Revascularization of the Heart
A Study of Mortality and Infarcts following Multiple Coronary Artery Ligation

By Richard S. Hahn, M.D., and Claude S. Beck, M.D.

This report on revascularization of the heart is based on work done in this laboratory in the period from Sept. 1, 1949 to Sept. 1, 1951. A brief description of the operation is given. After the operation was done an attempt was made to shift the inflow from the coronary arteries to the graft from the aorta. An attempt was made to occlude all coronary arteries. Four hundred operations were done on 100 dogs. Data on mortality and infarcts are given in this paper.

Previous reports from this laboratory indicated that blood from the aorta delivered into the coronary sinus protected the heart against ligation of a major coronary artery. This protection consisted of reduction in mortality and reduction in size of infarct after a major coronary artery was ligated. The test artery in these experiments was the descending ramus of the left coronary artery occluded in one step at the origin of the artery. During the past two years we extended the arterial ligations to include the other coronary arteries. Attempts were made to ligate the entire coronary artery system in dogs. Records were kept concerning mortality and infarcts as this study progressed and these results are included in this report.

The Operation

The operation as finally developed in this laboratory was done in two stages. The first stage consisted in placing a free graft of jugular vein between aorta and coronary sinus. Special clamps were developed for this operation. The anastomosis between sinus and graft had a stoma which was approximately 8 mm. in length. The stoma on the aortic end was 5 to 6 mm. in length. There were many factors in the technic of the operation which contributed to success or failure. After the graft had been placed blood flowed freely from the aorta, through graft and into the venous system of the heart. Most of the blood escaped into the auricle. The pressure in the coronary sinus after the graft had been placed measured 18 to 22 mm. of mercury. This elevation in pressure was not enough to rupture veins and capillaries in the heart but was sufficient to bring about thickening of the walls of veins so that they could tolerate routinely the higher pressure to which they were exposed at the second stage of the operation. It was readily possible to rupture veins and capillaries by the application of full aortic pressure to these structures. This complication could be obviated by allowing blood to escape freely into the auricle. This fistula also accomplished two additional results that were favorable. The rapid current of blood reduced the rate of thrombosis in the graft. It also prevented excessive thickening and fibrosis of intima which could go on to complete obliteration of veins.

Whether the thickening of veins was due to pressure or to alterations in the oxygen and carbon dioxide content of the contained blood was not determined. In order to maintain patency of graft and patency of the sinus and its tributary veins the flow through these channels had to be active and not sluggish. Complete ligation of the sinus at its ostium in the auricle produced a stagnant flow in the graft. One would expect this in dogs because on the other side of the capillary bed was normal coronary artery inflow pressure which was a barrier to any opposing flow. It was observed that, after ligation of one or
more of the coronary arteries in dogs, the veins became pink indicating retrograde flow.*

The second stage of the operation was done three weeks after the first stage. It consisted of placing a ligature around the sinus near its ostium in the right auricle. This ligature was tied down on a stilet to a diameter of 2.5 mm. or 3 mm. Complete ligation of the sinus was to be avoided. The pressure in the coronary sinus after partial occlusion measured 50 to 70 mm. of mercury. These pressures were readily tolerated as they were reflected back toward smaller veins and capillaries. In the human heart with occlusive disease of the coronary arteries, the veins and myocardium became pink after the second stage of the operation was done and heart was regarded as a protected heart. After the two stages of this operation were done in dogs, the heart was able to withstand coronary artery occlusion.

All operations were done under a closed system of ether anesthesia. A mechanical respiratory (Rand-Wolfe) was used.

Mortality of Operation in Dogs

The two stages of this operation were done in 100 consecutive dogs with no mortality. Several factors made this record possible. One factor in the record was that an attempt was made to care for these dogs in a proper manner. The other factors were the technical surgery, the anesthesia, oxygenation of the blood, and postoperative care. Some of the dogs were subjected to six operations on the heart. These repeated operations produced adhesions and scar tissue which made the technical surgery difficult and dangerous. Repeated dissections of coronary arteries produced a constant threat of hemorrhage, ventricular fibrillation and cardiac asystole. Four hundred operations were done on 100 dogs. Out of these 100 dogs, 30 were lost from immediate complications such as hemorrhage, fibrillation and asystole which occurred during the dissection of the artery. There were 15 postoperative deaths due to pneumothorax, infection, pneumonia, diarrhea from parasites.

