A Regurgitant Jet and Echocardiographic Abnormalities in Aortic Regurgitation: An Experimental Study

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SUMMARY Acute aortic regurgitation was created experimentally in 21 mongrel dogs to examine the relationship of the regurgitant jet to observed echocardiographic findings. The direction of the regurgitant jet was studied by echo contrast injections in the aortic root. Diastolic fluttering of the anterior mitral leaflet (AML) was noted in all 21 dogs irrespective of direction of the jet. Diastolic fluttering of the interventricular septum (IVS) was noted in six of the seven dogs with a tear of the noncoronary cusp and in one of seven dogs with lesions in the left coronary cusp. In all seven dogs with echocardiographically demonstrated IVS fluttering a regurgitant jet impinged on the anterior part of the IVS. Amplitude of the AML excision was not significantly different from control when the lesions involved the noncoronary or the left coronary cusps. However, all seven dogs that had a lesion in the right coronary cusp demonstrated a significant reduction in the amplitude of the AML excision. The regurgitant jet in these dogs impinged uniformly on the AML. We conclude that diastolic fluttering of the AML is uniformly observed and unrelated to the direction of the regurgitant jet, diastolic fluttering of the IVS is caused by the regurgitant jet impinging upon the IVS, and amplitude of the AML may be reduced as a result of a jet impingement of the AML.

JET LESIONS caused by the jet stream in various heart diseases were described in 1958 by Edwards and Burchell. They found that the common sites for a left ventricular jet lesion in aortic regurgitation were the ventricular surface of the anterior mitral leaflet (AML) and the surface of the interventricular septum (IVS) subjacent to the aortic valve. In aortic regurgitation, several echocardiographic findings have been reported. Diastolic fluttering of the AML and that of the IVS are thought to result from regurgitant jets impinging on them.

In the present study, using an experimental model of acute aortic regurgitation, we attempted to correlate the site of the jet impact with echocardiographic findings of diastolic fluttering of the AML and the IVS.

Materials and Methods

Twenty-one mongrel dogs that weighed 14–22 kg were anesthetized with i.v. pentobarbital and ventilated with room air. A midsternal thoracotomy was performed. Aortic regurgitation was produced by cutting an aortic cusp using a nerve hook through the cardiac apex (fig. 1).

The dogs were separated into three groups of seven dogs each. Dogs in group 1 had lesions in the noncoronary cusp (NCC), group 2 in the left coronary cusp (LCC) and group 3 in the right coronary cusp (RCC). The direction of the regurgitant jet was determined from contrast echocardiograms of cold saline solution injected into the ascending aorta about 2 cm above the aortic root. We also examined the direction of the regurgitant stream by pouring water into the aortic root of the excised heart. In all 21 dogs, the two methods were consistent.

Left ventricular and aortic pressures were measured by placing the fluid-filled catheter in the left ventricle through the cardiac apex and in the ascending aorta through the right carotid artery. The pressures were recorded using a strain-gauge transducer (Statham P23-ID). A flow probe was attached to the aortic root and the phasic aortic flow and integrated aortic flow were recorded by an electromagnetic flowmeter (Nihon-Kohden). Regurgitant fraction was calculated as regurgitant volume/total forward volume. M-mode echocardiograms were obtained using the Sonocardiograph SSL-51U with a 3.0-MHz transducer 5 mm in diameter. The direction of the regurgitant jet was recorded during contrast echocardiography using a two-dimensional echo format with a Toshiba SSH-11A while recording the images on a movie camera or Polaroid camera. The transducer was gently placed on the right ventricular outflow tract and angled to the anterior part of the IVS and the AML so as to simulate the parasternal approach of clinical practice. At autopsy, the anatomic relationships of the position of a transducer and the direction of ultrasound beam to the IVS and AML of the heart were examined (fig. 2).

Results

The overall results of the frequency of echocardiographic findings in each group of dogs are summarized in table 1.

The midportion of the NCC was vertically cut in six of seven dogs of group 1. In these dogs (nos. 1–6), a regurgitant jet impinged upon the anterior part of the IVS (fig. 3A). The echocardiographic findings in all six dogs consisted of fluttering of the IVS (fig. 4A). In dog 7, an oblique cut in the posterior portion of the NCC did not show IVS fluttering and the jet was directed to the lateral wall of the left ventricle.

In six of seven dogs of group 2 (nos. 8–13), the midportion of the LCC was vertically cut and a regurgitant jet impinged upon the posterior part of the IVS.
None of these demonstrated anterior IVS fluttering (fig. 4B). Dog 14, in whom the anterior portion of the LCC had an oblique cut, demonstrated jet direction to the anterior IVS with IVS fluttering.

In all seven dogs in group 3 (nos. 15–21), the midportion of the RCC was vertically cut, and a regurgitant jet was directed toward and impinged upon the AML (fig. 3B). In these dogs, diastolic fluttering of the IVS was not noted (fig. 4C).

