An Experimental Method for the Study of Aortic Insufficiency

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In the past, the pathophysiologic study of experimental aortic insufficiency has been hampered greatly by the lack of a reliable method for the measurement of instantaneous blood flow and by the inability to achieve a consistent and predictable degree of regurgitation. The techniques for producing valvular injury vary and have included the use of stylets, dilators, curettes, hooks, knives, the cauterity, probes, and biopsy forceps that are passed down the carotid artery, up through the left ventricle, or through the wall of the aorta. The results could not be forecast, but range from death due to acute cardiac decompensation to spontaneous healing of the valve without residual insufficiency.

Based on the past experience of other investigators, certain criteria may be outlined for the ideal method of creating aortic insufficiency: (1) there should be minimal trauma to the host, that is, little blood loss and no myocardial damage; (2) the valvular injury must not heal spontaneously; (3) the degree of insufficiency should parallel that seen clinically, and yet be compatible with life; and (4) the procedure should be technically simple. In addition, it should be possible to perform the procedure through the left side of the chest, if hemodynamic studies are of importance, since easy access to the aorta and coronary arteries is allowed.

The method of Roshe and Morrow, reported in 1955, employed a cylindrical leaflet punch which was passed into the ascending aorta during venous inflow occlusion and most adequately fulfills the ideal criteria. The mortality is relatively low, and a predictable degree of insufficiency can be obtained. Certain modifications of their technique allowed hemodynamic investigations of animals in the normal state, with acute aortic insufficiency, with chronic aortic insufficiency, and after correction of aortic insufficiency. If operative dissection is limited, it should be possible to study a single animal in all four states. However, if blood flows are to be measured and circumferential dissection of blood vessels is required, two series of animals must be prepared, since postoperative scarring and fibrosis will prevent adequate exposure of the vessel at a later date.

Methods

Mongrel dogs were anesthetized with intravenous sodium pentobarbital (30 mg./Kg.). Ventilation with room air was maintained by a mechanical respirator and cuffed endotracheal tube at a rate of 20/min. and a positive pressure of 12 cm. of water.

An eight-channel Sanborn 650 amplifier-recording system was employed to allow simultaneous measurement of pressures, mean and instantaneous blood flows, and electrocardiograms. Central aortic pressures were recorded through a no. 9 cardiac catheter in the right femoral artery with its tip 3 cm. above the aortic valve. Blood flows were determined with a square-wave electromagnetic flowmeter, with the flow probe placed around the ascending aorta immediately above the aortic valve. Zero flow reference was determined in the ascending aorta by subtracting the total flows of the brachiocephalic artery, left subclavian artery, and descending aorta from that of the ascending aorta, according to the method of Schenk. All flows were corrected for variations in hematocrit. Stroke volume and regurgitation were determined by planimetric measurement of the pulsatile flow tracings.

*Sanborn Company, Waltham, Massachusetts.
†Model 201 C, modified square-wave electromagnetic flowmeter, Carolina Medical Electronics, Inc., Winston-Salem, North Carolina.
Preparation of Chronic Aortic Insufficiency

Through an incision in the right third intercostal space, the azygos vein was ligated, and heavy cotton tapes were passed around both venae cavae. The pericardium overlying the ascending aorta was incised, and the right atrial appendage was retracted medially. After five minutes of ventilation with 100 per cent oxygen, both venae cavae were occluded, and a leaflet punch 5 mm. in diameter was insinuated through a 1-cm. lateral aortotomy (fig. 1). A circular opening was made in either the right or left coronary leaflet. After the punch was removed, a Beek clamp was applied to the aortic incision, and the caval ligatures were released. The aorta and chest wall were closed in a routine fashion, and the lungs were re-expanded. All animals received penicillin (600,000 units) postoperatively for seven days.

