Infarction of The Right Ventricle Caused by Multiple Coronary Vein Ligation

By Ferdinand F. McAllister, M.D., and David S. Leighninger, M.D.

Ligation of the coronary sinus and all the visible anterior cardiac veins led to death in 5 out of 24 dogs. In 15 out of 17 of these dogs coming to autopsy, varying degrees of infarction of the right ventricle were found. The work emphasizes the importance of the superficial venous system in the drainage of the myocardium and reveals the inadequacy of the intramural system when the latter is forced to assume the entire outflow load.

During the course of studies on the revascularization of the heart, it was found that infarction of the right ventricle might be produced by occlusion of the coronary sinus and the anterior cardiac veins. Apparently the intramural venous drainage system cannot accommodate the entire arterial inflow rapidly enough to prevent myocardial damage.

In general, the blood supplied to the heart substance is drained by superficial veins and by intramural vessels. The superficial channels consist of the coronary sinus system and the anterior cardiac veins. The coronary sinus is located on the posterior aspect of the heart in the groove between the left auricle and the left ventricle and empties into the right auricle close to the ostium of the inferior vena cava. The coronary sinus has a rich network of tributaries and probably accounts for over 60 per cent of the coronary outflow. The anterior cardiac veins (fig. 1) lie on the anterior surface of the heart where they arise from the wall of the right ventricle and drain directly into the right auricle near the auriculoventricular junction. The intramural vessels drain into the various heart chambers and consist of the thebesian veins, the arterioluminal vessels, and the myocardial sinusoids. The intricate anatomic arrangement of these latter vessels has been described by Wearn and his associates.1

In an effort to protect the heart against coronary artery occlusion, Beck and his associates2,3 have recently introduced the use of a vein graft to convey oxygenated blood from the aorta to the coronary sinus. If the coronary sinus has been ligated close to its ostium in the right auricle, the establishment of such a graft reverses the blood flow in the coronary sinus and the latter functions as an artery. That this is beneficial has already been demonstrated. However, it has been postulated that an arteriovenous fistula effect might be produced in the heart substance because of the many free connections between the radicals of the coronary sinus and the anterior cardiac veins (fig. 1).

The development of such connections would mean that increasing quantities of arterial blood entering the coronary sinus would be shunted through these superficial veins directly into the right auricle without benefit to the myocardium. In order to anticipate this possibility, a series of 24 dogs was prepared in which, as a preliminary operation, the coronary sinus and all the larger anterior cardiac veins were ligated. The latter were tied as near as possible to their ostia in the right auricle, care being taken not to include any arterial branches in the ligatures. Eight to twelve days later the surviving dogs were subjected to a second operation wherein a vein graft was inserted between the aorta and the coronary sinus. Seventeen of these dogs were examined post mortem one to forty-nine days following the initial
operation. These dogs constitute the subject of this report. Five of the 17 dogs had only the initial operation, while 12 underwent the additional vein graft operation. Inasmuch as the serious effects of the preliminary procedure were not at first apparent and were not the prime objects of our investigations, many interesting data, such as electrocardiograms and venous and arterial pressures, were not obtained.

**RESULTS**

One of the striking clinical results of ligating both the coronary sinus and the anterior cardiac veins was the prostrating effect upon the dogs. In contrast to simple ligation of the coronary sinus which causes relatively slight postoperative disability, these animals remained sedentary for from four to nine days or longer. All seemed disinterested in their surroundings and the majority refused to eat for several days. Some were dyspneic at rest and developed a peculiar hacking cough.

The postoperative mortality was 12.5 per cent, more than double that for ligation of the coronary sinus alone. Since 2 dogs not included in this figure were sacrificed because of extreme illness and imminent death, the actual mortality is probably much higher. On the other hand, in a recent series of 96 dogs subjected to coronary sinus ligation alone, the postoperative mortality was 4.2 per cent. While the present

**FIG. 1.—Photograph of a cleared dog heart.** The arteries have been injected with black dye and the veins with white. On the surface of the right ventricle the superficial veins which drain directly into the right auricle may be readily seen.
Fig. 2.—Gross appearance of a dog heart which has been subjected to ligation of the coronary sinus together with ligation of the superficial veins draining into the right auricle. A (Left). Dog 232. Autopsy performed 49 days following operation. The surface of the right ventricle shows extensive scarring. The right coronary artery has been opened and the major branches are patent. B (Right), Same specimen with the right ventricle opened and the wall turned back to show the endocardium. Note the numerous patches of scar.

