OPEN VERSUS CLOSED LEFT ATRIAL DRAINAGE DURING CROSS-CLAMPING OF THE THORACIC AORTA

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The hazards of cross-clamping the aortic arch distal to the carotid arteries fall into two categories. First is proximal hypertension, which may cause cerebral hemorrhage, cardiac dilatation with ventricular fibrillation, and occasionally pulmonary edema. The second is inadequate blood flow distal to the clamp, which may result in spinal cord damage or ischemic renal insufficiency. The treatment of aneurysms of the distal aortic arch necessitates cross-clamping of the aorta. The method currently employed to obviate these dangers is the pumping of blood from the left atrium to the femoral artery via a closed system. This procedure has not been entirely satisfactory, however, for De Bakey recently stated that 2 of 36 patients so treated have suffered ischemic spinal cord damage following cross-clamping of the descending thoracic aorta, in spite of left atrial to femoral artery bypass. A recent clinical case at the Oklahoma City Veterans Administration Hospital, in which closed left atrial drainage was employed, revealed inadequate proximal decompression with a systolic pressure greater than 250 mm. Hg and transient pulmonary edema in spite of pump flow settings which were increased to greater than 3 L. per minute. This patient developed hypertensive encephalopathy postoperatively, but eventually made a complete recovery. The experience prompted us to study closed left atrial drainage experimentally, and compare it to open, or reservoir, drainage.

MATERIALS AND METHODS

Mongrel dogs, weighing 25 to 35 kilograms, were anesthetized with intravenous Nembutal. Ventilation was maintained by a mechanical respirator. Through a left thoracotomy, a 30 Fr. catheter was inserted into the left atrium. Blood could be drained by either open or closed methods by means of plastic tubing and pumped into the femoral artery via a totally occlusive Sigmamotor finger pump which had been previously calibrated. This pump, when totally occlusive, delivers a constant flow against the pressures encountered in this experiment. A side-arm was provided to measure the actual flows delivered.

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Supported by U.S. Public Health Service (H-4104) and a grant from the Oklahoma Heart Association.

Received for publication June 28, 1959.
Pressures were measured in the carotid, femoral, and pulmonary arteries, pulmonary veins, and left atrium by means of polyethylene catheters, Statham strain gauges, and a Sanborn direct-writing oscillograph. Forty-one paired flow measurements of open and closed left atrial drainage were made on 13 dogs, utilizing flow settings between 500 and 2,600 c.c. per minute.

RESULTS

In 40 of these 41 flow measurements, closed drainage delivered less than the calibrated flow (Fig. 2). The single instance in which the flow from closed drainage equaled that of open drainage occurred in a dog which was hypervolemic and at a flow setting of only 500 c.c. per minute.

![Diagram of method for study of open and closed left atrial drainage during left atrial to femoral artery bypass.]

The dog's blood volume is an important determinant of the amount of blood drained from the left atrium (Fig. 3). With the pump set at 2,580 c.c. per minute during aortic arch cross-clamping, this volume of blood drained openly from the left atrium into a reservoir and was pumped into the femoral artery. This was the actual volume delivered, for the blood level in the reservoir remained constant. When the system was converted to closed atrial drainage, flow dropped to 525 c.c. per minute. With the measured withdrawal of serial volumes of blood, the amount of flow diminished progressively. After the loss of approximately one sixth of the dog's blood volume, flow had diminished to 195 c.c. per minute at a pump setting of 2,580 c.c. per minute. All 13 dogs showed this progressive decrease in closed bypass flow volumes with serial blood withdrawals; also, with flow settings as low as 500 c.c., progressive decrease in blood volume was accompanied by decrease in flow. Thus, at a setting of 500 c.c. per minute, closed bypass flow as low as 35 c.c. per minute was recorded.
a hypovolemic dog. This relationship is of extreme practical importance, for many surgeons, fearing proximal hypertension during aortic cross-clamping, prefer hypovolemia at this time.

Pressure measurements during thoracic aorta cross-clamping alone are represented in Fig. 4. The pulmonary venous pressure, represented by the mean pulmonary artery wedge tracing, was originally 5 mm. Hg and after aortic cross-clamping increased to 17 mm. Hg. After release of the clamp it rapidly fell to its original level. The arterial side of the pulmonary capillary bed, represented by the pulmonary venous wedge pressure, remained constant at a mean of 27 mm. Hg during this 20-second period of aorta cross-clamping.

![Diagram of flow measurements during open and closed left atrial drainage.](image)

Fig. 2.—Paired flow measurements during open and closed left atrial drainage.

