

## REVASCULARIZATION OF THE HEART BY VEIN GRAFT FROM AORTA TO CORONARY SINUS\*

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IN 1948 BECK and his associates<sup>1, 2</sup> reported that the introduction of arterial blood into the coronary sinus protected the dog's heart to a high degree against occlusion of a major coronary artery. The arterial stream was directed into the coronary sinus by anastomosis of the proximal end of the divided left common carotid artery to the previously ligated coronary sinus. In ten dogs with open shunts, subsequent ligation of the anterior descending branch of the left coronary artery at its origin caused two delayed deaths. Over half of the hearts showed no gross evidence of infarction. On the other hand, experience with over 100 normal dogs has shown that ligation of this same artery at the same site caused immediate death in seven out of ten. Each of these survivors developed a large infarct.<sup>3</sup> Such observations indicated the necessity of further studies and the probable application of such procedures to human beings suffering from coronary artery disease.

Having demonstrated the beneficial effect of arterialization of the coronary sinus we were next concerned with two major problems: (1) will the heart tolerate the procedures with reasonable safety, and (2) will the graft remain open in a reasonable number of cases? The following report deals with our efforts to resolve these problems.

Since it is impossible to employ the

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common carotid artery for the shunt in the human being and since there is no other satisfactory artery in the vicinity of the heart, we have used a free vein graft inserted between the side of the thoracic aorta and the side of the coronary sinus. The vein graft has been used exclusively in the work to be presented.

In this study there were certain variable factors that could not be evaluated. These include variation in the health and strength of the dog, variations in age and such other variables as operative technic and postoperative support. It will become apparent that the ability of the heart to tolerate this procedure under investigation depends upon a balance between inflow from aorta and the capacity of the coronary sinus and its venous tributaries to withstand this inflow. It is possible to produce hemorrhage into the heart muscle by increasing inflow from aorta or by reducing venous outflow from the heart. It will become apparent from the data that we present that the inflow-outflow balance has a small range of variation and can be disturbed to a limited extent only. It is our impression that the venous system in the heart with its intramural extensions seems to be more rigid and fixed and less adaptable and flexible. This idea developed out of our experience.

Again, excluding variables such as technic, anticoagulants, etc., the most important single factor in determining patency in the graft and in the coronary sinus system appears to be the rate of blood flow through these vessels. This has become more and more apparent as the work has advanced.

LIGATION OF THE CORONARY SINUS FOLLOWED SEVEN TO 21 DAYS LATER BY THE INSERTION OF A FREE VEIN GRAFT BETWEEN THE THORACIC AORTA AND THE CORONARY SINUS

In the early phase of the work a two-stage operation was used. At a preliminary procedure the coronary sinus was ligated close to its ostium in the right auricle. Seven to 21 days later the graft was inserted between the aorta and the coronary sinus. The operation was so staged because, after occlusion, the wall of the coronary sinus became thickened and it was easier to suture than in the virginal state when it was thin and delicate.

*A. The Regulation of Inflow.* Shortly after instituting the use of the free vein graft one fact became apparent. It was possible to deliver too much blood to the heart by this route, since many hearts failed on opening the shunt unless the inflow was considerably reduced. Accordingly, we instituted the custom of tying a triple silk ligature about the graft so as to reduce the lumen to 3 mm. diameter at this point. As this was done, there was improvement in the ability of the heart to tolerate the sinus graft and the number of deaths on the table diminished. Of ten dogs surviving this operation, however, subsequent examinations revealed that the silk had cut through the graft in two cases and in two others the silk was the site of a fibrous constriction thought to be the original locus of an occluding thrombus. A better method of reducing inflow had to be found.

We thought that a less resistant material than silk might reduce flow and yet not cut through the graft. Accordingly, a short segment of vein was sutured to itself as a band around a 3 mm. probe. The excess was cut off, thus giving a cuff of vein 3 mm. in diameter through which the graft was slipped before anastomosing it to the aorta. Of eight animals surviving one to three months, this vein cuff was found to have

cut through in two and in several others the band of tissue appeared to have excited a fibrous reaction which may have been instrumental in producing occlusion of the graft. Since these things happened in spite of the vein cuffs having the resiliency of a blood vessel, it appeared clear that the use of any material to constrict the vein graft would be unsuccessful.

Our next step was to control accurately the size of the opening in the aorta. A special measuring probe was constructed and, with this help, it was possible to open the aorta exactly 4.5 mm. longitudinally at each operation. An incision of this length yields a stoma of 3.5 to 4.0 mm. in diameter. This has proved to be the most successful method of limiting inflow and is the method which we now use.

*B. Occlusion of the Grafts.* Although the hearts would tolerate arterialization of the coronary sinus when the inflow was regulated, the grafts became thrombosed with annoying regularity. Patency of the grafts was determined by exploration one to three months after grafting and, in some cases, by Diodrast studies (Fig. 1). If the graft was occluded, the animal was killed for examination. Postmortem findings revealed a fairly characteristic picture depending upon the time interval following occlusion. An occlusion of long standing was revealed as simply a fibrous cord between the aorta and the sinus, with obliteration of the latter at the anastomosis site. In earlier specimens, however, the oldest areas of thrombosis or fibrosis almost invariably appeared at the region of the anastomosis of the graft to the sinus. The scarring in this area was exceedingly dense and obliterated both the stoma of the graft and the entire lumen of the sinus at that point. Frequently the aortic stoma would be open and the graft patent for several millimeters near the aortic end. At first we believed that the degree of dissection of the sinus and the quality of the anastomotic technic were the most im-

portant factors determining patency in the grafts.

