548±132*</td>
<td>509±126</td>
<td>524±91</td>
<td>513±84</td>
</tr>
<tr>
<td>Peak E (cm/sec)</td>
<td>52±12*</td>
<td>45±11</td>
<td>45±10</td>
<td>47±11</td>
</tr>
<tr>
<td>Peak A (cm/sec)</td>
<td>33±8†</td>
<td>30±8</td>
<td>32±9</td>
<td>33±7</td>
</tr>
<tr>
<td>Peak A/peak E</td>
<td>0.67±0.20†</td>
<td>0.72±0.26</td>
<td>0.75±0.26</td>
<td>0.73±0.21</td>
</tr>
<tr>
<td>1/2 FF (%)</td>
<td>49±9</td>
<td>50±10</td>
<td>47±8</td>
<td>48±8</td>
</tr>
<tr>
<td>1/2 FF (%)</td>
<td>66±6</td>
<td>66±8</td>
<td>65±7</td>
<td>65±7</td>
</tr>
<tr>
<td>AFF (%)</td>
<td>18±6</td>
<td>19±7</td>
<td>22±7</td>
<td>19±5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Inspiration</th>
<th>Expiration</th>
<th>Apnea</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tricuspid inflow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TVI (cm)</td>
<td>11.9±1.7*</td>
<td>14.2±3.1</td>
<td>13.4±2.8</td>
<td>13.1±2.5</td>
</tr>
<tr>
<td>DFP (msec)</td>
<td>502±137</td>
<td>519±135</td>
<td>526±174</td>
<td>502±155</td>
</tr>
<tr>
<td>Peak E (cm/sec)</td>
<td>56±11†</td>
<td>59±13</td>
<td>58±10</td>
<td>59±12</td>
</tr>
<tr>
<td>Peak A (cm/sec)</td>
<td>35±9*</td>
<td>40±8</td>
<td>36±7</td>
<td>38±8</td>
</tr>
<tr>
<td>Peak A/peak E</td>
<td>0.67±0.24†</td>
<td>0.71±0.22</td>
<td>0.65±0.19</td>
<td>0.67±0.21</td>
</tr>
<tr>
<td>1/2 FF (%)</td>
<td>52±12*</td>
<td>48±10</td>
<td>52±10</td>
<td>50±12</td>
</tr>
<tr>
<td>1/2 FF (%)</td>
<td>65±8*</td>
<td>63±7</td>
<td>65±7</td>
<td>65±6</td>
</tr>
<tr>
<td>AFF (%)</td>
<td>20±6</td>
<td>21±7</td>
<td>21±7</td>
<td>21±6</td>
</tr>
</tbody>
</table>

Values are mean±SD; n=17 subjects.

Mean, average of five to seven consecutive beats; TVI, time-velocity interval; DFP, diastolic filling period; Peak E, peak early velocity; Peak A, peak late velocity; 1/3 FF, first third filling fraction; 1/2 FF, first half filling fraction; AFF, atrial filling fraction.

*p<0.01 compared with respective values during expiration.

†p<0.05 compared with respective values during expiration.
Multiple linear regression analysis was performed to express the diastolic filling parameters as a function of age and heart rate, since both variables were found to be important determinants of normal filling dynamics. The multiple correlation coefficients and regression equations for the diastolic filling parameters of the right and left ventricles are presented in Table 4. The multiple correlation coefficient was highest for the peak A/peak E ratio at the tricuspid anulus \((r=0.92; \ r^2=0.85); \ \text{peak} \ A/\text{peak} \ E=-0.79+0.018 \ [\text{age}]+0.013 \ [\text{heart rate}]). \) Thus, 85% of the observed variance in tricuspid peak A/peak E ratio can be explained by age and heart rate alone.

The results of intraobserver and interobserver reproducibility and beat-to-beat variability in the determination of diastolic parameters by Doppler are shown in Table 6. Overall, larger variability was observed in the determination of right ventricular filling dynamics.

