A Method for the Detection and Estimation of Aortic Regurgitant Flow in Man

By Eugene Braunwald, M.D., and Andrew G. Morrow, M.D., F.A.C.S.

When a diastolic murmur is present at the base of the heart, it may be difficult on clinical grounds to determine whether or not aortic insufficiency is present. Further, in patients in whom this lesion definitely exists, the magnitude of aortic regurgitant flow has been the subject of considerable speculation among both clinicians and physiologists. A technic has been devised that not only makes possible the detection of aortic insufficiency but also permits an estimate of the regurgitant volume to be made.

The clinical and hemodynamic characterization of valvular heart disease has been limited by difficulties in the recognition and measurement of regurgitant flow. The present communication describes a technic whereby aortic regurgitant flow in man may be detected and its magnitude assessed. In the absence of aortic regurgitation, retrograde blood flow in the aortic arch is minimal. In the presence of aortic regurgitation, however, reverse flow in the aortic arch is increased and the volume of this retrograde arterial flow, in excess of that which occurs normally, is the volume of blood which regurgitates. An estimate of the magnitude of aortic regurgitation may be obtained by injecting an indicator dye into the descending aorta and detecting its presence upstream. With the detection site held constant, the lowest point in the descending aorta from which injected dye regurgitates is determined. The volume of blood contained within the segment of aorta between this point and the detection site during diastole represents the volume of reversed aortic flow; this in turn is a function of aortic regurgitant flow.

Experimental Technics
Aortic dye injections and pressure measurements were made through a no. 6 cardiac catheter which had been advanced through a no. 12 thin-wall needle introduced percutaneously into the femoral artery. A Wood ear-oximeter placed on the right ear was employed for the detection of indicator dye in the ascending aorta. Since the blood supplying the right ear is derived from the innominate artery, the presence of dye in the ascending aorta results in perfusion of the right ear with blood containing dye. A Statham P23A transducer was employed in the measurement of central aortic pressure and a cathode ray photographic instrument was used for the recording of dye curves and aortic pressures. Indigo carmine was employed as the indicator dye, since it could be injected repeatedly without skin discoloration. The dye was injected slowly enough to insure that the injection period included at least one complete diastole. In order to minimize baseline shifts, most of the patients inhaled 100 per cent oxygen during the procedure.

Under fluoroscopic control the catheter tip was introduced into the ascending aorta. Following the measurement of pressures, the catheter was withdrawn to the mid-point of the aortic arch. Dye was then injected at 2-cm. intervals as the catheter was withdrawn into the descending aorta. The position of the catheter tip at the lowest point from which injected dye could be detected in the right ear was then recorded roentgenographically (fig. 1).

Results
A total of 26 patients has been studied. No complications from the aortic catheterization occurred. The most distal sites in the aorta from which injected dye was detected in the right ear are indicated in figure 2. The 7 patients employed as controls had neither clinical nor hemodynamic findings suggestive of aortic regurgitation. Dye injected into the aorta immediately distal to the aortic

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arch could not be detected in the right ear during its primary circulation in any of these patients (figs. 2A and 3).

In contrast to the above findings, in all 10 patients in whom there was firm clinical evidence of aortic regurgitation, dye injected into the descending aorta could be detected in the right ear. The most distal sites in the aorta from which dye could be detected in these patients are indicated in figure 2B. These sites were referred to the corresponding vertebral bodies; the levels ranged from T-6 to L-2.

Patient A (fig. 2C) was considered to have pure aortic stenosis on the basis of clinical examination. However, the detection of dye in the right ear immediately following injection into the descending thoracic aorta at the level of the seventh thoracic vertebra, suggested the presence of aortic regurgitation. This was subsequently confirmed at postmortem examination.