* In human patients in whom this operation was done for coronary artery disease the retrograde flow through veins was considerably more active than it was in dogs with normal coronary arteries. After the graft was placed in these patients, occlusion of the sinus ostium produced marked and extensive pinking of veins and myocardium. Pulsation was noted in the veins. Such active retrograde flow favored success of the operation in patients with occlusive disease in the coronary arteries compared with conditions in the dog.

Cerebral complications, and other causes. Thrombosis of the graft occurred in eight dogs. Out of 100 dogs, there were 47 in the series for this study on multiple occlusion of arteries.

Patency of the Graft

The patency rate of the graft in this series of 100 dogs was 92 per cent. Compared with our results in the past, this was the highest rate that we have had. Any deviation in technic influenced this rate. Recently we used a new sinus clamp and the patency rate was 10 out of 15 dogs. The most important factor determining patency was the rapidity of flow in the graft. A rapid flow favored patency; a sluggish flow favored thrombosis. An open fistula into the auricle favored patency. This was one reason for the two-stage operation. The surgical technic also influenced the rate of patency and these factors are not discussed. The patency rate in human patients so far has not been as high as in the experiments.

Method of Producing Occlusion of Coronary Arteries

The method for producing occlusion of a coronary artery consisted of dissection of the artery so that it could be identified and ligated. Partial occlusion of the artery was done by tying a ligature around both the artery and a probe or stilet and then removing the probe or stilet after the knot was tied. One mistake was made in identification of the artery. The degree of occlusion of the artery was always checked by examination of the specimen so that when an artery was said to be occluded it was checked by the specimen. Another consideration in placing these ligatures was that no branch of the artery was missed. Most of the statistics upon coronary artery ligation are based upon experiments in which the ligature might be 1.0 cm. below the origin of the artery; in such experiments one or two branches were usually missed and this made a definite difference in mortality and infarct. The repeated dissections of the coronary arteries were extremely difficult and dangerous because they were imbedded in scar. Another consideration concerning our experiments was that we counted delayed deaths occurring days or weeks after ligation of the
artery. Our experiments were done under aseptic surgical conditions so that survival was possible.

Another consideration of our method of producing occlusion concerned the time factor of the occlusion. Our ligations, whether complete or partial, were done in abrupt steps. In human patients the occlusion produced by coronary artery disease is frequently gradual, extending over a period of days, weeks, or months. It is known that if the occlusive process is slow enough in patients, the entire coronary inflow may be occluded. The time factor in producing occlusion is an important factor in mortality. This time factor in the occlusive process is important because when the arterial inflow is reduced, another factor appears for consideration. This other factor can be referred to as the factor of safety or the margin of safety. If the heart is to tolerate the occlusive process, the margin of safety over and above minimal requirements for maintenance of the heart beat must be great enough to withstand the inflow reduction. This margin of safety is elastic. It can increase with time so that an inadequate margin of safety producing mortality can be changed to an adequate margin of safety producing recovery if the circulation is given opportunity to make adjustment to the arterial occlusion.

Mortality Following Repeated Occlusions
Interval of One Week between Successive Occlusions of Coronary Arteries

The variety of occlusions makes the presentation somewhat complicated. The results are given in table 1. Eleven dogs (group A) were taken in which the graft was instituted in two stages. There was a period of three weeks between the two stages. At the second stage of the operation, immediately after the sinus was partially ligated, the right coronary artery was dissected out and was completely ligated at its origin from the aorta. Four of these dogs died and seven lived. One week after the right coronary artery was ligated, the descending ramus and the circumflex ramus of the left coronary artery were partially occluded in three of these dogs. Two died and one lived. One week later this one survival was operated upon and the descending ramus of the left coronary artery was completely occluded. This dog died.

Three dogs (group B) were taken in which the two-stage operation was done with an interval of three weeks between placing the graft and partial occlusion of the sinus. One week after the second stage was done, the descending ramus and the circumflex ramus of the left coronary artery were partially occluded. One animal died, two lived. One week later these two survivals were operated upon and the descending ramus was completely occluded. Two dogs survived. One week later these two dogs had the circumflex artery completely occluded. One died, one lived. One week later the one survival had the right coronary artery completely occluded. This dog lived for 35 minutes. The specimen showed all coronary arteries including the septal artery to have been completely occluded.