**Discussion**

This study demonstrates that, in a normal population, Doppler parameters of right ventricular filling dynamics are altered by age and heart rate in addition to respiration. With increasing age, peak E decreases while peak A increases, with a resultant augmentation of the peak A/peak E ratio. Likewise, a reduction in first third and first half filling fractions with an increase in the atrial contribution to filling

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Table 4. Univariate Linear Correlation Coefficients Between Age, Heart Rate, and Doppler-Derived Diastolic Filling Parameters

<table>
<thead>
<tr>
<th></th>
<th>Tricuspid inflow</th>
<th>Mitral inflow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age</td>
<td>Heart rate</td>
</tr>
<tr>
<td>Peak E</td>
<td>-0.68</td>
<td>-0.20*</td>
</tr>
<tr>
<td>Peak A</td>
<td>0.63</td>
<td>0.40</td>
</tr>
<tr>
<td>Peak A/peak E</td>
<td>0.84</td>
<td>0.39</td>
</tr>
<tr>
<td>1/3 FF</td>
<td>-0.60</td>
<td>-0.42</td>
</tr>
<tr>
<td>1/2 FF</td>
<td>-0.72</td>
<td>-0.42</td>
</tr>
<tr>
<td>AFF</td>
<td>0.69</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Peak E, peak early velocity; Peak A, peak late velocity; 1/3 FF, first third filling fraction; 1/2 FF, first half filling fraction; AFF, atrial filling fraction.

*r>0.05 for the linear regression.*
were observed with advancing age in both ventricles. In addition, significant relations were observed between heart rate and the parameters of diastolic filling, with the exception of peak E. A differential effect of respiration on right and left filling dynamics was observed. During inspiration, both early and late right ventricular filling are enhanced while left ventricular filling is reduced.

Comparison With Previous Studies

Previous studies assessing the effect of aging on diastolic properties of the heart have predominantly focused on the left ventricle. Animal studies have demonstrated a prolonged relaxation time and increased myocardial and chamber stiffness with advancing age.\textsuperscript{20-25} In humans, an increase in isovolumic relaxation time, time to peak filling rate, and a reduction in early peak filling rate has been associated with increasing age.\textsuperscript{10,15} Using Doppler echocardiography, we\textsuperscript{4} and others\textsuperscript{12-14} have observed a decrease in the early filling velocity and an increase in the atrial contribution to left ventricular filling with advancing age. This Doppler pattern of inflow velocity has been recently associated with prolonged ventricular relaxation in cardiac patients.\textsuperscript{26}

Several investigators have demonstrated in experimental animals an increase in passive stiffness and profound slowing of relaxation of right ventricular myocardium with aging.\textsuperscript{27-30} In humans, a reduction in right ventricular compliance in elderly subjects (mean age, 81 years) was suggested by Sebban et al.\textsuperscript{31} who combined measurements of cardiac output with pressure determination by micromanometry. Preliminary Doppler observations have revealed that filling dynamics of the right ventricle are altered with aging in a normal population.\textsuperscript{32,33} The findings in this study of decreased early filling parameters and increased atrial contribution to filling of the right ventricle with increasing age further confirm these observations and support the hypothesis that alterations in diastolic properties of the heart occur in both ventricles with aging.

The present study shows a lesser dependence of filling dynamics of both ventricles on heart rate; similar observations were reported for left ventricular filling by Van Dam et al.\textsuperscript{34} in a large normal population but were not observed by Gardin et al.\textsuperscript{13} The high multiple correlation coefficients observed between Doppler filling parameters, age, and heart rate, especially for the peak A/peak E ratio ($r=0.92$),