Six patients had mitral valve disease, pulmonary hypertension, and high-pitched diastolic murmurs along the left sternal border without the peripheral circulatory dynamics of aortic regurgitation. It was not possible to ascertain whether the murmur represented pulmonic insufficiency, aortic insufficiency, or a combination of these lesions. The detection of dye in the right ear after injection into the descending thoracic aorta indicated that aortic insufficiency was present in 5 of these patients (fig. 2C, patients C, I, T, U, V). In the sixth patient (fig. 2C, patient S) there was no reflux of dye injected from a point distal to the aortic arch, a finding thought to exclude the presence of significant aortic regurgitation.

In 1 patient (fig. 2C, patient F) a murmur, thought to be continuous, was audible at the base of the heart. The differential diagnosis was between a left-to-right shunt and combined aortic stenosis and insufficiency. The presence of dye circulating through the right ear following its injection into the descending aorta suggested that the patient had aortic insufficiency. The presence of a left-to-right shunt was subsequently excluded by other diagnostic studies.

Patient W (fig. 2C) presented the typical clinical and hemodynamic findings of congenital aortic stenosis. In addition there was a grade II blowing diastolic murmur over the aortic area. Angiocardiography demonstrated a subvalvar obstruction in the outflow tract of the left ventricle. Dye injected into the descending aorta at the level of T-8 was detected at the right ear. Postmortem examination confirmed the presence of the subvalvar obstruction. The aortic valve leaflets were thickened, did not approximate completely, and the valve was obviously incompetent.
FIG. 2. The most distal site in the aorta from which injected dye could be detected in the right ear. Left A. Patients without evidence of aortic regurgitation. Middle B. Patients with clinical evidence of aortic regurgitation. Right C. Other patients discussed in the text.

**DISCUSSION**

Since Corrigan's classic description of the bounding pulse in patients with aortic regurgitation, clinicians and physiologists alike have speculated on the magnitude of aortic reflux. Several investigations have suggested that only relatively small volumes of aortic regurgitation could be tolerated. Recent experiments on metered aortic regurgitant flow in the dog have shown that acutely produced regurgitant flows in excess of resting forward cardiac output are accompanied by substantial depression of the forward cardiac output and marked elevations of left ventricular end-diastolic pressure. Other investigators have suggested that regurgitant volumes may be equal to or even exceed forward cardiac output. The recent observations of Warner and Toronto are in accord with this view.

It was therefore of interest that in patients with clinical evidence of severe aortic regurgitation, there was a reflux of dye into the ascending aorta following its injection into the abdominal aorta. Such observations indicated that the volume of regurgitant flow could be quite large. An attempt was then made to utilize the data obtained in an estimation of the magnitude of aortic regurgitation. This was done by determining the approximate volume of blood contained in the aorta between the origin of the innominate artery and the lowest point from which the injected dye was detected. The patient's total aortic volume was estimated from the aortic pressure-volume relationships determined in human cadavers by Remington, Noback, Hamilton, and Gold. The patient's mean diastolic central aortic pressure was determined by planimetric integration and
TABLE 1.—Estimated Aortic Reflux in Patients with Clinical Signs of Aortic Regurgitation

<table>
<thead>
<tr>
<th>Patient</th>
<th>Central aortic pressure (mm. Hg)</th>
<th>Estimated total aortic vol. ml.</th>
<th>% Total aortic vol. which regurgitated</th>
<th>Estimated aortic regurgitant flow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S/d</td>
<td>m. d.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>106/29</td>
<td>52</td>
<td>100</td>
<td>70</td>
</tr>
<tr>
<td>G</td>
<td>142/74</td>
<td>91</td>
<td>151</td>
<td>30</td>
</tr>
<tr>
<td>H</td>
<td>120/63</td>
<td>70</td>
<td>117</td>
<td>62</td>
</tr>
<tr>
<td>K</td>
<td>129/49</td>
<td>72</td>
<td>135</td>
<td>47</td>
</tr>
<tr>
<td>M</td>
<td>138/45</td>
<td>65</td>
<td>113</td>
<td>53</td>
</tr>
<tr>
<td>X</td>
<td>82/51</td>
<td>58</td>
<td>114</td>
<td>53</td>
</tr>
<tr>
<td>Q</td>
<td>96/54</td>
<td>65</td>
<td>108</td>
<td>40</td>
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<tr>
<td>0</td>
<td>82/42</td>
<td>51</td>
<td>102</td>
<td>33</td>
</tr>
<tr>
<td>X</td>
<td>89/46</td>
<td>59</td>
<td>59</td>
<td>47</td>
</tr>
</tbody>
</table>

S = systolic pressure.

d = diastolic pressure.

m. d. = mean diastolic pressure.

was used together with the age and body surface area for the determination of diastolic aortic volume from the published graph of Remington et al.