*C. The Technic of Performing the Anastomoses.* It is reasonable that the better the technic of performing an anastomosis the more likely will the anastomosis remain open. Because we were dealing with small vessels, stomas of 3 to 4 mm. diameter, delicate tissue and a moving target, it became evident that the best technic was also the simplest. The external jugular vein used for grafting was dissected cleanly in situ, for it is easier to strip the adventitia with both ends of the vein anchored than after the vein has been excised. The graft was handled as little as possible, flushed with heparin solution, and stored in a saline soaked sponge until needed. In so far as possible, sections without valves were used. The sinus was isolated and opened as previously described<sup>1</sup> although we have recently employed a new clamp which obviates the necessity of dissecting and completely occluding the sinus. The aortic segment was isolated in a Pott's clamp or, more recently, in a specially designed clamp which obviates the necessity of dissecting the aorta. The aorta and sinus were opened by a clean incision in their longitudinal plane. The coronary sinus is so small that attempts to take an ellipse out of the roof or to use a transverse incision usually end in reducing the sinus lumen. Anything other than a linear incision in the dog's aorta brings the opening so near the jaws of the aortic clamp that there is little resiliency of the remaining aortic wall and sutures tend to cut through as they are pulled snug. We have found that a simple over and over stitch starting on the vein graft and going inside out on the sinus, or the aorta, is the least traumatic method of suture. A number 5.0 braided silk suture with a curved arterial needle at each end is used and a simple Lembert stitch is taken at one angle. The over-and-over stitch is carried up either side, uniting the vessels end to side, and the

two strands of silk are tied at the opposite angle. This suture technic is easier, quicker and far less traumatic than the everting mattress suture and little more silk remains within the lumen.

*D. Anticoagulants.* Even when the anastomoses were achieved with acceptable technic, thrombosis of the grafts occurred in

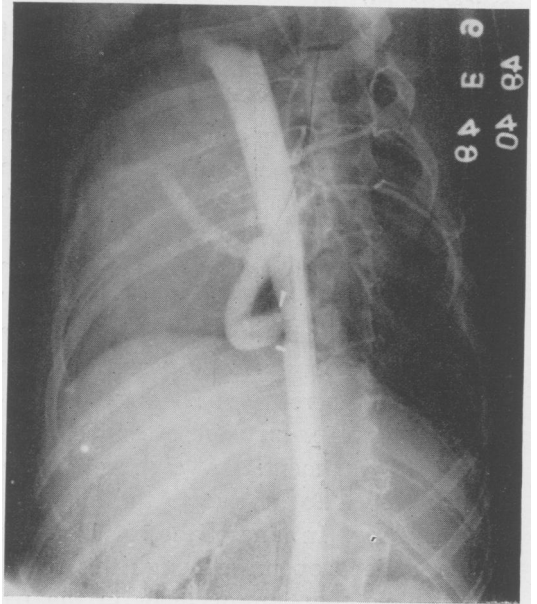


FIG. 1.—Demonstration of a patent vein graft and coronary sinus system. A cardiac catheter has been introduced into the femoral artery and passed retrograde up the aorta to the level of the graft as marked by silver clips. Injection of 30 cc. of 70 per cent Diodrast through the catheter and exposure of the roentgen ray film has clearly outlined the vein graft and the coronary sinus.

all but occasional cases, so we early used anticoagulants. It is generally conceded by workers in this field that, with Dicumarol, a blood level of 20 per cent or less of normal prothrombin activity is required to prevent thrombosis.<sup>4</sup> Accepting this figure, we administered Dicumarol to the dogs two to five days before operation and operated when the prothrombin time was close to the required level. Postoperatively the dogs were maintained at these levels for five to seven days. Oozing at operation was moderately severe but, in most cases, minute attention to hemostasis on opening and

closing the chest permitted completion of the operation without undue blood loss. In some cases, however, hemorrhage from the suture holes in the aorta became uncontrollable even with tamponade using crushed muscle and fibrin, and the dogs were lost on the table from hemorrhage. In other cases, the suture lines appeared dry at closure but subsequently developed leaks which were frequently fatal. Occasionally, cessation of the anticoagulant therapy, together with the administration of blood and Hykinone, were sufficient to stop the hemorrhage. In such instances there was a large hematoma around the anastomosis which healed with excessive scar and stricture. Another complication was sudden fatal hemorrhage on the ninth or tenth postoperative day. Almost invariably such hemorrhage came from a blowout of a poorly healing aortic suture line. In all, there were 28 dogs that received adequate, but not excessive, anticoagulant treatment. In eight of these, death was felt to be due to the anticoagulant therapy. In nine of the survivors the graft remained open. Although this represented a notable improvement in the patency rate, seven grafts became thrombosed in the presence of adequate prothrombin levels. Because of the latter, because of the complications, and because the effects of anticoagulant therapy are so difficult to evaluate, we decided to abandon its use.