Preparation and Study of Acute Aortic Insufficiency

After femoral arterial cannulation, a left thoracotomy was performed through the third intercostal space; the descending aorta, left subclavian artery, and brachiocephalic artery were dissected circumferentially for a distance of 3 cm. The pericardium was opened widely and the aortic fat pad removed. The ascending aorta and pulmonary artery were separated and encircled with heavy cotton tapes. Ascending aortic blood flows and central aortic blood pressures were measured, and the animal was ventilated for five minutes with 100 per cent oxygen. Following this, the pulmonary, brachiocephalic, and subclavian arteries and the descending aorta were occluded. The leaflet punch was passed through a left lateral aortotomy to incise the valve and produce insufficiency (fig. 2). After closure of the aorta and restoration of the circulation, all measurements were repeated.
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Figure 4

Study of Chronic Aortic Insufficiency and Repair of Valvular Defect

After femoral arterial cannulation, a bilateral third intercostal space thoracotomy was performed, and dissection and measurements were carried out in a manner similar to the previous procedure. Heparin (2.5 mg./Kg.) was administered intravenously, a large-bore cannula was inserted into the left carotid artery, and both venae cavae were cannulated through the right atrium. By means of a modified Kay-Cross oxygenator with DeBakey roller pumps and a Harrison-Brown heat exchanger, cardiopulmonary bypass was instituted at a perfusion rate of 80 ml./Kg./min. Body temperature was lowered to 33 C., and the aorta was cross clamped proximal to the brachiocephalic artery (fig. 3). A 3-em. anterior aortotomy was made down to the base of the aorta to allow adequate exposure of the valve and to repair the valvular defect. Two disks of compressed polyvinyl sponge were secured with a single mattress suture to either side of the leaflet (fig. 4). The aorta was then closed, and air was excluded from the heart. The aortic clamp was removed, and the animal was warmed to 37 C., at which point cardiopulmonary bypass was discontinued and all measurements were repeated. The animal was then sacrificed, and the heart was removed and weighed.

Results

An overall operative mortality rate of 15 per cent was sustained in the creation of aortic insufficiency. Death was due either to ventricular fibrillation or hemorrhage from an irreparable laceration of the aorta. One animal expired 85 days postoperatively from pneumonia, while the remainder of those surviving were in apparent good health until the time of the second procedure.

Acute Aortic Insufficiency

Fifteen dogs, ranging in weight from 13.2 to 25.5 Kg. (average, 18.3 Kg.), underwent measurements of central aortic blood pressure and ascending aortic blood flow in the normal state and immediately after valvular injury. The left coronary cusp was punctured in five of these and the right coronary cusp in ten. There was no detectable difference in the measurements in these two groups, and therefore, the right coronary cusp was perforated in all later studies because of its anatomical accessibility.

Average mean blood pressure in the normal state was 110 ± 14 mm. Hg, decreasing to 106 ± 18.3 mm. Hg with acute aortic insufficiency. The mean central aortic pulse pressure was 31 ± 7 mm. Hg in the normal state, increasing to 61 ± 12.8 mm. Hg with acute aortic insufficiency.

The normal mean values were as follows: cardiac output, 121.4 ± 29.8 ml./Kg./min.; stroke volume, 12.6 ± 3.1 ml.; per cent regurgitation, 0. Mean values after creation of acute aortic insufficiency were: effective cardiac output, 75.1 ± 25 ml./Kg./min.; stroke volume, 12.9 ± 5.5 ml.; per cent regurgitation, 41. Thus, in the acute state, cardiac output fell 22 per cent, and stroke volume was effectively unaltered.

Chronic Aortic Insufficiency

Eleven dogs, ranging in weight from 15.9 to 20.5 Kg., were studied 132 to 168 days after aortic insufficiency was produced. In five, valvular repair was attempted; four animals were effectively repaired, and one was only partially relieved of aortic insufficiency.

Average mean blood pressure was 110 ± 24.2 mm. Hg and, after valvular repair, 96 ± 7.3 mm. Hg. Mean pulse pressure was 63 ± 17.8 mm. Hg and with repair fell to 37 ± 8.3 mm. Hg.