The carotid artery pressure rose to 260 to 280 mm. Hg and the femoral artery pressure fell to 20 mm. Hg during this same interval. During open bypass, left atrial and pulmonary venous pressures were equal and ranged between 10 to 0 mm. Hg. Pulmonary artery pressure was unchanged. Carotid artery and femoral artery pressures were maintained within physiologic limits and varied according to the dog's blood volume and amount of bypass flow. With open left atrial drainage, the reservoir was either raised or lowered until the level remained constant at a given flow setting. If the dog was hypovolemic, left atrial pressure was low and atrial return was diminished. Blood was then
importance, for cross-clamping, ping alone are resembed by the Hg and after of the clamp it monary capillary nained constant cross-clamping.

added to the system and in this manner the animals tended to regulate their own blood volume. The same is true clinically of total cardiac bypass in which the caval blood is drained by gravity. Consequently, in these studies, left atrial pressure and bypass flow were regulated by the dog’s blood volume. Upon switching to closed drainage, left atrial pressure dropped to -10 to -25 mm. Hg, and occasionally to levels as low as -100 mm. Hg. The pulmonary venous pressure, however, as measured from the wedged pulmonary artery catheter, did not fall, but slowly increased. Pulmonary artery pressure remained constant. The carotid artery pressure rose and the femoral artery pressure fell (Table I). Interestingly enough, if the flow setting was increased at this time, these differences were often magnified.

![Graph showing influence of blood volume on bypass blood flow during closed left atrial drainage.](image)

**Fig. 3.**—Influence of blood volume on bypass blood flow during closed left atrial drainage.

<table>
<thead>
<tr>
<th>Blood Volume (cc)</th>
<th>Flow (cc/min)</th>
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<tbody>
<tr>
<td>100</td>
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<tr>
<td>200</td>
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<td>300</td>
<td>300</td>
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<td>400</td>
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<td>500</td>
<td>500</td>
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<td>600</td>
<td>600</td>
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</tbody>
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**Table I. Successive Pressure Readings During Thoracic Aorta Cross-Clamping on Changing From Open to Closed Left Atrial Drainage During Left Atrial to Femoral Artery Bypass**

<table>
<thead>
<tr>
<th></th>
<th>OPEN DRAINAGE (2,100 c.c./min.)</th>
<th>CLOSED DRAINAGE (550 c.c./min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carotid artery</td>
<td>125/110</td>
<td>170/130</td>
</tr>
<tr>
<td>Femoral artery</td>
<td>122/96</td>
<td>96/78</td>
</tr>
<tr>
<td>Pulmonary artery</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Pulmonary vein</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>Left atrium</td>
<td>2</td>
<td>-12</td>
</tr>
</tbody>
</table>

**DISCUSSION**

Two mechanisms may be involved during closed left atrium to femoral artery bypass to account for the observed pressure changes. The first is collapse of the left atrium due to the negative pressure. This was observed readily in these dogs. This partially occludes the catheter and limits egress of blood from the left atrium. The second is probably the partial or intermittent obstruction of the pulmonary veins at the venous-atrial junction. A valve mechanism
Fig. 4.—Aortic Cross-Clamping Without Vent. Pressure measurements during occlusion of descending aortic arch. (Meaning circuit of oscillograph alternately on and off during pulmonary pressure tracings.)
exists at this junction, for it is known that during normal atrial systole there
is very little reflux of blood into the pulmonary veins. This is probably the result
of the contraction of atrial muscle around the pulmonary venous orifices. Simi-
larly, with the application of negative pressure within the left atrium, the
atrial walls around the vein orifices may be drawn together, partially or inter-
mittently obstructing pulmonary venous return and resulting in an increase
in pulmonary venous pressure.

The practical importance of these findings is obvious. Closed atrial drain-
age may yield inadequate proximal decompression and insufficient flows distally.
Increasing the pump flow setting often magnifies these difficulties. The prefer-
eence for hypovolemia during this period may be disastrous, for it markedly de-
creases flow. The direct relationship between blood volume and available venous
return during extracorporeal circulation has been pointed out by others.  

An additional disadvantage of closed drainage which was encountered in
these studies was coronary air embolism, invariably fatal in the 5 dogs in which
it occurred. This is due to the negative pressure sucking air into the left atrium
around the catheter. In the dog, this air lodges in the coronary arteries and
can be seen in these vessels.

Open drainage obviates the dangers which result from attempting to suck
blood from a closed system. Therefore, during surgical procedures necessitating
aortic arch cross-clamping at this institution, closed left atrial drainage has
been replaced by open, or reservoir drainage.

SUMMARY

Comparisons were made between open and closed left atrial drainage,
during left atrium to femoral artery bypass, in 13 dogs with thoracic aorta
cross-clamping. At the same pump flow settings, open drainage yielded greater
left atrial drainage with larger and consistently reliable flow volumes to the
distal aorta. These differences were magnified in hypovolemic dogs. Mechanisms
for differences between open and closed drainage are discussed.

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