The Ligation of Coronary Arteries with Electrocardiographic Study*

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This article is based on a study of sixty-six dogs in which known myocardial lesions had been produced by the ligation of definite branches of the coronary arteries of the heart. While the experiments were made with the primary object of determining the change in the electrocardiograms brought about by these ligations, other results, anatomic and pathologic, are deemed worthy of brief mention.

Method

Dogs were anesthetized with ether and electrocardiograms taken. The chest was surgically prepared and a tracheal cannula introduced for positive pressure. An incision was made parallel to the sternum at about the left costosternal margin, from the third to the sixth rib, then to the left in the fifth interspace. The flap, including the deep muscle layer down to the ribs, was dissected back. Blunt scissors were pushed through the intercostal muscle in the fifth interspace into the pleural cavity, and this incision was carried from the sternum well lateralward. The third to the fifth rib, inclusive, were severed at the costosternal margin and the ribs retracted, thus affording a good exposure of the heart. This exposure was especially satisfactory for the ramus descendens anterior sinister. To ligate the circumflexus sinister to the best advantage the incision had to be carried especially far to the left side with the animal lying on the right side. To expose the right coronary artery an incision similar to the one described was made on the right side of the chest. The pericardium was slit as nearly as possible over the desired artery, which was ligated with strong linen. The pericardial sac and chest cavity were then closed as quickly as possible without regard to the pleura.

Electrocardiograms were taken before the ligations. Early in the work records were made immediately following the ligation and at intervals of ten minutes, over a period of thirty to forty minutes,

except in two cases, in which observations were made over a period of four hours. There seemed to be no special advantage in taking these frequent records, so that later they were ordinarily taken at the end of the operation, which was usually from twenty to thirty minutes following the ligation, and then not for several hours.

During the postoperative periods, records were taken at varying intervals. In the first thirty animals the interval was from seven to ten days. Later, electrocardiograms were taken every day for the first week or ten days. After this period every week. Frequent observations in the early postoperative course were found to be desirable.

The dogs were watched for evidence of cardiac failure and were frequently tested for such condition by forced exercise. Signs of other diseases, such as infections, were also noted. In case of death, an early necropsy was performed, especial attention being paid to the lesions found in the heart, their location, extent and histologic structure.

Artery Ligated

In eleven dogs the ramus descendens anterior sinister was ligated from 1 to 2 cm. from its origin. Dog 2 died within two minutes following the ligation. The ventricles suddenly went into fibrillation. It was afterward discovered that the dog had been previously used by Dr. Woodyatt for sugar injection. It is possible that before our operation there

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Figure 1. Normal electrocardiogram of a dog.

was disturbed function of the heart, as it was noted that the electrocardiogram taken before operation differed from the normal in that the T-wave was distinctly negative in all leads.

Ten dogs survived the operation, one died from sepsis on the eighth day. Dog 9 died on the seventeenth day with symptoms of failing myocardium. At necropsy the left ventricle was dilated and the anterior wall, including the apex, was very thin. The tenth dog of the series was found dead in the cage on the eighteenth day. No cause was found for death. Seven of the series remained in good condition until necropsy. They gained in weight, showed no evidence of fatigue on walking them to and from the electrocardiograph room, which was over one block distant. The time elapsing between operation

Figure 2. Dog 48. The record was taken twenty-five minutes following the ligation of the ramus descendens anterior sinister and the first descending branch of the ramus circumflex sinister. The T-wave is markedly elevated—left ventricular extrasystole in Lead I.

Figure 3. Dog 17. Record taken five minutes following the ligation of the ramus circumflex sinister—auricular flutter; auricular rate 500; ventricular rate 166–250. The T-wave is elevated as in Figure 2.

and necropsy varied from eighteen to sixty-three days.

The ramus circumflex sinister was ligated from 1 to 2 cm. from its origin in fourteen dogs. Four animals died during the operation; ten awakened from anesthesia in fairly good condition; of these, four died the following night; six animals lived until necropsy time. They became fat and responded well to exercise. In fact, Dog 20 at one time fought several minutes with another dog without being much winded.

The right coronary artery was ligated 2 to 3 cm. from its origin in eight dogs. Four died within five

Figure 4. Dog 40. The electrocardiogram was taken five days after the ligation of the ramus descendens anterior and the first descending branch of the ramus circumflex sinister. The T-wave is sharply negative in Leads II and III. It was strongly positive immediately following operation.

