CLINICAL STUDY OF LEFT ATRIAL COMPLIANCE AND LEFT ATRIAL VOLUME IN MITRAL STENOSIS

SHIGEO SATO, M.D., YASUNARU KAWASHIMA, M.D., HAJIME HIROSE, M.D.
SUSUMU NAKANO, M.D., HIKARU MATSUDA, M.D.
AND YASUHISA SHIMASAKI, M.D.

We studied left atrial compliance and left atrial volume in 21 patients with mitral stenosis showing a normal sinus rhythm.

1. A significant \( p < 0.001 \) negative linear correlation of \( r = 0.72 \) was found between the mitral valve area (MVA) and left atrial mean pressure (LAm).

2. A significant \( p < 0.005 \) positive linear correlation of \( r = 0.60 \) was found between MVA and left atrial compliance \( \left( \Delta V/\Delta P \right) \).

3. A significant \( p < 0.001 \) hyperbolic correlation of \( r = 0.73 \) was found between LAm and \( \Delta V/\Delta P \).

4. A significant \( p < 0.001 \) hyperbolic correlation of \( r = 0.65 \) was found between left atrial specific compliance \( \left( \Delta V/\Delta P/LAV_{\text{max}} \right) \) and left atrial mean volume.

5. These findings led to the conclusion that in patients with mitral stenosis showing a normal sinus rhythm, left atrial compliance was decreased in patients whose left atrial volume was increased, and the decrease of left atrial compliance was related to narrowing of the mitral valve area and elevation of the left atrial pressure.

In mitral stenosis (MS) it is believed that the left atrium is chronically subject to a volume load resulting from narrowing of the mitral valve orifice, showing a gradually progressive enlargement. As atrial enlargement progresses, atrial fibrillation (AF) supervenes at a high incidence,1,2 inducing left atrial thrombus,3 arterial thromboembolism4 and low cardiac output. The association of AF is believed to further promote left atrial enlargement5.

To date, there has been no reports available on the mechanism of left atrial enlargement in MS. Left atrial compliance is assumed to be closely associated with an increase in left atrial volume. However, no information is available about left atrial compliance in patients with MS. Therefore, we studied left atrial volume and left atrial compliance in patients with MS.

SUBJECTS

The subjects were 21 patients with MS showing a normal sinus rhythm who were examined by cardiac catheterization. They consisted of 4 men and 17 women, aged 23 to 56 years (average 40). By pathological classification of stenosed mitral valve according to Sellers,6 4 patients showed type I-mobile cusps without subvalvular lesions, 13, type II-thickened cusps with mild to

Key words:
Left atrial compliance
Left atrial volume
Mitral stenosis
Sinus rhythm

(Received May 12, 1990; accepted August 18, 1990)
First Department of Surgery, Osaka University Medical School, 1-1-50, Fukushima, Fukushima-ku, Osaka 553, Japan.
Mailing address: Shigeo Sato, M.D., Department of Cardiovascular Surgery, Kure National Hospital, 3-1 Aoyamacho Kure-city, Hiroshima 737, Japan

Japanese Circulation Journal Vol. 55, May 1991 481
Fig. 1. Left atrial and left ventricular pressure tracing in mitral stenosis. $\Delta P$ was defined the pressure difference between the X' trough and the peak of the v-wave. RR interval, RV interval and RX' interval were determined by the electrocardiogram and the left atrial pressure tracing.

Fig. 2. Electrocardiogram and Left atrial volume curve. RX' interval and RV interval were the same as determined in the electrocardiogram and the left atrial pressure tracing (Fig. 1). $\Delta V$ was the increased left atrial volume from the X' trough to the peak of the v-wave in the left atrial volume curve.

Fig. 3. Relationship between $\Delta V$ and stroke volume measured by left atrial volumetric analysis.

$Y = 0.52X - 1$
$r = 0.95$
$p < 0.001$

moderate subvalvular lesions and 4, type III-rigid cusps with severe subvalvular lesions. Mitral regurgitation was noted in 3 patients, but all of them were less than minimal by left ventricular cineangiography. Eighteen patients were in the New York Heart Association functional class II and 3 patients were in class III. The cardiothoracic ratio ranged from 44 to 60% with a mean of 54±5 (standard deviation)%.