Another dog (group C) had both stages of the operation done three weeks apart. One week after the second stage was done, the circumflex ramus of the left coronary artery was completely occluded. The dog lived. One week later the right coronary artery was completely occluded. The dog died.

Seven dogs (group D) had both stages of the operation done three weeks apart. One week after the second stage was done, the left common coronary artery above the septal branch was partially occluded to a diameter of 2.5 mm. One dog died and six lived. One week later these six dogs were operated upon and the common left coronary artery was partially occluded to a lumen of 1.5 mm. Four dogs died and two lived. One week later these two survivals had complete occlusion of the common left coronary artery and both died.

Comment on These Experiments. Under the conditions of the experiment it would appear that the graft did not protect seven dogs from complete occlusion of the right coronary artery. One dog survived complete occlusion of all coronary arteries for a period of 35 minutes. It was our opinion that the blood supply from the aorta through the graft made this possible. Total occlusion of the common left coronary artery was not accomplished even though this artery was taken down in stages. It was our
opinion that an interval of one week between successive occlusions of the coronary arteries was not long enough to give the best results. We believed that the circulation needed a longer period of time to make adjustments to the inflow occlusions. We are of the opinion that the margin of safety following occlusion can increase with time up to a certain point, so that survival might follow the next occlusion if an adequate interval of time existed between the occlusions.

Interval of Three Weeks between Successive Occlusions of Coronary Arteries

In table 2 the results are shown. An attempt was made to produce complete occlusion of the left common coronary artery above the septal branch in seven dogs (group A). The graft had been placed in two stages as usual before the artery was occluded. Three weeks after the second stage was done, the left common coronary artery was partially occluded to a diameter of 2.5 mm. Two dogs died and five survived. Three weeks later, the right coronary artery was completely ligated in these five dogs. Three died and two survived. Three weeks later, the left common coronary artery was partially occluded to a diameter of 1 mm. in the two surviving animals. Both dogs died.

These experiments indicated the high mortality in experimental occlusion of the left common coronary artery even in the presence of the graft and even when the occlusions were done in stages. It was decided to occlude the two major branches of the left coronary artery instead of the common left artery itself.

The graft was placed in 15 dogs (group B) and the second stage was done three weeks after the first stage. Three weeks after the second stage was done the descending ramus of the left coronary artery was totally occluded at its origin. One animal died and 14 lived. Three weeks later the right coronary artery was completely occluded at its origin in one stage in six of these dogs. One died and five lived. Three weeks later the circumflex ramus of the left coronary artery was completely occluded in one stage in these five dogs. Three died and two lived. In one of these dogs the death occurred immediately after the artery was ligated. In the other two dogs death occurred seven days and 22 days after ligation of the artery. The significance of the delayed deaths was that these dogs almost survived the ligations. Indeed it would be correct to state that at the end of the six days following the last occlusion there were four living dogs with complete occlusion of all three major coronary arteries. The two long term dogs were killed after five months. These dogs were believed to have had total coronary occlusion. The specimens from these dogs showed complete occlusion of all arteries except the septal branch. The check by autopsy examination of the specimen was essential because while these dogs were alive we believed that the septal branch was also occluded.

By altering the procedure another animal was obtained in which we believed total occlusion was accomplished. The remaining eight out of 14 dogs that survived ligation of the descending ramus of the left coronary artery were operated upon after an interval of three weeks and the circumflex ramus of the left coronary artery was ligated in one stage at its origin. Six dogs died and two lived. Notation is made here that, if we had interposed ligation of the right coronary artery between ligations of the two major branches of the left coronary artery, the survival record might have been greater than two out of eight. The adjustment to the occlusions might have been better. Of the two survivals, one was operated upon three weeks later and the right coronary artery was totally occluded at its origin in one step. This dog survived. It was kept for a period of five months. It was then killed, and the specimen showed complete ligation of the three major coronary arteries. The septal branch was patent.

Two dogs (group C) were subjected to total ligation of the right coronary artery three weeks after the second stage of the graft. Both dogs lived. Three weeks later one of these dogs had total ligation of the descending ramus of the left coronary artery. This dog lived. Three weeks later the dog had the circumflex ramus of the left coronary completely ligated and died.