The total aorta was divided into 4 anatomic divisions. On the basis of calculations derived from anatomic studies, it was possible to assign a fraction of the total aortic volume to each of these sections. In this manner the ascending aorta was estimated to contain 19.8 per cent of the total aortic volume, the aortic arch 13.5 per cent, the descending thoracic aorta 46.0 per cent, and the abdominal aorta 20.7 per cent. The descending thoracic aorta was subdivided into segments corresponding to the related vertebral bodies (T-6 to T-12); 6.6 per cent of total aortic volume then corresponded to the descending thoracic aortic segment in front of each vertebral body. Similarly, the abdominal aorta was subdivided into 4 parts, one for each of the upper four lumbar vertebral bodies; 5.2 per cent of the total aortic volume was assigned to each lumbar aortic segment.

From the above calculations it was possible to determine the fraction of the total aortic volume that regurgitated. This was represented by the volume between the tip of the injection catheter and the origin of the innominate artery. Since the total aortic volume could be estimated from the data of Remington et al., the regurgitation per beat could be calculated. The results in the 10 patients (fig. 2B) with evidence of aortic regurgitation are presented in table 1. The estimated regurgitant stroke indices ranged from 13 to 43 ml. per M.² B.S.A., while the estimated total aortic regurgitant flows ranged from 1.8 to 5.6 L. per minute.

The approximate nature of these calculations is well recognized. The major sources of error appear to be: 1. The average values for total aortic volume were obtained from a relatively small group of cadavers. Considerable variation in these volumes occurs in any given age group. 2. Average values were also employed in the partition of the total aortic volume. 3. The pressure-volume relationships of the aorta in patients with aortic regurgitation may well differ from those in the subjects without circulatory disease studied by Remington. 4. The regurgitant volume calculation is based on an estimation of reverse flow in the aorta alone and no consideration has been given to the regurgitant volume contained in other arteries, which may be considered to be in parallel with the aorta. On this basis it is likely that the aortic regurgitant flows were underestimated. In spite of these limitations in accuracy, the volumes calculated furnish at least an approximation of regurgitant flow.

The presence of aortic regurgitation can be
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Fig. 3. Dye-dilution curves recorded from the right ear following injection into the aorta at the level of the aortic valve (left) at the origin of the innominate artery (center) and 1 cm. distal to the origin of the innominate artery (right) in a patient without clinical or hemodynamic evidence of aortic regurgitation (patient E, fig. 2A). Vertical arrows indicate midpoints of injection. Vertical time lines equal 1.0 second.

demonstrated merely by the detection of dye in the right ear following an injection at any level distal to the aortic arch. The procedure has been found of particular value in the assessment of patients in whom the diagnosis of aortic insufficiency is in doubt. Among these are patients with highpitched, decrescendo diastolic murmurs at the left sternal border. The exclusion of aortic regurgitation by this technic may be helpful in more clearly defining the incidence of pulmonic incompetency as well as the clinical and hemodynamic picture with which this lesion is associated. Also it is of interest that significant aortic regurgitation has been detected in a patient without the characteristic murmur (patient A, fig. 2C) and in another (patient W, fig. 2C) whose predominant lesion was subvalvular aortic stenosis. In patients with left-to-right shunts originating from the aortic root, blood also regurgitates into the ascending aorta during diastole and the technic described permits estimation of the diastolic component of the shunt. As has been described elsewhere the differential diagnosis between such a shunt and aortic insufficiency can be made by injecting dye into the ascending aorta and noting the contour of the dilution curve obtained from the femoral artery.