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
 & Tricuspid inflow & Mitral inflow \\
\hline
\textbf{Peak A} & 0.74 & 0.75 \\
Peak A/peak E & 0.92 & 0.88 \\
1/3 FF & $-0.73$ & $-0.60$ \\
1/2 FF & $-0.82$ & $-0.69$ \\
AFF & 0.75 & 0.71 \\
\hline
\end{tabular}
\caption{Multiple Linear Correlations Between Doppler-Derived Diastolic Filling Parameters, Age, and Heart Rate}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
 & Tricuspid inflow & Mitral inflow \\
\hline
\textbf{Peak A} & 0.74 & 0.75 \\
Peak A/peak E & 0.92 & 0.88 \\
1/3 FF & $-0.73$ & $-0.60$ \\
1/2 FF & $-0.82$ & $-0.69$ \\
AFF & 0.75 & 0.71 \\
\hline
\end{tabular}
\caption{Multiple Linear Correlations Between Doppler-Derived Diastolic Filling Parameters, Age, and Heart Rate}
\end{table}

$r$, multiple correlation coefficient; Peak A, peak late velocity; Peak A/peak E, ratio of peak A to peak early velocity; HR, heart rate; 1/3 FF, first third filling fraction; 1/2 FF, first half filling fraction; AFF, atrial filling fraction.
TABLE 6. Intraobserver, Interobserver, and Beat-to-Beat Variability in Doppler-Derived Parameters of Right and Left Ventricular Filling

<table>
<thead>
<tr>
<th></th>
<th>Tricuspid inflow</th>
<th>Mitral inflow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intraobserver</td>
<td>Interobserver</td>
</tr>
<tr>
<td>Peak E (%)</td>
<td>10±7</td>
<td>14±8</td>
</tr>
<tr>
<td>Peak A (%)</td>
<td>17±13</td>
<td>14±10</td>
</tr>
<tr>
<td>Peak A/peak E (%)</td>
<td>10±8</td>
<td>13±8</td>
</tr>
<tr>
<td>1/3 FF (%)</td>
<td>12±8</td>
<td>10±8</td>
</tr>
<tr>
<td>1/2 FF (%)</td>
<td>7±6</td>
<td>7±3</td>
</tr>
<tr>
<td>AFF (%)</td>
<td>13±11</td>
<td>14±9</td>
</tr>
</tbody>
</table>

Values are mean±SD. Intraobserver and interobserver variability values are expressed as mean percent error; beat-to-beat variability is expressed as coefficient of variation (see "Methods").

Peak E, peak early velocity; Peak A, peak late velocity; 1/3 FF, first third filling fraction; 1/2 FF, first half filling fraction; AFF, atrial filling fraction.

are an indication of how well the data fit the regression equations.

A differential effect of respiration on right and left ventricular filling has been recently determined through the use of Doppler echocardiography.16,34–37 During inspiration, commensurate with an enhancement in venous return, an increase in both early and late right ventricular filling velocities has been observed, without a significant change in the peak E/peak A ratio.16,35,36 The magnitude of the change in right ventricular filling velocities may depend on the age group studied. In adults, similar to our observations, a mean increase of 14% or less has been reported,16,35 whereas in children (1.5–11 years), a mean change of 26% or less was recently observed.36 In neonates, however, the changes were less marked (mean, ±11%) and may reflect a combination of factors, including faster heart and respiratory rates and reduced right ventricular compliance as a result of intracellular dominance.37 In the present study, no relation was observed between the changes in filling dynamics during respiration and age, within an age range of 21–48 years. In contrast to the right ventricle, a decrease in left ventricular filling velocities, smaller magnitude (mean, <10%), has been observed during inspiration in all age groups studied and reflects a complex interplay among preload, afterload, and ventricular interdependence.16,34–37

The present findings, in a predominantly adult population, further support these observations and stress the importance of consideration of respiration in the assessment of filling dynamics. Ideally, simultaneous recording of respiration allows precise measurements at different phases of the respiratory cycle. However, if recording of respiration is unavailable, the effects of respiration can be minimized, at least in adults, by taking measurements during short periods of apnea or by averaging multiple consecutive beats.