One dog (group D) was subjected to total ligation of the circumflex artery three weeks
after the second stage of the graft and lived. Three weeks later the right coronary artery was totally ligated and the dog survived.

Comment on These Experiments. The septal artery originates from the common left coronary artery or from the descending ramus of this artery. In many instances the septal branch was ligated together with the descending ramus of the left coronary artery. We could not be certain whether the septal branch was ligated with the descending ramus until the specimen was examined. In this series there were five dogs that survived complete ligation of the descending ramus of the left coronary artery, the circumflex ramus of the left coronary artery and the right coronary artery. Only the septal branch was patent. One of these dogs died seven days and one died 22 days after ligation of the circumflex ramus of the left coronary artery. The remaining three dogs were kept for five months. During this period of time the dogs were active and appeared to be normal. Electrocardiograms on these dogs, taken at rest, showed minimal evidence of infarction. These dogs were given an anesthetic; the chest was opened and the graft was identified. The graft was clamped off for a period of 30 minutes. There was no change in the electrocardiogram and there was no objective change in the heart beat while the graft was occluded. The only interpretation that can be given to these observations is that the graft was not essential to the maintenance of the heart beat for a period of 30 minutes under the conditions of the experiment. This raised doubt as to whether a significant quantity of blood flowed in a retrograde direction in these experiments. We have evidence to show that retrograde flow occurs immediately after arterial occlusion. Studies on retrograde flow occurring days or weeks after arterial occlusion are being carried out. The dogs were killed and the specimens were examined. In the hearts of two of these dogs complete occlusion existed in the descending ramus of the left coronary artery, the circumflex ramus of the left coronary artery and the right coronary artery. Only the septal branch was patent. This arose from the common left at a level proximal to the descending ramus. In the third specimen all coronary arteries, including the septal branch, were completely ligated except that the occlusion of the circumflex ramus was not quite complete. It had a lumen of 1.0 mm. and it is possible that this artery was completely occluded at the time the ligation was placed and that this small lumen developed subsequently.

Survival and mortality following complete occlusion in one stage of one, two and finally three major coronary arteries can be obtained from tables 1 and 2. Table 3 summarizes these results. Out of the 47 ligations there were 29 that survived one-stage ligation of one major artery: right coronary seven in group A table 1, two in group A table 2 and two in group C table 2; descending ramus two in group B table 1 and 14 in group B table 2; circumflex ramus one in group C table 1 and one in group D table 2. Out of these 29 survivals there were 10 that survived complete occlusion of a second major artery: one in group B table 1, seven in group B table 2, one in group C table 2 and one in group D table 2. Out of these 10 survivals there were three that survived occlusion of the third major artery: three in group B table 2. In addition to these three long term survivals there was one dog that lived seven days and one that lived 22 days after all three major arteries were occluded (two in group B table 2).

Table 4 shows the figures for each of the three arteries: descending ramus, 17 (15 in group B table 2 and two additional dogs not in the table); right coronary artery, 13 (group A table 1 and group C table 2); circumflex ramus, two (group C table 1 and group D table 2). Partial occlusion of the left common coronary artery was done in 14 dogs (group D table 1, and group A table 2). A combination of partial occlusion of the descending ramus and partial occlusion of the circumflex was done in three dogs (group B table 1).

Discussion

Several conclusions can be drawn from these experiments. The survival rate in the animals referred to in table 2 was greater than in those referred to in table 1. It would appear that an interval of three weeks between operations on
the coronary arteries (table 2) gave a higher survival rate than occurred when this interval was one week (table 1). Perhaps the dog required a longer period than one week to recover from one operation before the next operation was done. This would involve such general considerations as nutritional disturbance and other side effects of the anesthetic and the operation. Another factor concerned the adjustments of the circulations that take place after a coronary artery was partially or completely occluded. These adjustments were important and required time to run their course and reach an end point. We have had experience in the past which has led us to attach importance to this factor.

The mortality following ligation of the right coronary artery in group A of table 1 was higher than occurred in normal control dogs. A satisfactory explanation of this cannot be given. In other experiments not included in this series the mortality was lower when an interval of three weeks or longer existed between partial occlusion of the sinus and subsequent ligation of this artery. We believe that the time interval was a factor in this mortality.