The following mean values were obtained: effective cardiac output, 106.3 ± 53 ml./Kg./min.; stroke volume, 21.8 ± 8.3 ml.; per cent regurgitation, 49. After valvular repair, the
effective cardiac output was 100.8 ± 41 ml./Kg./min.; stroke volume was 17.4 ± 8.0 ml.; and there was 14 per cent regurgitation.

Calculated from the tables of Herrmann, the estimated mean normal heart weight for the 11 dogs with chronic aortic insufficiency was 138 ± 19.1 Gm., while postmortem measurement of these hearts gave a mean of 195 ± 22.3 Gm. This appeared to be solely on the basis of left ventricular hypertrophy, and represented a 41 per cent increase above the expected normal heart weight (table 1).

**Discussion**

There are many poorly understood complications following direct-vision repair of the aortic valve, including alterations in cardiac rhythm, cardiac hemodynamics, pulmonary function, and tissue metabolism. The method outlined herein has achieved reasonably consistent results with an acceptable mortality rate, marked cardiac hypertrophy, and a predictable degree of regurgitation, and thus provides an experimental animal adaptable to the study of these alterations. In addition, it has been found that the animals with chronic aortic insufficiency and consequent cardiac hypertrophy more closely parallel the patients with this disease. For this reason, we have devoted our studies solely to chronic preparations.

The method for valvular repair has only been employed in five animals to date, and the mean residual regurgitation has been 14 per cent; however, four of the five animals demonstrated regurgitation of less than 10 per cent. We have not attempted to obtain long-term survivors after valvular repair, although there is no evidence that these animals could not survive for studies of cardiac hemodynamics as the heart returns to normal size.

**Summary**

A method is presented for the experimental creation and correction of acute and chronic aortic insufficiency in dogs. Fifteen animals with acute, 11 with chronic, and 5 with corrected aortic insufficiency were studied. In all animals, mean central aortic blood pressure

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**Table 1**

<table>
<thead>
<tr>
<th>Summary of Results</th>
<th>Normal Mean ± S.D.</th>
<th>Acute A* Mean ± S.D.</th>
<th>After repair of A* Mean ± S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of animals</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Body weight, Kg.</td>
<td>18.3 ± 2.9</td>
<td>18.3 ± 2.9</td>
<td>18.3 ± 2.9</td>
</tr>
<tr>
<td>Mean central aortic blood pressure, mm. Hg</td>
<td>110 ± 14.0</td>
<td>106 ± 14.3</td>
<td>110 ± 14.3</td>
</tr>
<tr>
<td>Central aortic pulse pressure, mm. Hg</td>
<td>31.0 ± 7.0</td>
<td>31.0 ± 7.0</td>
<td>31.0 ± 7.0</td>
</tr>
<tr>
<td>Effective cardiac output, ml./Kg./min.</td>
<td>121.4 ± 29.8</td>
<td>121.4 ± 29.8</td>
<td>121.4 ± 29.8</td>
</tr>
<tr>
<td>Stroke volume, ml.</td>
<td>12.9 ± 3.1</td>
<td>12.9 ± 3.1</td>
<td>12.9 ± 3.1</td>
</tr>
<tr>
<td>Per cent regurgitation</td>
<td>0 ± 4.1</td>
<td>41 ± 4.1</td>
<td>41 ± 4.1</td>
</tr>
<tr>
<td>Heart weight, Gm.</td>
<td>138 ± 10.1</td>
<td>138 ± 10.1</td>
<td>138 ± 10.1</td>
</tr>
</tbody>
</table>

*A* — aortic insufficiency.

S.D. = standard deviation, allowing one degree of freedom.
was essentially normal, while pulse pressure was widened in the acute and chronic states, returning to normal with valvular repair. In the acute state, 41 per cent regurgitation was achieved without a significant alteration in stroke volume. However, in the chronic preparations, when 49 per cent regurgitation was present, there was a 70 per cent increase in stroke volume, accompanied by cardiac hypertrophy. Valvular repair in four of five animals reduced the aortic regurgitation to less than 10 per cent without altering cardiac output. Because of the consistent and predictable results, this method can be used for studies of the pathophysiological alterations attendant upon aortic insufficiency in humans.

References
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