Diastolic fluttering of the AML was noted in all 21 dogs after creation of aortic regurgitation. However, diastolic fluttering of the IVS in six of seven dogs in group 1 and in one dog in group 2 correlated with the jet direction to the anterior IVS.

The amplitude of the AML was not changed significantly by the production of aortic regurgitation in group 1 or 2. The amplitude of the AML after aortic regurgitation in group 3 dogs (RCC cut) was decreased significantly (p < 0.01) compared with that in the control state (fig. 5).

One dog in group 3 (dog 21) underwent an additional second cut of the NCC. With the RCC lesion, a regurgitant jet impinged upon the AML, and the amplitude of the AML was decreased from 25 to 9 mm (fig. 6), as in the other six dogs in group 3. After the NCC cut, two regurgitant jets, one originating from the RCC and one from the NCC, collided in the left ventricular outflow tract above the AML. The AML then recovered its normal amplitude despite the larger regurgitant volume.

**Table 1. Results of 21 Dogs Studied**

<table>
<thead>
<tr>
<th>Dog</th>
<th>Cusp included in the cut</th>
<th>Site of the jet impact</th>
<th>Diast. flutter of AML</th>
<th>Diast. flutter of IVS</th>
<th>Amplitude of AML (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Control</td>
<td>AR</td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>NCC</td>
<td>Midportion</td>
<td>Anterior part of IVS</td>
<td>6/6</td>
<td>6/6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Posterior portion</td>
<td>Lateral part of LV</td>
<td>1/1</td>
<td>0/1</td>
</tr>
<tr>
<td>Group 2</td>
<td>LCC</td>
<td>Midportion</td>
<td>Posterior part of IVS</td>
<td>6/6</td>
<td>0/6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Anterior portion</td>
<td>Anterior part of IVS</td>
<td>1/1</td>
<td>1/1</td>
</tr>
<tr>
<td>Group 3</td>
<td>RCC</td>
<td>Midportion</td>
<td>AML</td>
<td>7/7</td>
<td>0/7</td>
</tr>
</tbody>
</table>

Values are mean ± sd.

*p < 0.01.

Abbreviations: Diast. flutter = diastolic fluttering; AML = anterior mitral leaflet; IVS = interventricular septum; AR = aortic regurgitation; LV = left ventricle; NCC = noncoronary cusp; LCC = left coronary cusp; RCC = right coronary cusp.
There were no significant differences between three groups in heart rate, diastolic pressure of the aorta, left ventricular end-diastolic pressure, total forward volume, net forward volume, regurgitant volume and regurgitant fraction in both the control state and aortic regurgitation (table 2).

**Discussion**

The results of the present study are summarized in figure 7.

We studied the relationship between the site upon which a regurgitant jet impinged and the location and direction of the cut within an aortic cusp. The results revealed that (1) a regurgitant jet is directed to and impinges upon the anterior part of the IVS when the midportion of the NCC is vertically cut and the anterior part of the LCC is obliquely cut; (2) a regurgitant jet is directed to the posterior part of the IVS when the midportion of the LCC is vertically cut; (3) a regurgitant jet is directed to and impinges upon the AML.

**Table 2. Hemodynamic Data**

<table>
<thead>
<tr>
<th>Group</th>
<th>Heart rate (beats/min)</th>
<th>Diastolic aortic pressure (mm Hg)</th>
<th>LVEDP (mm Hg)</th>
<th>Total forward volume (ml/beat)</th>
<th>Net forward volume (ml/beat)</th>
<th>Regurgitant volume (ml/beat)</th>
<th>Regurgitant fraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>AR</td>
<td>C</td>
<td>AR</td>
<td>C</td>
<td>AR</td>
<td></td>
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<tr>
<td>1</td>
<td>142±14</td>
<td>143±14</td>
<td>88±30</td>
<td>40±11</td>
<td>10.1±3.9</td>
<td>14.6±4.9</td>
<td>27.7±6.8</td>
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<tr>
<td>2</td>
<td>132±23</td>
<td>125±27</td>
<td>72±20</td>
<td>30±16</td>
<td>9.0±2.2</td>
<td>15.9±6.3</td>
<td>25.1±9.0</td>
</tr>
<tr>
<td>3</td>
<td>137±18</td>
<td>145±19</td>
<td>71±16</td>
<td>33±11</td>
<td>10.0±1.6</td>
<td>15.1±7.2</td>
<td>24.0±8.6</td>
</tr>
</tbody>
</table>