### Table 1.—Both Stages of Operation. Serial Ligation of Arteries. Interval between Ligations One Week

<table>
<thead>
<tr>
<th>Coronary Artery Ligated</th>
<th>Number of Dogs</th>
<th>Died</th>
<th>Survived</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>11</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Descending ramus, partial</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Circumflex ramus, partial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Descending ramus, complete</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Group B**

<table>
<thead>
<tr>
<th>Coronary Artery Ligated</th>
<th>Number of Dogs</th>
<th>Died</th>
<th>Survived</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descending ramus, partial</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Circumflex ramus, partial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Descending ramus, complete</td>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Circumflex ramus, complete</td>
<td></td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Right</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**Group C**

<table>
<thead>
<tr>
<th>Coronary Artery Ligated</th>
<th>Number of Dogs</th>
<th>Died</th>
<th>Survived</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumflex ramus, complete</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>1</td>
<td>1</td>
<td></td>
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**Group D**

<table>
<thead>
<tr>
<th>Coronary Artery Ligated</th>
<th>Number of Dogs</th>
<th>Died</th>
<th>Survived</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left common, partial, 2.5 mm.</td>
<td>7</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Left common, partial, 1.5 mm.</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Left common, complete</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

Complete occlusion of the common left coronary artery above the septal branch carried out in stages was not successful, as shown in group D of table 1 and group A in table 2. This artery could be occluded to a lumen of 1.0 or 1.5 mm. It would appear that the amount of blood going through such a small opening was necessary for the heart beat. The two major branches of the left coronary artery excluding the small septal artery were completely occluded. It would appear that the septal branch might have been a factor in mortality and yet
in the ligation of the descending ramus the septal branch was frequently included with the descending ramus and recovery occurred.

The highest recovery rate in arterial occlusions occurred in the dogs composing group B of table 2. We believed that the order of occlusions was a factor in this recovery rate. This order was first the descending ramus, second the right coronary artery and third the circumflex ramus. It would appear that this rotation was followed by the most favorable circulatory adjustments after each occlusion.

The recovery rate following complete occlusion of the descending ramus in one stage (16 out of 17 dogs) was of special significance (table 4). The two-stage operation with the institution of the graft made this possible. The operation protected the heart after this artery was occluded. After this series of experiments was done this artery was ligated in 13 additional dogs. Out of these there were seven deaths and six recoveries. These experiments were done during a period of hot weather. The interval between the second stage of the operation and the arterial ligation was two weeks. One dog died when the artery was being dissected and before the artery was occluded. Perhaps factors other than the ligation of the descending ramus determined this mortality.

Beck, Stanton, Batiuchok and Leiter1 reported on mortality and recovery following ligation of this same test artery. In these dogs an anastomosis was made between the carotid artery and the coronary sinus and the sinus at its ostium in the auricle was either partially or completely occluded. Out of 10 dogs with patent anastomosis there were eight recoveries and two deaths. In the two dogs that died, deaths were delayed. These dogs almost survived. In 10 identical experiments in which the graft was occluded by thrombosis the mortality was seven and the recovery was three.

A second series of experiments was reported by McAllister, Leighninger and Beck.4 The test artery was ligated in 13 dogs with 12 survivals and one death. At the time this report was made several dogs were kept for long term study. Since the report was made and since the specimens were examined it was found that the test artery was ligated in 10 dogs with one death.

The descending ramus was missed in three specimens.

The total experience for ligation of this test artery from this laboratory was 37 dogs with 33 recoveries and four deaths. If a recent series not in these tables was included, the total figure was 50 dogs with 39 recoveries and 11 deaths. This was a mortality of approximately 9 per cent with the lower figure and 22 per cent with the higher figure. Our experience with ligation of this test artery in over 100 normal control dogs was a recovery rate of 30 per cent and a mortality rate of 70 per cent. It was obvious that the two-stage operation gave definite pro-

<table>
<thead>
<tr>
<th>Table 3.—Survival after Successive One-Stage Ligations of Three Major Coronary Arteries—Descending, Circumflex, Right.</th>
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<tbody>
<tr>
<td>Number of Ligations</td>
</tr>
<tr>
<td>Total Number of Dogs...</td>
</tr>
<tr>
<td>Survivals .....................</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4.—Complete Occlusion of Coronary Arteries in One Stage</th>
</tr>
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<tbody>
<tr>
<td>Artery</td>
</tr>
<tr>
<td>Descending Ramus.......</td>
</tr>
<tr>
<td>Right..................</td>
</tr>
<tr>
<td>Circumflex Ramus......</td>
</tr>
</tbody>
</table>

tection to the heart after occlusion of the test artery.