Figure 5. Dog 54. The electrocardiogram was taken two days after the ligation of the first two lateral branches of the ramus descendens anterior and the first descending branch of the ramus circumflexus sinister. The T-wave in Leads II and III is sharply negative. The T in Lead III has become positive.

hours. Dog 30 died on the third day from sepsis. Dogs 31 and 32, which gradually grew thin and coughed and vomited frequently, were killed on the tenth and twentieth days, respectively. At necropsy they were found to have bronchopneumonia. Dog 28 was killed on the twenty-eighth day, having completely recovered from the operation.

In eighteen dogs the ramus descendens anterior sinister and one or more branches of the ramus circumflexus sinister were ligated. Nine dogs died within twenty-four hours. Three died from infection in three, twelve and twenty-one days, re-

Figure 6. Dog 29. The record was taken two days after the ligation of the right coronary artery. There is a left ventricular preponderance. The T-wave in Leads II and III has changed from a negative to a markedly positive phase.

Figure 7. Dog 8. The record was taken thirty-eight days following the ligation of the ramus descendens anterior sinister. The T-wave is negative in all leads.

spectively. Two grew thin and died from failing heart on the fifteenth and seventeenth days. The remaining four dogs were killed by anesthesia in from forty-two to eighty-nine days and necropsy held.

The first lateral branch of the ramus descendens anterior sinister and one or more of the branches of the left circumflex were tied off in sixteen dogs. The portion of the ramus circumflexus sinister was either the large anterior descending or the descending posterior branch. Six dogs died within twelve hours, one from hemorrhage from a surgical blunder. Two became infected and died on the second and tenth days. The remaining eight were in

Figure 8. Dog 20. Electrocardiogram taken fifteen days following operation. An attempt was made to ligate the ramus circumflexus sinister. The ligature was around the vessel at necropsy, but the lumen was only partially occluded. The moderate left ventricular hypertrophy indicated by the electrocardiogram was verified at necropsy.

Figure 9. Dog 16. The record was made fifteen days following the ligation of the ramus circumflex sinister. The T-wave in Leads II and III has grown positive from a sharply negative phase. There are right ventricular premature contractions.

fine condition. There was no evidence of cardiac weakness.

Electrocardiographic Study

The electrocardiographic curves taken before operation were fairly constant in conformation. Figure 1 represents a type of curve which was encountered in the majority of cases. The R wave in Lead I was always small; it was most prominent in Leads II and III. The T-wave was small in all leads and not infrequently negative. In those dogs in which the T-wave was inverted in all leads, the mortality seemed to be high within twenty-four hours following operation.

Premature Contractions

Premature contractions were noted usually within a few minutes following the ligation. The

Figure 10. Dog 16. Record taken thirty-five days following operation. The R-wave in Leads I and III is blunt. This was the only record of the series which showed this condition. The ramus circumflexus sinister was ligated.

Figure 11. Dog 1. Record taken fifty-one days after ligation of the ramus descendens anterior sinister. The hypertrophy of the right ventricle indicated by the electrocardiogram was verified at necropsy.

type depended on the portion of the heart involved. When the right coronary artery or the circumflex branch of the left, both of which arteries supply blood liberally to the corresponding auricles and ventricles, was ligated, the premature contractions were both auricular and ventricular in type. The ramus descendens anterior sinister supplies portions of the left ventricle and a limited area of the right. Following the ligation of this artery left ventricular premature contractions and an occasional right were often noted.

The number of premature contractions after one hour's time depended in a large degree on the artery ligated. They were usually far more numerous following the occlusion of the right coronary artery and the circumflex branch of the left. It was not uncommon to note many runs of three to five of

Figure 12. Dog 18. Record taken twenty-six days following the ligation of the ramus circumflexus sinister. It shows the onset of two attacks of paroxysmal tachycardia.

Figure 13. The ramus descendens anterior sinister is ligated. The lesion is typical of that resulting from the ligation of this artery. There is a thinning and fibrosis of the anterior wall of the left ventricle and septum especially marked at the apex.

these premature contractions. This was especially noticeable on the day after operation, when at times there were runs of eight to ten. After this, as a rule, they gradually decreased in number day by day. After one week's time only an occasional one was seen in the electrocardiogram. In some dogs, however—those in which the ramus circumflexus sinister had been ligated—premature contractions were observed in the electrocardiograms until death.