*E. End-to-End Anastomosis, Vein Graft to Coronary Sinus.* If the vein graft is sutured to the sinus end to end an excellent lumen is obtained and it was felt that such an improvement of the lumen might increase the possibilities of the anastomosis remaining open. However, out of 25 dogs so treated, only two grafts remained open for more than one month; therefore this method was discontinued.

*F. Shortening the Time Interval Between Operations.* By the seventh day after coronary sinus ligation, that vessel is already involved in a dense fibroplastic reac-

tion so that considerable dissection is required for its exposure. In view of this, it seemed likely that shortening the time interval following ligation might render the sinus easier to dissect and lead to less reaction. This was attempted in six dogs and it was found that the sinus was easier to dissect on the fourth or fifth postoperative day. However, the pressure in the coronary sinus clinically seemed higher at this time and the heart tolerated the operation poorly. Three of the six dogs died and in every survivor the graft thrombosed. It seemed useless to continue this particular study.

*G. Cumulative Fibroplasia.* The striking fibrosis so often observed at the site of the sinus anastomosis led us to wonder whether or not the initial operation on the sinus furnished an abnormal stimulus for fibroplasia. Sandblom<sup>5</sup> has recently reported that fibroplasia in a second wound, made five to ten days after the original, may proceed at double the rate of the original. Such a process was possibly a contributing factor in causing occlusion of the grafts. It would be desirable to avoid such a source of extensive fibrosis.

From the above data and speculations it became apparent that some factor concerned with preliminary ligation of the coronary sinus predisposed the procedure to failure. Out of over 200 operations on 100 dogs we were able to produce only 16 animals with open grafts. This was obviously unsatisfactory and a change in technic was essential.

## II. SIMULTANEOUS LIGATION OF THE CORONARY SINUS AND INSERTION OF GRAFT BETWEEN THE THORACIC AORTA AND THE CORONARY SINUS

In view of the experience with preliminary ligation of the coronary sinus it seemed desirable to turn to a one-stage procedure. Accordingly, in three dogs, the graft was inserted and the sinus tied off simultaneously. This resulted in a rather

remarkable phenomenon. As all the hemostatic clamps were released, bright red arterial blood from the aorta advanced only a short distance into the graft, where its progress was stopped by a column of dark reduced blood from the sinus. Through the thin-walled graft the interphase could easily be seen to oscillate with each pulsation

This observation and the innumerable failures with preliminary sinus ligation presented a new fact. We had inadequately assessed the venous exits of the heart and had assumed that the anterior cardiac veins together with the intramural vessels constituted a highly distensible system. We could no longer accept this assumption. Certain

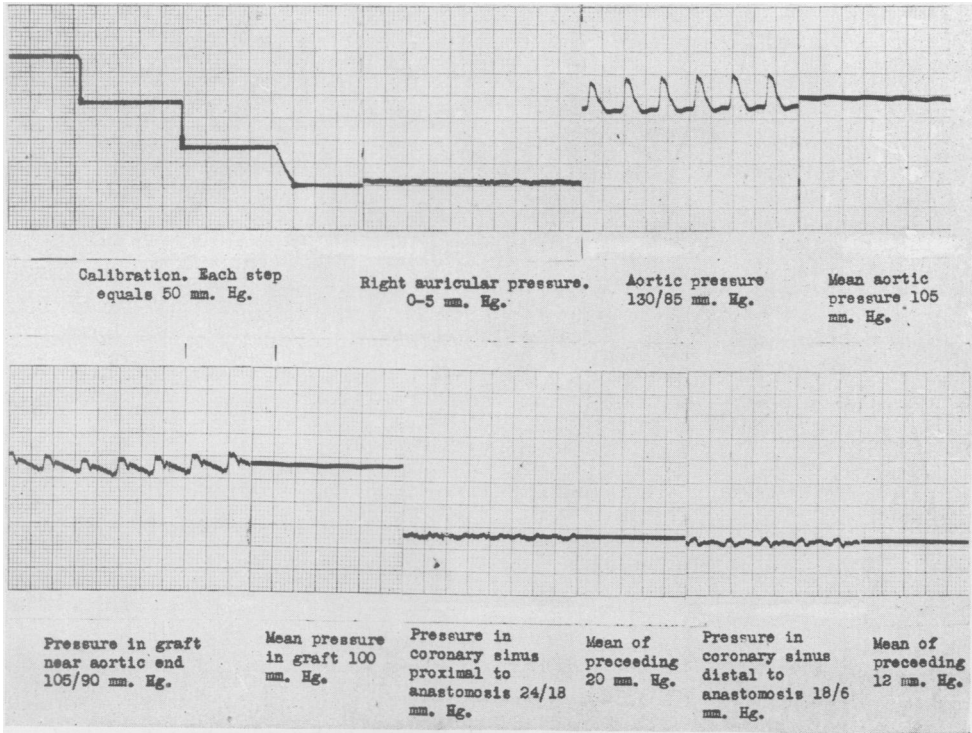


FIG. 2.—Dog No. 49-50, experiment performed June 20, 1949. Free vein graft was inserted between the aorta and the coronary sinus June 2, 1949. Sinus was left open so as to produce aortic right auricular fistula. Pressure tracings were taken on the eighteenth day before and after sinus ligation, with a graft in place but with the coronary sinus left open. Note that the creation of the fistula between the thoracic aorta and the right auricle has not appreciably raised the pressure in the right auricle. On the other hand, the pressure in the coronary sinus proximal to the anastomosis has been raised to 20 mm. Hg. mean pressure.

and with little or no progression into the heart. If the aorta was now temporarily occluded proximal to the anastomosis the reduced blood readily flowed from the graft into the peripheral aorta. Such a situation could hardly be beneficial. One animal died on the table, and in the other two the graft became thrombosed.

physiologic studies emphasized this limitation of the venous tree and revealed that the introduction of additional blood into the veins must inevitably lead to a great elevation in pressure and a retardation of blood flow. The former led to myocardial engorgement and injury while the latter led to thrombosis.