Values are mean ± sd.
Abbreviations: LVEDP = left ventricular end-diastolic pressure; C = control; AR = aortic regurgitation.
Figure 4. (A) Representative echocardiograms from a group 1 dog before (left) and after (right) production of aortic regurgitation. The midportion of the noncoronary cusp (N) was vertically cut. Diastolic fluttering of the anterior mitral leaflet (AML) (black arrow) and that of the interventricular septum (IVS) (white arrow) are shown. (B) Representative echocardiograms from a group 2 dog. The midportion of the left coronary cusp (L) was vertically cut. Only diastolic fluttering of the AML (arrow) is shown. (C) Representative echocardiograms from a group 3 dog. The midportion of the right coronary cusp (R) was vertically cut. A marked decrease in the amplitude and diastolic fluttering of the AML (black arrow) are clearly shown. Ch = chordae; AoP = aortic pressure; LVP = left ventricular pressure; AoF = integrated aortic flow during one cardiac cycle.
when the midportion of the RCC is vertically cut; and (4) a regurgitant jet is directed to the lateral wall of the left ventricle when the posterior portion of the NCC is obliquely cut. Thus, the direction of a regurgitant jet in aortic regurgitation is determined not only by the aortic cusp that is cut, but also by the location and direction of the cut made on the cusp.

We also examined the relationship between the direction of a regurgitant jet and the echocardiographic findings. All 21 dogs had diastolic fluttering of the AML. This finding appears to have no relation to the site upon which a jet impinges, but merely shows the presence of aortic regurgitation. It may result from a vortex formed in the left ventricular outflow tract caused by aortic regurgitation.

Diastolic fluttering of the IVS was observed in all dogs in which a regurgitant jet impinged upon the anterior part of the IVS through which ultrasound beam passed (nos. 1–6 and 14), but it was not observed in dogs in which a regurgitant jet was directed to the posterior part of the IVS through which the beam did not pass (nos. 8–13). This is probably related to the echo beam sampling of the anterior IVS in the present study. Such a beam orientation is also seen in the left parasternal transducer placement in the clinical studies.

The findings in this experimental study are in agreement with clinical observations by D'Cruz et al., who performed aortography in 19 patients with aortic regurgitation to observe the direction of the regurgitant jet. They found that diastolic fluttering of the IVS was present in seven of 12 patients in whom the main jet, or a major component of the broad fan-shaped jet, was directed anteriorly so as to impinge upon the IVS. However, fluttering of the IVS was not found in seven patients in whom the regurgitant jet was directed centrally or posteriorly, away from the IVS. In some of their five patients, in whom diastolic fluttering of the IVS was not observed, despite an anteriorly directed jet, the jet might have been directed to a location of the IVS outside of the ultrasound beam, as in our group 2 dogs.

The most interesting finding in this study was decreased amplitude of the AML, which was observed when a regurgitant jet impinged upon the AML (group 3). It was not seen in the absence of jet impingement

**Figure 5.** Changes in the amplitude of the anterior mitral leaflet (AML) after production of aortic regurgitation (AR) in groups 1 (left), 2 (middle) and 3 (right). C = control.

**Figure 6.** Echocardiograms from dog 21 before (left) and after (middle and right) production of aortic regurgitation. After cutting vertically the midportion of the right coronary cusp (R) (middle), the amplitude of the anterior mitral leaflet (AML) was markedly decreased and diastolic fluttering of the AML was observed. An additional cut of the midportion of the noncoronary cusp (N) resulted in an improvement of decreased amplitude of the AML to the initial level. L = left coronary cusp; IVS = interventricular septum.
upon the AML (groups 1 and 2). Appearance of the decreased amplitude of the AML did not depend on the severity of aortic regurgitation or left ventricular dysfunction because regurgitant volume, regurgitant fraction or stroke volume was not significantly different among the three groups.

From these observations, we think that the decreased amplitude of the AML seen in this experiment was caused by the jet impact upon the AML.

The observation in dog 21 that decreased amplitude of the AML appeared at the first cut of the RCC and then disappeared after the second cut of the NCC may be explained by the presence or absence of jet impingement upon the AML. To our knowledge, there has been no systematic study on the change of the amplitude of the AML in aortic regurgitation. Two of our patients had aortic regurgitation and decreased amplitude of the AML in the absence of clinical manifestation of advanced heart failure (New York Heart Association Class II). Aortography showed a regurgitant jet directed posteriorly to the AML. We believe that the decreased amplitude of the AML in these cases may be due to the jet impact, which prevents it from opening during diastole.

We conclude that in aortic regurgitation, the direction of the regurgitant jet is an important determinant in producing diastolic fluttering of the IVS and in decreasing the amplitude of the AML. This conclusion may be useful in the interpretation of echocardiographic abnormalities demonstrated in patients with aortic regurgitation.

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References

Figure 7. Results of the study. Arrows show the regurgitant jet. Relationship between the direction of a regurgitant jet and the aortic cusp cut as well as the site and direction of the cut within the cusp is shown. In addition, relationship between the direction of a jet and ultrasound beam is also clearly shown. LVPW = left ventricular posterior wall; PML = posterior mitral leaflet; AML = anterior mitral leaflet; IVS = interventricular septum; L (LCC) = left coronary cusp; R (RCC) = right coronary cusp; N (NCC) = noncoronary cusp.
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