METHOD

Cardiac catheterization was performed in
a supine position. Cardiac output was determined by the dye dilution method. For measurement of the left atrial pressure, a catheter was introduced into the left atrium by Brockenbrough’s technique. Intracardiac pressures with the mid-chest as point 0 were recorded using a Hewlett-Packard 4560 recorder with a Statham p23 D6 transducer at a paper speed of 10 cm/sec. In left angiography, Brockenbrough’s catheter was used and cineangiogram was taken in 2 directions in the right anterior oblique position at a rate of 60 frames/sec by the Hitachi DC–1510 cine biplane system.

The left atrial volume was obtained by the two-dimensional area-length method and corrected by Sauter’s formula, as follows:

\[
LAV = \frac{4}{3} \cdot \pi \cdot \frac{a}{2} \cdot \frac{b}{2} \cdot \frac{c}{2}
\]

LAV: left atrial volume
a: left atrial maximum diameter
b: left atrial minimum diameter in the right anterior oblique position
c: left atrial minimum diameter in the left anterior oblique position

\[
V_{\text{actual}} = 1.12 \times V_{\text{calculated}} - 10.6
\]

The average of left atrial maximum volume (LAVmax) and left atrial minimum volume (LAVmin) was used as the mean left atrial volume (LAVmean).

The left atrial compliance was obtained from \( \Delta V / \Delta P \). \( \Delta P \) was the pressure difference between the X’ trough and the peak of the v-wave in the left atrial pressure tracing (Fig. 1). \( \Delta V \) was the increased left atrial volume from the X’ trough to the peak of the v-wave in the left atrial volume curve (Fig. 2). Left atrial volume at the point of X’ trough was obtained as shown in the Fig. 2. RX’ interval and RV interval were the same as determined in the Fig. 1. \( \Delta V \) had a good correlation with stroke volume measured by left atrial volumetric analysis (LAVmax−LAVmin) (Fig. 3). Simultaneous left atrial pressure and volume measurements were obtained by a catheter-tip micromanometer (model PC–484A, Miller co.) in 4 patients (Fig. 4). \( \Delta V / \Delta P \) values were compared with \( \Delta V’ / \Delta P’ \) values (Fig. 4) determined by simultaneous left atrial pressure and volume curve in 4 patients examined by a catheter-tip micromanometer (Fig. 5). The 2 parameters showed practically identical values (r=0.995). Therefore, \( \Delta V / \Delta P \) was regarded as actual left atrial compliance. Specific compliance\(^8,10\) was obtained by dividing \( \Delta V / \Delta P \) by LAVmax (\( \Delta V / \Delta P / \text{LAVmax} \)). The mitral valve area (MVA) was calculated by the formula of Gorlin and Gorlin\(^1\).

**RESULTS**

Left atrial mean pressure (LAm), mitral valve area (MVA), left atrial maximum volume (LAVmax), left atrial mean volume (LAVmean), left atrial compliance (\( \Delta V / \Delta P \))
TABLE RESULTS