### III. PRELIMINARY INSERTION OF A FREE VEIN GRAFT BETWEEN THE THORACIC AORTA AND THE CORONARY SINUS WITH SUBSEQUENT LIGATION OF THE CORONARY SINUS

In order to eliminate poor blood flow through the graft during the healing of the anastomosis, the graft was inserted without tying off the coronary sinus. This creates a fistula between the aorta and the right auricle. Over the short course of the fistula the pressure gradient is steep since

The creation of this fistula is exceedingly well tolerated. Of 70 dogs subjected to this procedure there were only three operative deaths. Two of these occurred while the sinus was tied off during the anastomosis. Recently we have found that digitalis improves the heart function during this period and every case now receives 1 cc. of Cedalanid intravenously at the start of the operation. In the last 47 successive

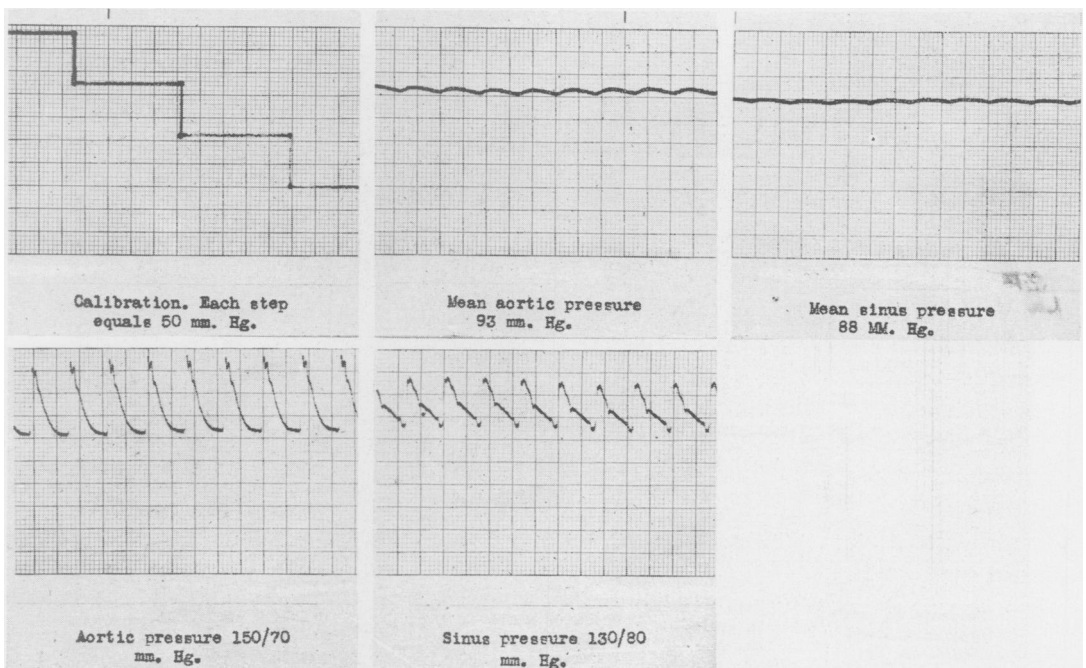


FIG. 3.—Dog No. 49-44, experiment of May 31, 1949. Vein graft from aorta to coronary sinus was done on May 11. Pressure tracings from aorta and coronary sinus were taken one hour after ligation of the coronary sinus with the graft open. With the graft in place subsequent ligation of the coronary sinus has caused mean pressure in the coronary sinus system to rise to the aortic level

pressure in the right auricle is relatively unchanged (Fig. 2). A rapid flow of blood is thus insured and is evidenced at operation by the presence of a brisk thrill. A murmur may usually be heard postoperatively. The swift blood flow encourages patency, and of 67 dogs surviving the procedures the graft remained open for three to six weeks in 43, a patency rate of 64 per cent.\*

\* Additional experiments have placed the patency rate at 85 per cent or better.

dogs the operation has been completed without mortality.

The creation of the fistula raises the pressure in the coronary sinus (Fig. 2) and stimulates the formation of shunts between the sinus tributaries and anterior cardiac veins. Hence, it was hoped that subsequent ligations of the sinus would not cause excessive development of pressure or retardation of blood flow. However we were wrong, for even with a graft in place for two or more weeks, ligation of the sinus in

some cases caused the pressure to rise to aortic levels (Fig. 3) and to reduce blood flow to such an extent as to cause clotting. In nine dogs with open grafts secondary sinus ligation caused death in three and thrombosis in three others.