Tachycardia

In four dogs after the ramus circumflexus sinister had been ligated, premature contractions of the left ventricular type were numerous within one hour's time. There were many small runs of three to four, which gradually increased in number to from six to eight. Finally a permanent tachycardia set in which ended in ventricular fibrillation and death. Possibly this was the explanation of the death of many of the dogs that died within the first twenty-four hours. In fact, one dog, just prior to death, which was twenty-four hours following operation, was observed with such tachycardia. Dog 18 of this series, which had the ramus circumflexus sinister ligated, had many premature contractions until the time of necropsy. On two occasions the animal was observed in paroxysms of tachycardia. (Fig. 12.) These attacks were usually only a few minutes in duration. They could be produced by exercise and were checked by keeping the dog very quiet.

Figure 14. The ramus circumflexus sinister is ligated at the site of the ligature. The external change is a slight sinking and thinning of the posterior wall of the left ventricle. The endocardial change is a fibrosis of the posterior papillary muscle and in the immediate vicinity.

Ventricular Fibrillation

Ventricular fibrillation was invariably the outcome of a permanent tachycardia. Fibrillation of the ventricles was not, however, always preceded by tachycardia. In six instances the condition came on quite abruptly soon followed by the death of the animal. In one case the string of the galvanometer fluttered as in ventricular fibrillation; within one minute's time rhythmical contractions followed. No record was taken, for we felt confident that the ventricles were fibrillating and that the experiment would in a few seconds or minutes be finished by the complete stopping of the heart. The dog, however, recovered from the operation and was allowed to live seventy-four days.

In Dog 17 the auricles were fluttering within five minutes following the ligation of the ramus circumflexus sinister. An electrocardiogram taken five minutes later showed auricular fibrillation. This was followed shortly by ventricular fibrillation and death.

T-Wave

The changes in the T-wave following the ligation of any branch of the left coronary artery were among the most constant and most remarkable, and have not, we believe, been previously recorded by other observers. There was a fairly constant change from the strongly positive peak to a markedly negative, and then a slower return to the positive or iso-electric form. These changes were usually as

Figure 15. The first descending and the large posterior descending branches of the ramus circumflexus sinister were ligated. Illustration shows a fibrosis of the posterior papillary and a slight involvement of the anterior papillary muscle.

follows: Immediately following the ligation the T-wave became more prominent. As a rule, the height of this wave seemed to vary directly with the size of the branch of the left coronary artery ligated. Where a large vessels was occluded, the T-wave became very tall (Figs. 2 and 3). In some instances it exceeded the height of the R-wave (Fig. 3). On the other hand, when a small artery was ligated the increase in the height of the T-wave was very slight. Within twenty-four hours it became sharply negative (Fig. 4). The larger the artery the greater was the condition of negativity. This persisted for three or four days, after which it gradually grew less, until by the sixth or seventh day this peak again

Figure 16. The second descending branch and the posterior portion of the ramus circumflexus sinister were ligated. The posterior papillary muscle has changed to a knot of fibrous tissue.

became positive in one lead, for example, Lead III. The duration of the negative T-wave seemed to depend on the size of the artery ligated. Where the artery was small the negative T lasted not more than from two to four days. While the T-wave usually became positive in Lead III first, followed successively by Lead II and I, occasionally the order was reversed, T in Lead I becoming positive first, followed by II and III.

The change of the T-wave from a negative to a positive phase was a gradual one, but progressed until the curve became markedly positive. This condition was usually observed from the second to the fourth week, and was frequently associated with a low voltage R-wave (Fig. 9).

After the fourth week the T-wave again became iso-electric or negative in one or more leads and remained so until necropsy. In some cases this wave was very much below the base line (Fig. 7). This was especially true after the ligation of large arteries, as the ramus descendens anterior and circumflex sinister.

Cardiac Hypertrophy

Those dogs in which the ramus descendens anterior sinister was ligated, after a period of from four to six weeks, gave an electrocardiogram typical of right ventricular preponderance. At necropsy the right ventricle was found hypertrophied (Fig. 11). Those dogs in which small branches of the left coronary artery were ligated, developed electrocardiograms typical of left-side preponderance, which was also verified at necropsy.