<table>
<thead>
<tr>
<th>Case</th>
<th>Age (yr) &amp; Sex</th>
<th>LAm (mmHg)</th>
<th>MVA (cm²)</th>
<th>LAVmax (ml)</th>
<th>LAVmean (ml)</th>
<th>ΔV/ΔP (ml/mmHg)</th>
<th>ΔV/ΔP/LAVmax (/mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>51 F</td>
<td>8</td>
<td>1.8</td>
<td>194</td>
<td>161</td>
<td>4.0</td>
<td>0.021</td>
</tr>
<tr>
<td>2</td>
<td>38 F</td>
<td>23</td>
<td>1.0</td>
<td>307</td>
<td>294</td>
<td>1.2</td>
<td>0.0039</td>
</tr>
<tr>
<td>3</td>
<td>32 F</td>
<td>10</td>
<td>1.9</td>
<td>362</td>
<td>342</td>
<td>1.3</td>
<td>0.0036</td>
</tr>
<tr>
<td>4</td>
<td>45 F</td>
<td>16</td>
<td>1.1</td>
<td>159</td>
<td>134</td>
<td>1.5</td>
<td>0.0094</td>
</tr>
<tr>
<td>5</td>
<td>43 F</td>
<td>11</td>
<td>1.8</td>
<td>231</td>
<td>202</td>
<td>2.8</td>
<td>0.012</td>
</tr>
<tr>
<td>6</td>
<td>30 F</td>
<td>13</td>
<td>2.3</td>
<td>138</td>
<td>108</td>
<td>2.3</td>
<td>0.017</td>
</tr>
<tr>
<td>7</td>
<td>41 M</td>
<td>22</td>
<td>0.8</td>
<td>248</td>
<td>228</td>
<td>1.3</td>
<td>0.0050</td>
</tr>
<tr>
<td>8</td>
<td>54 F</td>
<td>6</td>
<td>1.6</td>
<td>191</td>
<td>173</td>
<td>4.0</td>
<td>0.021</td>
</tr>
<tr>
<td>9</td>
<td>56 M</td>
<td>13</td>
<td>1.2</td>
<td>187</td>
<td>160</td>
<td>2.5</td>
<td>0.013</td>
</tr>
<tr>
<td>10</td>
<td>42 F</td>
<td>18</td>
<td>1.1</td>
<td>175</td>
<td>159</td>
<td>1.8</td>
<td>0.010</td>
</tr>
<tr>
<td>11</td>
<td>29 M</td>
<td>27</td>
<td>1.3</td>
<td>321</td>
<td>306</td>
<td>1.2</td>
<td>0.0037</td>
</tr>
<tr>
<td>12</td>
<td>36 F</td>
<td>15</td>
<td>2.1</td>
<td>163</td>
<td>126</td>
<td>2.8</td>
<td>0.017</td>
</tr>
<tr>
<td>13</td>
<td>39 F</td>
<td>20</td>
<td>1.2</td>
<td>218</td>
<td>180</td>
<td>2.3</td>
<td>0.011</td>
</tr>
<tr>
<td>14</td>
<td>51 F</td>
<td>12</td>
<td>2.4</td>
<td>248</td>
<td>204</td>
<td>7.4</td>
<td>0.030</td>
</tr>
<tr>
<td>15</td>
<td>35 F</td>
<td>7</td>
<td>2.0</td>
<td>115</td>
<td>75</td>
<td>5.6</td>
<td>0.049</td>
</tr>
<tr>
<td>16</td>
<td>28 F</td>
<td>20</td>
<td>1.2</td>
<td>272</td>
<td>254</td>
<td>1.3</td>
<td>0.0048</td>
</tr>
<tr>
<td>17</td>
<td>48 F</td>
<td>30</td>
<td>0.9</td>
<td>162</td>
<td>153</td>
<td>0.5</td>
<td>0.0031</td>
</tr>
<tr>
<td>18</td>
<td>23 F</td>
<td>26</td>
<td>0.8</td>
<td>150</td>
<td>137</td>
<td>1.3</td>
<td>0.0089</td>
</tr>
<tr>
<td>19</td>
<td>42 F</td>
<td>11</td>
<td>1.3</td>
<td>216</td>
<td>179</td>
<td>3.6</td>
<td>0.017</td>
</tr>
<tr>
<td>20</td>
<td>35 M</td>
<td>16</td>
<td>1.1</td>
<td>259</td>
<td>231</td>
<td>5.0</td>
<td>0.019</td>
</tr>
<tr>
<td>21</td>
<td>44 F</td>
<td>27</td>
<td>0.6</td>
<td>216</td>
<td>181</td>
<td>1.6</td>
<td>0.0074</td>
</tr>
</tbody>
</table>

LAm: left atrial mean pressure, MVA: mitral valve area, LAVmax: left atrial maximum volume, LAVmean: left atrial mean volume, ΔV/ΔP: left atrial compliance, ΔV/ΔP/LAVmax: left atrial specific compliance.

Fig.6. Relationship between mitral valve area (MVA) and left atrial mean pressure (LAm).

and left atrial specific compliance (ΔV/ΔP/LAVmax) are shown in the Table.