Another fact was now clear. At no stage in the procedure should the coronary sinus be completely ligated. In support of this an array of data may be presented. We have accumulated the following facts indicating that the cardiac venous tree is one of definitely limited distensibility:

2. The animals that die appear to be those in which the pressure in the coronary sinus, after ligation, approximates that in the aorta (Fig. 5).

3. After coronary sinus ligation, pressure in that vessel remains elevated for as long as 18 months or more (Fig. 6). This elevation in pressure persists in spite of the development of obvious shunts between the sinus tributaries and the anterior cardiac veins.

4. If all the visible superficial cardiac veins are blocked the heart is seriously

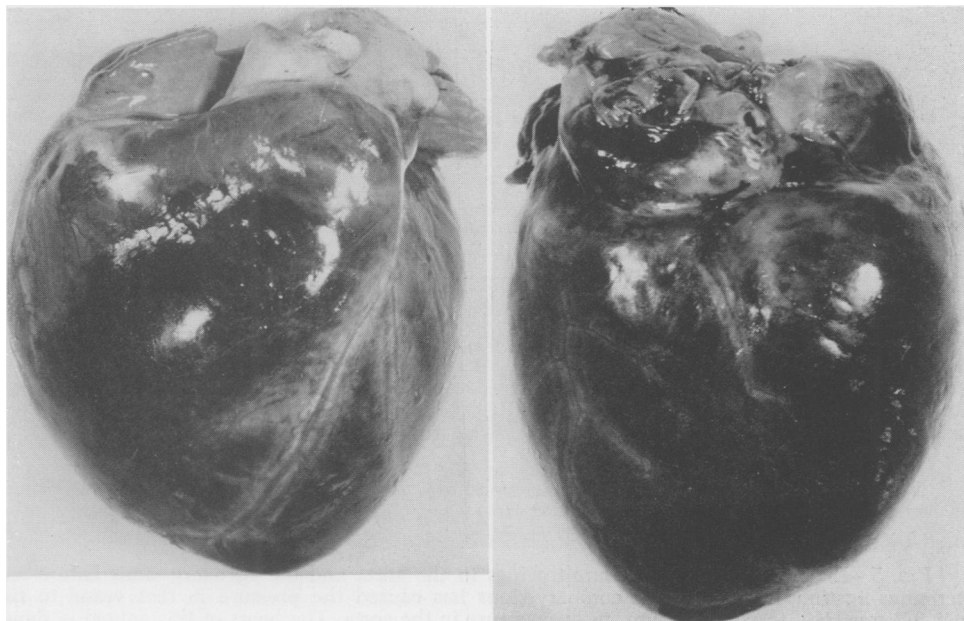


FIG. 4.—Experiment No. 9—Coronary sinus ligation. Anterior and posterior views of the heart of a dog which died as a result of ligation of the coronary sinus. There is bloody engorgement of the whole left ventricle and a large portion of the right ventricle bordering the interventricular groove.

1. Not every dog heart can tolerate coronary sinus ligation alone. From experience with over 200 dogs we have found that this procedure carries a 2 to 4 per cent mortality. The hearts of those animals that die present a characteristic picture of myocardial engorgement and hemorrhage involving the left ventricle and a portion of the right ventricle along the interventricular groove (Fig. 4).

damaged.<sup>6</sup> In 24 dogs in which this was done death occurred in three and two additional animals were killed because of extreme illness. Nineteen animals in which ligations were complete and in which autopsy data have become available have all shown varying degrees of damage to the right ventricle. Thus, in no case, does it seem that the intramural system is capable of immediately assuming 100 per cent of

the venous drainage of the heart without either death or damage to the right ventricle.

Furthermore, in dogs in which the coronary sinus has been completely ligated and in which the graft has remained open for over three months, there occurs a slow

occurred in three and partial occlusion in three more. In all the remaining, the graft was open and pulsating. Nine of these presented a discouraging phenomenon. If blood were trapped in the graft by occluding the aortic end, the trapped blood could be forced into the heart with difficulty or