We do not have statistical evidence to indicate that the operation made it possible to ligate all three of the major coronary arteries except the septal branch with recovery. Ligation of the circumflex ramus alone in normal dogs had a high mortality. Our estimation of this mortality in normal dogs was about 90 per cent. Allen and Laadt reported mortality of 82 per cent within 24 hours after ligation of the circumflex artery at its origin.7 We never attempted ligation of both descending ramus and circumflex ramus in normal dogs but we would estimate the mortality to be 100 per cent.

INFARCTS

The infarcts that developed after ligation of one or more coronary arteries were classified as
large, small and absent. A large infarct measured approximately 4 cm. in its greatest transverse diameter. A small infarct was less extensive but showed a definite area of scar. The term no infarct was applied to those specimens in which the fibrosis was limited to discrete areas of about 1.0 to 2.0 mm. in diameter. This definition of no infarct was not strictly accurate

Fig. 1. Photographs of hearts five months after the last coronary artery was occluded. A. Complete occlusion of descending ramus, circumflex ramus and right coronary artery. Only the septal branch was patent. There was slight fibrosis of myocardium but there was no extensive destruction and no thinning of the myocardium. B. Complete occlusion of circumflex ramus and right coronary artery. The descending ramus and the septal branch were patent. Small areas of fibrosis were present, but no extensive infarct. C. Complete occlusion of descending ramus, septal branch, and right coronary artery. The circumflex ramus was occluded to a lumen of 1 mm. With the exception of this small lumen all coronary artery inflow was occluded. A few small areas of fibrosis were present beneath the endocardium. There was no extensive infarct. D. Complete occlusion of descending ramus, circumflex ramus and right coronary artery. Only the septal branch was patent. There was no extensive destruction of heart muscle. The specimen was discolored by injection of colored material into the coronary arteries.
and was used to indicate little or no destruction of heart muscle.

Of 29 specimens in which one artery was ligated the infarct was large in four, small in three and "absent" in 22. Of 10 specimens in which two arteries were ligated the infarct was large in two, small in one and "absent" in seven. Of three specimens in which three major coronary arteries were ligated (all coronary arteries except the septal branch) the infarct was large in none, small in one and "absent" in two.

Of 16 specimens in which the descending ramus of the left coronary artery was ligated, the infarct was large in two, small in two and "absent" in 12. Of nine specimens in which the right coronary artery was ligated the infarct was large in one, small in one and "absent" in seven. Of two specimens in which the circumflex ramus was ligated the infarct was large in one, and "absent" in one. Four specimens are shown in which several coronary arteries were occluded (fig. 1). None of these specimens showed extensive destruction of the heart muscle.

Discussion

We have data from this laboratory on infarcts following ligation of the descending ramus of the left coronary artery in normal control dogs. In a series of 50 dogs in which this artery was totally occluded at its origin in one stage there were 15 dogs that survived this operation. The infarct was classified as large in seven, intermediate in size in four and small in four. In no specimen was there no infarct. The conclusion was made that this two-stage operation protected the heart against destruction of myocardium after the descending ramus of the left coronary artery was occluded. In some of these protected hearts there was little or no destruction of heart muscle following occlusion of this artery. In our experience this never occurred in normal control dogs. No doubt the two-stage operation afforded similar protection to the myocardium following occlusion of the circumflex ramus of the left coronary artery but our data for this artery are inadequate to make this statement. The recovery rate following ligation of the circumflex ramus in normal dogs was such that a satisfactory series for the normal was never obtained.

Conclusions

1. A free vein graft was placed between aorta and coronary sinus. Several weeks later the coronary sinus was partially occluded at its ostium in the right auricle. Statistics on mortality from these operations and patency of graft were given.

2. After this operation was done in two stages it was possible to produce almost total occlusion of all coronary arteries. Total occlusion of all coronary arteries with long term recovery was not accomplished but complete occlusion of the descending ramus, the circumflex ramus and the right coronary artery with long term recovery was accomplished.

3. The operation did not give complete protection against experimental occlusion of major coronary arteries but it afforded significant protection. This protection was shown in reduction of mortality and in reduction in size of infarcts after occlusion of major coronary arteries.

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