Pathology

The pathologic lesions resulting from the ligation of the ramus descendens anterior were fairly constant in type, but varied widely in the extent of the involvement of the heart wall. This would suggest the possibility of a difference in the amount of collateral circulation. Externally there was invariably a triangular area of depression on the anterior surface of the heart along the line of the interven-tricular septum, involving the left ventricular wall (Fig. 13). The base of this triangle was at the apex of the heart. This area was pale in color and soft or firm in consistency, depending on the age of the lesion. There was, however, often an area occupying the apex that was of soft consistency regardless of the age of the lesion and the amount of fibrosis in the surrounding tissue. In six hearts the ventricular wall at the apex was reduced almost to paper thickness, with beginning aneurism. This was observed in those hearts in which the lesion was extensive.

The endocardial degeneration was more extensive than the epicardial. The endocardium of the lower half of the septum, and the anterior left ventricular wall, including the apex and a small portion of the right ventricle adjoining the septum, were usually involved. Occasionally the base of the anterior papillary muscle was pinched off by the contraction of the fibrous tissue which later developed. The endocardium was pale or mottled in appearance, soft or firm in consistency, depending on the age of the lesion. In a few instances the lower portion of the septum was quite thin. Figure 13 illustrates a typical lesion resulting from the ligation of the ramus descendens anterior sinister.

The pathologic findings resulting from the ligation of the ramus circumflexus sinister were the most surprising, in that the external changes were comparatively small; in fact, in one instance,

Figure 17. The anterior descending branch and the posterior descending portion of the ramus circumflexus sinister were ligated. The resulting endocardial lesion is a fibrosis of the posterior papillary muscle, showing the constancy of the lesion resulting from the ligation of these arteries.

the only change noted was a small depression in the posterior wall of the left ventricle near the septum (Fig. 14). On palpation, however, the posterior wall of the left ventricle was found to be somewhat thinned out. The endocardial changes were usually confined to the posterior wall of the left ventricle, involving especially the posterior papillary muscle (Fig. 17).

The most extensive endocardial degeneration, as compared with that of the epicardium, was produced by the ligation of the various branches of the ramus circumflexus sinister. The ligation of the first descending branch of this artery generally

Table 1. Summary of Results Following the Ligation of the Ramus Descendens Anterior Sinister

Dog Number	Date of Operation	Vessel Lig.	Date of Neeropsy	Duration of Life, Days	Cause of Death
1	1/20/17	Ramus descend. ant. sinister	3/12/17	51	Anesthetized
2	1/23/17	Ramus descend. ant. sinister	1/23/17	Died during operation 63	Ventricular fibrillation
3	1/24/17	Ramus descend. ant. sinister	3/28/17		Anesthetized
4	1/25/17	Ramus descend. ant. sinister	2/17/17	23	Anesthetized
5	1/26/17	Ramus descend. ant. sinister	2/3/17	8	Sepsis
6	1/27/17	Ramus descend. ant. sinister	2/17/17	21	Anesthetized
7	1/30/17	Ramus descend. ant. sinister	2/17/17	18	Anesthetized
8	1/31/17	Ramus descend. ant. sinister	3/24/17	53	Anesthetized
9	2/1/17	Ramus descend. ant. sinister	2/18/17	17	Anesthetized
10	2/3/17	Ramus descend. ant. sinister	2/21/17	18	Failing heart
11	2/6/17	Ramus descend. ant. sinister	3/12/17	33	Anesthetized

resulted in fibrosis of the anterior papillary muscle; the ligation of the posterior descending portion of the ramus circumflexus sinister resulted in fibrosis of the posterior papillary muscle. So constant were these results that we could produce lesions of either one of these papillary muscles. In a large percentage of the cases the epicardial change was usually a depression less than the size of a five cent piece at the site of the ligation (Figs. 15 and 16).

The lesion resulting from the ligation of the right coronary artery was confined to the lateral and anterior surface of the right ventricle. It was usually about the size of a silver dollar, being more extensive on the endocardial than epicardial side. In addition, there were small areas of fibrosis from 1 to 5 mm in diameter disseminated throughout the right auricle.

Microscopic Findings

The microscopic changes were those which have many times been described as resulting from experimental or clinical occlusion. Within twenty-four hours from the time of operation there was an infiltration of round cells and red blood corpuscles within and between the muscle cells. The protoplasm of the cells stained less deeply and the nuclei

were paler. After one week fibrous tissue cells had already begun to form, and the muscle cells were in a more advanced stage of degeneration. The fibrous tissue gradually replaced the degenerated cells until by the end of three weeks the fibrosis was fairly extensive.