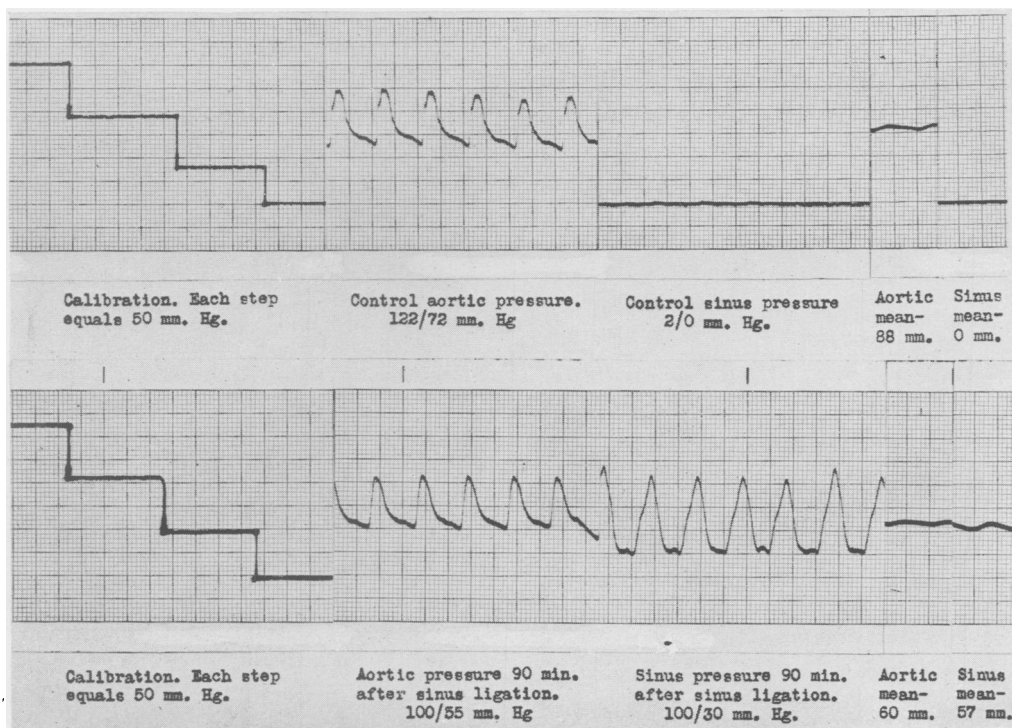


FIG. 5.—Experiment No. 9; pressure tracings in the aorta and the coronary sinus before and after sinus ligation. Ligation of the coronary sinus has caused the pressure in that vessel to rise from 0-2 mm. Hg. to within 3 mm. mean pressure in the aorta. The heart of this animal is shown in Figure 4.

strangulation of the venous tree. This is brought about either by thrombotic phenomena or by a remarkable degree of thickening of the intima (Figs. 7 and 8) of the small veins to a point where they permit little or no blood flow. These late observations may be summarized as follows: 20 dogs, with grafts known to be open one to nine weeks, were re-explored between three and 18 months after the original operation. All of these animals had had complete sinus ligation. Late complete thrombosis had

not at all. The graft was open but not functioning. Six of these animals were given a test of benefit by ligating the anterior descending branch of the left coronary artery at its origin. Four of the six animals died within 48 hours. Thus there was little or no protection and the tests confirmed the operative observation of a nonfunctioning system. Postmortem examinations of the dogs with nonfunctioning systems revealed fairly constant findings. The graft was considerably dilated but



open and the sinus was open for a variable distance from the anastomotic site. Many of the smaller radicals of the sinus were occluded, however, and the graft, together with the open areas of the sinus, constituted a blind sac or aneurysmal pouch of the aorta. Injection of the grafts with barium sulfate gelatin mixture illustrated this

The final observation contraindicating complete ligation of the coronary sinus deals with the volume of new blood entering the venous system. Since reduction of the aortic stoma below 3.5 mm. diameter has been found to increase the incidence of thrombosis, we have been committed to an inflow stoma at least this large. On the

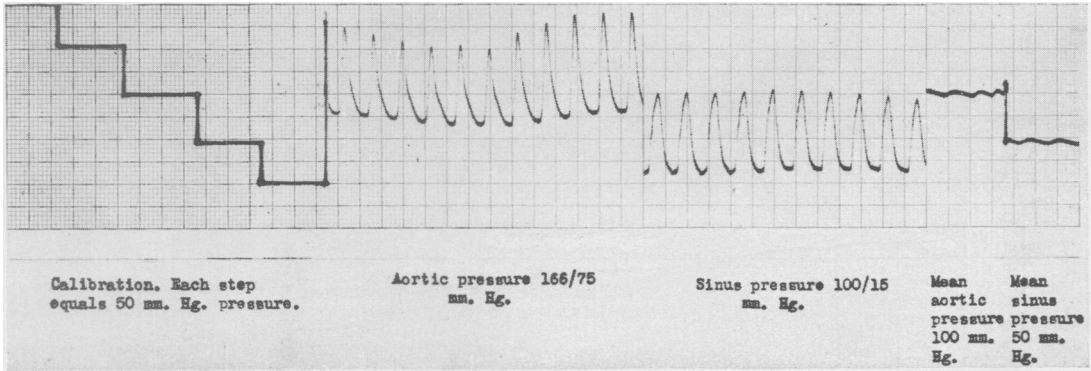


FIG. 6.—Dog No. N-133; experiment performed June 25, 1949. Pressure tracings from the aorta and the coronary sinus were taken 18 months following ligation of the sinus. In spite of the development of some collateral venous drainage, pressure in the coronary sinus after ligation had remained elevated for many months. Here, even after 18 months, the coronary sinus pressure is 50 per cent of that in the aorta.

fact. Varying degrees of this process were seen and the end stage would probably have been complete thrombosis of the sinus. Microscopic sections taken through branches of the coronary sinus showed in many instances that the small veins had become partially or completely occluded by organized thrombus or by sclerosis of the intima. The latter is of such striking nature and so apparently related to pressure that it will be made the subject of a special report.

Five dogs were found at exploration to have grafts which were not dilated and from which blood could be easily squeezed into the coronary sinus. Four of these were given the test of benefit and all four survived in good condition the ligation at its origin of the anterior descending branch of the left coronary artery.

other hand, blood flow measurements, using a bubble flow measuring tube, have revealed in four dogs with assumed mean pressure between 95 and 100 mm. of mercury and with 3.5 to 4 mm. aortic stomas, that 175 to 200 cc. of blood flows through the graft per minute. This compares with a left common coronary artery flow of 70 to 90 cc. per minute in similar sized dogs.<sup>7</sup>

Therefore, with a normal coronary artery inflow and with a venous tree of definitely limited distensibility one could hardly expect to cut off a vein that drains 60 per cent or more of the blood from the heart and at the same time to introduce into the venous tree more than double the amount of blood delivered by the main coronary artery.