Comparison of Right and Left Ventricular Filling

In this study, we have not determined volumetric right ventricular filling rates because of the difficulties in measuring tricuspid flow area. Measurements of peak E and peak A at the tricuspid anulus were significantly lower than at the mitral anulus. In the absence of valvular insufficiency, stroke volume, calculated as the product of flow area and TVI at the mitral anulus, should be equal to that at the tricuspid anulus. Since TVI at the tricuspid anulus was, on the average, 16±14% less than that at the mitral anulus, it can be inferred that the flow area of the tricuspid anulus is, on the average, larger than that of the mitral anulus by a similar magnitude. This is compatible with previous reports38,39 and explains in part the lower velocities at the tricuspid anulus. However, peak E at the tricuspid anulus was, on the average, 21±14% less than that at the mitral anulus, a greater difference than that expected from differences in flow area alone (p=0.048), suggesting that the early filling rate of the right ventricle may in fact be lower than that of the left ventricle. This is further supported by the observations of a lower first third filling fraction and a longer acceleration time for the right ventricle. Since ventricular filling dynamics are dependent, among other factors, on loading conditions,40,41 this finding may be secondary to a lower pressure difference between right atrium and ventricle in early diastole and does not necessarily imply slower relaxation of the right ventricle. During the later phases of diastole (one half filling fraction and atrial filling fraction), the filling dynamics were similar for both ventricles.

Advantages and Limitations of the Study

Doppler echocardiography allows the noninvasive and beat-to-beat evaluation of ventricular filling dynamics. This method is especially useful in the evaluation of global right ventricular filling because M-mode and two-dimensional echocardiography are both limited in this regard and because gated radionuclide angiography has difficulties separating the right atrium from the right ventricle. However, several limitations and sources of error are present with the Doppler technique. The cross-sectional area of the valve anulus changes during diastole and has been found to increase by approximately 12% from the onset to the end of diastole for the mitral anulus.42 A similar behavior during the cardiac cycle was observed for the tricuspid anulus.38 In addition, Doppler-derived parameters of ventricular filling are dependent, among other factors, on the site of the sample volume.14,43 Positioning the Doppler sample volume at the tip of the atrioventricular valve leaflets
results in higher diastolic velocities, as well as a higher peak E/peak A ratio, than those at the anulus level because of a smaller flow area at the valve orifice.14,43 We have elected to determine Doppler filling dynamics at the anulus level because the changes in cross-sectional area during diastole at that level are much smaller than those at the valve orifice. Moreover, in a recent study14 assessing left ventricular filling dynamics in a large normal population, Doppler recordings at the mitral anulus resulted in a narrower 95% confidence interval for the peak E/peak A ratio than those obtained at the mitral orifice. Since the plane of the valve anulus moves apically in systole, care was taken to ensure that, during most of diastole, the sample volume remained as close as possible to the level of the valve anulus. Another source of error is the beat-to-beat variability in flow dynamics, especially on the right side, due to respiration. We have averaged multiple consecutive beats to minimize errors and improve reproducibility of measurements. Results with this approach were similar to those obtained during apnea. To avoid underestimation of velocity by the Doppler technique due to a significant angle of incidence, multiple windows were used to record the flow velocity at the tricuspid anulus, with measurements performed from the window providing the highest velocities. Nevertheless, it should be emphasized that the latter error predominantly affects absolute measurements of velocity or velocity integral and, to a lesser degree, the parameters derived as ratios of velocities or TVIs.

**Clinical Implications**

In a normal population, Doppler parameters of right ventricular filling have been demonstrated in this study to be related to age and heart rate in addition to respiration. Careful consideration for age, heart rate, and the effect of respiration are therefore necessary in investigating the effect of disease states or therapeutic interventions on ventricular filling dynamics. Since right and left ventricular filling dynamics are similarly affected by aging and heart rate, the finding of significant differences in filling dynamics between ventricles may identify differences in pathological or loading conditions affecting either ventricle.

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**References**


**KEY WORDS** • right ventricle • echocardiography, Doppler • diastole • age
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