Fig. 3.—Photomicrographs of infarcted areas of the right ventricle. A (Left), Section from Dog 237 made ten days postoperatively. The muscle fibers have been split apart by edema fluid and extravasated red blood cells. B (Middle), Section from Dog 271 made twenty-three days postoperatively. There is necrosis of muscle cells with swelling, granulation, and vacuolation. There is round cell infiltration and fibrosis. C (Right), Section from Dog 232 made forty-nine days postoperatively. There is phagocytosis of hemosiderin, advanced fibrosis, and complete muscle replacement.
table 1.—gross findings and duration of process

<table>
<thead>
<tr>
<th>dog no.</th>
<th>no. days after first operation that autopsy was performed</th>
<th>Gross findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>258</td>
<td>1</td>
<td>Marked hemorrhagic engorgement of right ventricular wall</td>
</tr>
<tr>
<td>209</td>
<td>3</td>
<td>Heart dilated. Hemorrhagic engorgement, right ventricle</td>
</tr>
<tr>
<td>269</td>
<td>7</td>
<td>Hemorrhagic necrosis of right ventricular wall with thinning and mural thrombus. Advanced congestion throughout both lung fields but no emboli found</td>
</tr>
<tr>
<td>309</td>
<td>7</td>
<td>Marked hemorrhagic engorgement of right ventricular wall</td>
</tr>
<tr>
<td>237</td>
<td>10</td>
<td>Extensive hemorrhagic necrosis of right ventricular wall. Latter thin and devoid of muscle. Mural thrombus. Massive bilateral pulmonary infarction with pulmonary emboli</td>
</tr>
<tr>
<td>271</td>
<td>23</td>
<td>(Cardiac decompensation following op.) Fibrotic, thinned right ventricle with dense plaque of scar in infundibulum</td>
</tr>
<tr>
<td>256</td>
<td>24</td>
<td>Moderate thinning and fibrosis, right ventricle</td>
</tr>
<tr>
<td>270</td>
<td>31</td>
<td>Advanced fibrosis and muscle replacement in a wide zone of the right ventricle along the interventricular groove</td>
</tr>
<tr>
<td>259</td>
<td>37</td>
<td>Some fibrosis. Large vein entering floor of sinus found open</td>
</tr>
<tr>
<td>261</td>
<td>37</td>
<td>No damage to right ventricle. Large vein entering floor of sinus found open</td>
</tr>
<tr>
<td>260</td>
<td>40</td>
<td>Slight, patchy fibrosis of right ventricle</td>
</tr>
<tr>
<td>272</td>
<td>41</td>
<td>Small patches of fibrosis in the infundibulum of the right ventricle</td>
</tr>
<tr>
<td>262</td>
<td>42</td>
<td>Marked fibrosis of right ventricle with areas of complete muscle replacement</td>
</tr>
<tr>
<td>255</td>
<td>43</td>
<td>No damage to right ventricle. Large vein entering floor of sinus found open</td>
</tr>
<tr>
<td>254</td>
<td>44</td>
<td>Thinning, patchy fibrosis and much muscle replacement</td>
</tr>
<tr>
<td>251</td>
<td>45</td>
<td>Slight thinning and fibrosis, right ventricle</td>
</tr>
<tr>
<td>252</td>
<td>49</td>
<td>Markedly thinned and fibrotic right ventricle</td>
</tr>
</tbody>
</table>

The series is perhaps too small to yield a statistically significant mortality rate, nevertheless, the above-mentioned elevated mortality figure of 12.5 per cent is in keeping with the clinical course and the pathologic findings to be described below.

Of the 17 dogs studied by postmortem examination, 15 showed a varying degree of disease of the right ventricle. This ranged from thinning and patchy fibrosis to extensive infarction. An example of moderately severe scarring may be seen in figure 2. The most striking damage to the right ventricle was usually seen in that portion which is normally the thinnest near the interventricular groove and particularly in the infundibulum. Early changes were those of edema, subendocardial and subepicardial hemorrhage, and hemorrhagic necrosis. Later changes consisted of muscle replacement, atrophy, hemosiderosis, and fibrosis (fig. 3). Table 1 describes the gross findings in each case and the duration of the process.

The 2 dogs which were sacrificed at seven and ten days respectively because of extreme illness are of especial interest. Both showed massive infarction of the right ventricle with mural thrombi and extensive hemorrhage into the lungs. In one of these there were bilateral pulmonary infarcts involving complete lobes and molded emboli almost occluding the main branches of the pulmonary artery. Another animal is of considerable interest in that it was explored at ten days and found to be in frank decompensation with a greatly dilated, laboring, cyanotic heart and pericardial effusion and bilateral hydrothorax.

In those specimens showing severe disease, the right coronary artery was dissected out with its radicals or injected with dye in order to determine whether or not any significant arterial branches had been included in the ligatures placed about the veins. Although a few tiny arterial twigs had been thus ligated, no instance of occlusion of a significant arterial branch was found.