Recognizing this, and particularly that we were bucking a normal coronary artery

FIG. 7

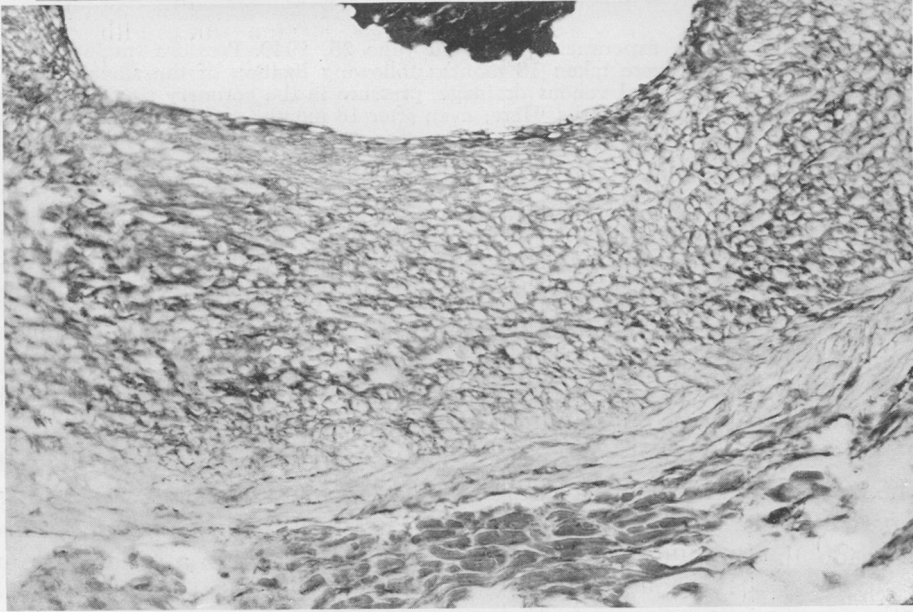
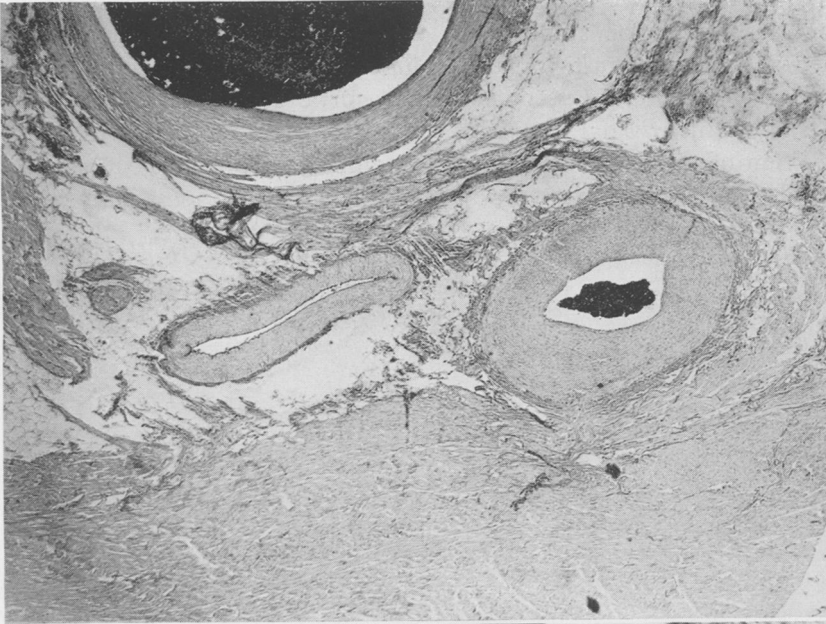


FIG. 8

FIG. 7.—Cross section through anterior descending coronary artery and accompanying veins. Hematoxylin and Eosin. Veins filled with injection material. Artery (center) not injected. Note intimal proliferation in specimen on lower right.

FIG. 8.—Cross section vein wall, high power, of vein accompanying anterior descending coronary artery. Elastica van Giesan stain. Injection material (top center) in lumen. Note thickness of intimal layer which extends to the three indefinite striations marking the elastic membrane of the original intimal layer. Beyond this is the adventitial layer immediately adjacent to myocardium. In the original slide the elastic membrane stains black and the intimal layer tan. The photograph is not able to reproduce this important distinction.

inflow throughout the work, we hoped that in the larger human heart with a greatly diminished coronary artery inflow due to coronary artery disease, the additional blood introduced by the graft would be accepted more readily. This assumption was incorrect. Two patients, in whom the graft was introduced and the sinus ligated, came to autopsy showing engorged hearts similar to the dogs. This occurred in spite of the fact that in neither heart was a major coronary artery open.

With complete ligation of the coronary sinus, then, the overall picture was indeed poor, for after well over 300 operations on 121 dogs, we were able to produce only 20 animals with temporarily patent grafts. Of these only five remained open for three months to one and one-half years. All this, of course, raised the question of whether or not the coronary sinus need be occluded at all and if so, how much. In answer to these questions we are able to present further experiments.