The method has already proved of value in assessing the magnitude of regurgitation in patients with mixed aortic valve lesions being selected for aortic commissurotomy. It also furnishes an index of the effect of the operation on the aortic regurgitant flow. Although the technic is not directly applicable in the measurement of aortic regurgitation before and after the insertion of a Hufnagel valve, it should prove useful in assessing the effectiveness of prostheses placed into the ascending aorta or left ventricle.

SUMMARY

A method for the detection and estimation of the magnitude of aortic regurgitant flow in man is described. Aortic regurgitant flow was detected by the injection of indicator dye at various levels in the descending aorta through a catheter introduced percutaneously from the femoral artery. The lowest point in the descending aorta from which injected dye regurgitated back to the ascending aorta and perfused the right ear was determined by means of an oximeter placed on the right ear.

In all 7 patients without aortic regurgitation dye injected distal to the aortic arch could not be detected in the right ear. In all 10 patients with clinical and hemodynamic

Fig. 4. Dye-dilution curves recorded from the right ear following injection into the aorta at various distances from the origin of the innominate artery in a patient with clinical and hemodynamic evidence of severe aortic regurgitation (patient H, fig. 2B and table 1). The lowest point in the aorta from which dye could be detected in the right ear was 20 cm. distal to the origin of the innominate.
evidence of aortic regurgitation, dye injected into the descending aorta regurgitated to the ascending aorta. The technic was also found useful in demonstrating aortic insufficiency in patients with diastolic murmurs at the base of the heart, but without other hemodynamic evidence of aortic valve disease.

Employing aortic pressure-volume relationships obtained from human cadavers the magnitude of aortic regurgitant flow was estimated. In 10 patients with aortic insufficiency the estimated regurgitant flow ranged from 1.2 to 2.8 L per minute per M.2 B.S.A.

**SUMMARIO IN INTERLINGUA**

Es describite un metodo pro le detection e estimation del magnitude de aortic fluxos regurgitante in humanos. Le presentia de iste condition eseva detegite per le injection de un colorante indicatori a varie nivellos in le aorta descendente per medio de un catheter introduse percutaneamente ab le arteria femoral. Le plus basse puncto in le aorta descendente ab ubi le colorante eseva regurgitate verso le aorta ascendente con le consequente perfusion del aure dextere eseva determinate per medio de un oxymetro placiate al aure dextere.

In omnes de 7 patientes sin regurgitation aortic, colorante injecite a un puncto distal con respecto al arco aortic non poteva esser detegite in le aure dextere. In omnes de 10 patientes con signos clinic e hemodynamic de regurgitation aortic, colorante injecite in le aorta descendente eseva regurgitate verso le aorta ascendente. Le technica se provava utile etiam in demonstrar insufficientia aortic in patientes con murmures diastolic al base del corde sed sin altere signos hemodynamic de morbo del valvula aortic.

Super le base de relationes inter pression e volumine aortic determinate in cadaveres human, le magnitude del regurgitante fluxo aortic eseva estimate. In 10 patientes con insufficientia aortic le estimate fluxo regurgitante variava inter 1.2 e 2.8 litros per minuta per metro quadrade de superficie corporee.

**REFERENCES**


DETECTION AND ESTIMATION OF AORTIC FLOW


The clinical and angiocardiographic findings in 4 patients with pulmonary arteriovenous fistula are presented. Apparently 40 per cent of the cases reported in the literature also have hemangiomas elsewhere in the body, suggesting familial telangiectasis (Rendu-Osler-Weber disease). The classical syndrome of cyanosis, digital clubbing, polycythemia and a vascular murmur was present in only 2 of 13 patients; only 8 of the 13 were symptomatic, and 3 of these had acute cerebral conditions: brain abscess, meningoencephalitis, and hemiplegia. Conventional roentgenography was adequate to raise the index of suspicion, but angiocardiography was necessary not only to establish the diagnosis, but also to delineate the location and extent of the afferent and efferent connections, so necessary to the thoracic surgeon for excision (segmental resection or lobectomy).
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