Microscopic sections taken through the diseased areas of the right ventricle (fig. 3) show variable pictures depending upon the duration of the process. In the early period there is engorgement of the tissue with edema fluid and extravasated red blood cells. The muscle bundles become split apart and the cells become
swollen. Later specimens show the cytoplasm to become pale, vacuolated, and granular. Macrophages appear and contain ingested hemosiderin together with fragments of cellular debris. The muscle bundles disintegrate and young fibroblasts grow in to replace them. As the process advances, the ventricular wall becomes thinner and, in the late specimens, is represented almost entirely by connective tissue.

Discussion

Naturally, one would wonder what role the second operation has played in the production of this pathologic picture. It is probable that it has had very little to do with the damage to the right ventricle since some of those animals sustaining the most severe myocardial injury were not subjected to the second operation. Furthermore, extensive damage to the

Two of the 17 dogs showed normal-appearing myocardium in the right ventricles. In these 2 animals, a large vein was found buried in the epicardial fat, freely communicating with the right ventricle and draining into the floor of the sinus just at the ostium. In this hidden position, it was missed at operation and escaped inclusion in the coronary sinus ligature. In one other dog showing a very mild degree of fibrosis there was an open vein in this location.

right ventricle is not seen in dogs that have been subjected to exactly the same procedures as this present group with the single exception that the anterior cardiac veins have not been ligated.

What is the mechanism responsible for producing infarction in this group? To answer this question requires further study, but one may reason as follows: Gregg and Dewald have shown that the intravenous pressure in a coro-
nary vein or in the coronary sinus rises after ligation of the coronary sinus to values approaching the aortic systolic pressure during systole and to 20 to 40 mm. Hg during diastole. Some idea of the extent of these changes may be obtained from the pressure tracings in figure 4 taken from the coronary sinus before and after ligation of the latter. The ligation of the additional superficial veins draining the right ventricle puts the entire load for venous drainage from that chamber on the thebesian and arterioluminal vessels. The "run off" into the latter is inadequate and, with pressure in the capillaries and veins approaching aortic levels, blood and edema fluid extravasate into the interstitial spaces. The thin-walled right ventricle can ill accept such engorgement. Furthermore, it has been our observation that the radicals of the right coronary artery of the dog are of very small caliber and the flow through these radicals is probably reduced not only by the greatly elevated intraluminal peripheral resistance but also by extraluminal compression from distention of the myocardium. The net result of these forces is a markedly diminished or absent flow of oxygenated blood through the right ventricle. With the passage of time, compensation eventually occurs, but not before there has been considerable destruction of ventricular muscle.

That the effect is largely one of venous occlusion and not reduction in available channels for arterial inflow may be deduced from the fact that by inadvertently leaving one moderate-sized superficial vein free to drain into the right auricle, the right ventricle was spared in two dogs and only slightly damaged in a third.

These observations are in agreement with those of Gregg and Shipley on superficial cardiac vein occlusion and lend support to their view that the thebesian vessels are not, in themselves, sufficient for adequate drainage of all the blood from the myocardium.

The value of these observations is twofold. In the first place, the discovery of the destructive effect on the right ventricle instituted by ligating both the coronary sinus and the anterior cardiac veins should eliminate this procedure as a method of preventing an arteriovenous fistula effect in the Beck operation. Unless some other technic can be devised, it would be preferable to accept the risk of any arteriovenous fistula which might develop. In the second place, a method has presented itself whereby acute and chronic disease of the right ventricle may be produced for experimental study.

**Summary and Conclusions**

1. Twenty-four dogs were subjected to ligation of the coronary sinus together with ligation of the anterior cardiac veins. This was found to be a prostrating operation and carried a mortality of over 12.5 per cent.

2. Seventeen of the dogs were studied post mortem one to forty-nine days postoperatively. Twelve of the 17 dogs had sustained a second operation consisting of a vein graft connecting the aorta with the coronary sinus. Reasons are given why it is felt that this second procedure was not instrumental in producing the pathologic picture presented.

3. Fifteen of the 17 dogs showed damage to the right ventricle, varying from thinning and patchy fibrosis to massive infarction. The microscopic sections resembled various stages of infarction.

4. Two dogs showing no damage to the right ventricle were found to have one large patent vein opening into the floor of the coronary sinus at its ostium.

5. The following conclusions are drawn:
   a. Ligation of the coronary sinus and the anterior cardiac veins alone produces infarction of the right ventricle by raising the intraluminal pressure to such an extent that, together with extraluminal compression from edema fluid, there is inadequate flow of oxygenated blood.
   b. The intramural venous drainage system is incapable of assuming the entire venous outflow load.
   c. Ligation of the anterior cardiac veins should not be used to prevent the development of an arteriovenous fistula effect in the Beck operation.

**References**


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