IV. PROTECTION FURNISHED THE HEART BY INSERTION OF A FREE VEIN GRAFT BETWEEN THE THORACIC AORTA AND THE CORONARY SINUS, LEAVING THE SINUS OPEN SO AS TO PRODUCE AN AORTIC-RIGHT AURICULAR FISTULA

Ten dogs with open grafts between the aorta and the coronary sinus and with the sinus free to drain into the right auricle were subjected to ligation of the anterior descending branch of the left coronary artery at its origin three to six weeks after grafting. None of these dogs died on the table. One died at nine hours, one at 24 hours, one at 48 hours, and one at five days—four deaths in all. All died of left-sided failure, with massive pulmonary edema. The one that lived five days was found to have an infarct about 2.5 cm. in diameter near the apex of the left ventricle. From experience with 100 normal dogs, it will be remembered, it has been found that ligation of this same artery at the same site will

cause the death of seven out of 10 usually within 25 minutes of ligation. The three survivors will each show a large infarct. While this small series of ten cannot be considered statistically significant, in the light of the large experience with normal dogs, the findings indicate some benefit from the graft alone.

V. PROTECTION FURNISHED THE HEART BY INSERTION OF A FREE VEIN GRAFT BETWEEN THE THORACIC AORTA AND THE CORONARY SINUS FOLLOWED BY SECONDARY PARTIAL OCCLUSION OF THE CORONARY SINUS

Although there appeared to be some benefit from the fistula, it was not striking. Hence, it was hoped that partial secondary sinus ligation would increase the benefits without either adding to the mortality rate or causing additional thrombosis of the grafts. Thirteen dogs with patent grafts were then subjected, two to three weeks after operation, to partial closure of the coronary sinus. This was accomplished by passing a ligature beneath the coronary sinus near its ostium and tying the silk around a 3 mm. diameter probe. This figure was selected so that the runoff stoma would be slightly less than the 3.5 to 4 mm. diameter aortic inflow opening. This greatly reduced but did not abolish the thrill. None of the animals died, nor were they much disturbed by the procedure. Two to four weeks later the anterior descending branch of the left coronary artery was ligated at its origin. Twelve of the 13 dogs have survived and are apparently in good health. In the dog that died, the anterior descending branch of the left coronary artery was larger than the circumflex. Death occurred 48 hours after ligation from pulmonary edema and left heart failure. Clearly then, this two stage procedure afforded a very high degree of protection to the heart in the face of a major coronary artery occlusion.

## DISCUSSION

The above experiments cover only a brief period following insertion of the graft, and it is essential that we determine how the sinus system stands up over a long period of time when the sinus is only partially occluded. Hence, all dogs surviving the artery ligations are to be kept for long time study.

Insofar as the immediate picture is concerned, we have advanced sufficiently far to justify proceeding to human application in view of the short life expectancy of those cases presenting themselves for operation. In support of this view the experimental results may be summarized as follows: We are now able to offer a two stage operation, which, when completed, offers the heart an excellent degree of protection against occlusion of a major coronary artery. In 47 cases the primary procedure has caused no mortality and little morbidity. The second procedure done in 13 cases has caused no mortality or additional morbidity. The rate of patency in the grafts is 65 per cent or better, under the above conditions. Thus, the expectancy for success lies around 65 per cent, as far as the experimental animal is concerned. Further improvements will result in a still higher yield of patency.\*

We are no longer concerned with any possible detrimental effect of arteriovenous fistula. In our experience the development of sufficient collateral venous drainage has been difficult to achieve. If a detrimental effect is to appear it has not yet become apparent in the few dogs with open sinus systems observed from six months to two years.

Some question may be raised as to whether or not there is actual retrograde flow of arterial blood in the venous system when the sinus is only partially occluded. However, the protection against reduced coronary artery inflow demonstrates that

arterial blood reaches the myocardial bed by the new route. The observation of benefit is the important fact to be considered in this work.

## SUMMARY

1. A progress report on the problem of revascularization of the heart is presented.
2. Arterial blood has been directed into the coronary sinus by inserting a free vein graft between the aorta and the coronary sinus.
3. Arterial inflow must be restricted by an aortic stoma no larger than 3.5 to 4.0 mm. diameter.
4. The coronary sinus should not be completely ligated either as a preliminary, simultaneous, or subsequent secondary procedure. If it is, too much blood is introduced into the venous tree so that the pressure approaches aortic levels and blood flow becomes greatly reduced. The excessive pressure causes cardiac failure or myocardial hemorrhage and scarring, and the reduced blood flow results in thrombosis of the grafts.
5. If a vein graft is inserted between the aorta and the coronary sinus and if the sinus is left open so as to create an aortic-right auricular fistula, the operation is exceedingly well tolerated. Forty-seven consecutive cases have been done without mortality and the grafts have remained open in 65 per cent of the cases. This procedure, of itself, furnishes some protection to the heart against occlusion of a major coronary artery.
6. If, at a second stage, the coronary sinus is partially occluded to 3 mm. diameter, there is no further mortality nor does it cause the grafts to become thrombosed. On the other hand, this two stage procedure has protected 12 out of 13 dog hearts against occlusion at its origin of the anterior descending branch of the left coronary artery.

\* See footnote page 158.

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