1) Relationship between MVA and LAm (Fig. 6)

A significant (p<0.001) negative linear correlation of r=0.72 was found between MVA and LAm.

2) Relationship between LAm and LAVmean (Fig. 7)

LAVmean (Fig. 7)
There was no significant correlation between the 2 parameters.

3) Relationship between MVA and $\Delta V/\Delta P$ (Fig. 8)
A significant ($p<0.005$) positive linear correlation of $r=0.60$ was found between MVA and $\Delta V/\Delta P$.

4) Relationship between LAm and $\Delta V/\Delta P$ (Fig. 9)
A significant ($p<0.001$) hyperbolic correlation of $r=0.73$ was found between LAm and $\Delta V/\Delta P$.

5) Relationship between LAVmean and $\Delta V/\Delta P$ (Fig. 10) or $\Delta V/\Delta P$/LAVmax (Fig. 11)
Patients with a large LAVmean showed a low $\Delta V/\Delta P$ value, but the $\Delta V/\Delta P$ value was not constant in those with a small LAVmean. There was no significant correlation between the 2 parameters (Fig. 10). In contrast, a significant ($p<0.001$) hyperbolic correlation of $r=0.65$ was found between LAVmean and $\Delta V/\Delta P$/LAVmax (Fig. 11).

DISCUSSION
Although left atrial enlargement in the patients with MS is a common clinical finding, there have been unexpectedly few reports on the relationship between left atrial volume and left atrial pressure. Sauter detected a linear correlation between pressure at the peak of the v-wave and left atrial maximum volume, whereas Soloff found no significant relationship between pulmonary arterial wedge pressure and left atrial volume. Another report showed that in experiments
using dogs, the change in the amplitude of the v-wave was found to be linearly related to the volume of saline injected into the left atrium. Thus, the relationship between left atrial volume and pressure remains to be controversial. The present investigation failed to find a clear relationship between the left atrial mean pressure and left atrial mean volume, because some patients with moderate left atrial enlargement showed high left atrial mean pressures.

Left atrial compliance, which is an indicator of left atrial extension, is assumed to be closely associated with an increase in the left atrial pressure. However, the only available data on left atrial compliance were those from a laboratory circuit model with no clinical study performed on patients with MS. Marco reported that in a laboratory model, cardiac output and left atrial pressure were significantly related to left atrial compliance. According to Suga cardiac output-mean atrial pressure relationship was markedly improved by increase in atrial compliance in a circulatory analog model.

We studied left atrial compliance (ΔV/ΔP) in 21 MS patients with normal sinus rhythm. At the start of left ventricular contraction, the base of the ventricle descends toward the apex, showing an X’ trough in the left atrial pressure tracing. After that, the left atrium is filled with blood from the pulmonary vein, with a v-wave forming on the record. We defined ΔP as the pressure difference between the X’ trough and the peak of the v-wave during left atrial filling (Fig. 1). We also defined ΔV as the increased left atrial volume from the point of X’ trough to the peak of the v-wave during left atrial filling (Fig. 2).

ΔV/ΔP values were very similar to ΔV/ΔP’ values determined from the pressure-volume curve (Fig. 4) in the 4 patients examined by a catheter-tip micromanometer (Fig. 5). Therefore, ΔV/ΔP was assumed to indicate the left atrial compliance in left atrial diastole. ΔV/ΔP showed a significant (p<0.005) linear correlation with MVA and a significant (p<0.001) hyperbolic correlation with LAm. While LAVmean showed no significant correlation with ΔV/ΔP, it showed a significant (p<0.001) hyperbolic correlation with ΔV/ΔP/LAVmax, the value obtained by correcting ΔV/ΔP with LAVmax.

REFERENCES
9. LEWIS BS, GOTSMAN MS: Current concepts of left ventricular relaxation and compliance. Am Heart J 99: 101, 1980
11. GORLIN R, GORLIN SG: Hydraulic formula for calculation of the area of the stenotic mitral valve, other cardiac valves, and central circulatory shunts. Am Heart J 41: 1, 1951
14. MARCO JD, STANDEVEN JD, BARNER HB: Pulmonary and left atrial hemodynamics in mitral stenosis. Am Heart J 94: 73, 1977