DISCUSSION

Mortality

In general the mortality in our series compares closely with that of late experimenters, where ether is used as an anesthetic, where artificial respiration is kept up, and where a rapid aseptic surgical operation is done. The earlier experimenters, as Cohnheim, it will be remembered, had a much higher mortality, and even Porter,¹ whose results were much more favorable because of better technic, lost more dogs than later investigators. The mortality in our series following the ligation of the ramus descendens anterior sinister was 9 per cent. Porter's was 64 per cent. Miller and Matthews² had no deaths following the ligation of this artery. Where in addition we ligated one or more small branches of the ramus circumflexus sinister, the mortality was increased to 50 per cent. This was about the same as that from the ligation of either the main

Table 2. Summary of Results Following the Ligation of the Ramus Circumflexus Sinister

Dog No.	Date of Operation	Vessel Ligated	Date of Necropsy	Duration of Life, Days	Cause of Death
12	2/7/17	Ramus circumflexus sinister	3/12/17	33	Anesthetized
13	2/9/17	Ramus circumflexus sinister	2/17/17	29	Anesthetized
14	2/12/17	Ramus circumflexus sinister	2/12/17	Died during operation	Acute dilatation of heart
15	2/12/17	Ramus circumflexus sinister	2/12/17	Died during operation	Tachycardia; acute dilatation of heart
16	2/14/17	Ramus circumflexus sinister	3/20/17	25	Anesthetized
17	2/15/17	Ramus circumflexus sinister	2/15/17	Died during operation	Ventricular fibrillation acute dilatation of heart
18	2/17/17	Ramus circumflexus sinister	4/12/17	59	Anesthetized
19	2/21/17	Ramus circumflexus sinister	2/21/17	Died following night	?
20	2/21/17	Ramus circumflexus sinister	2/22/17	54	Anesthetized
21	2/22/17	Ramus circumflexus sinister	2/22/17	Died following night	Acute dilatation of heart
22	3/28/17	Ramus circumflexus sinister	3/28/17	25 minutes following operation	Tachycardia and ventricular fibrillation
23	3/3/17	Ramus circumflexus sinister	3/3/17	Died following night	Acute dilatation of heart
24	3/3/17	Ramus circumflexus sinister	4/14/17	41	Anesthetic
25	3/8/17	Ramus circumflexus sinister	3/9/17	Morning following	Acute dilatation of heart

trunk of the ramus circumflexus sinister or the right coronary artery, which was 57 per cent. and 54 per cent., respectively. Miller and Matthews had a mortality of only 8.7 per cent. from the ligation of the ramus circumflexus sinister. The difference between our figures and those obtained by Miller and Matthews is, perhaps, explained because we used no digitalis or allied drugs prior or subsequent to ligation. These investigators feel certain that intravenous administration of strophanthin decreased their mortality.

The mortality following the ligation of the first lateral branch of the ramus descendens anterior and either the large anterior or posterior descending branch of the ramus circumflexus sinister was $37\frac{1}{2}$ per cent. These figures approached those obtained from the ligation of the ramus circumflexus sinister or the right coronary artery, yet the area supplied with blood by the last named arteries far exceeds that supplied by the former. Even though

the area supplied with blood in the former is less, the papillary muscles are involved, which perhaps may be the explanation for the high death rate.

Pathology

One fact, strikingly brought out, was that where a lesion was brought about by ligation of the left coronary artery, the softening or fibrosis involved to a much greater extent the endocardial and subendocardial structures than the subpericardial or the body proper of the myocardium. This was true in two cases in man with coronary artery occlusion which we had the opportunity of observing while the work was going on. Oppenheimer and Rothschild³ have recently called attention to this condition in sclerosis of the coronary arteries. Eight of their cases had occlusion of the ramus descendens anterior of the left coronary artery. While confirming their observations as to the location of the

Table 3. Summary of Results Following Ligation of the Right Coronary Artery

Dog No.	Date of Operation	Vessel Ligated	Date of Necropsy	Duration of Life, Days	Cause of Death
26	3/6/17	Right coronary artery	3/16/17	Died 6 hours following operation	Tachycardia; acute dilatation of heart
27	3/10/17	Right coronary artery	3/10/17	2 hours following oper.	Tachycardia; acute dilatation of heart
28	3/14/17	Right coronary artery	3/4/17	3-4 hours following oper.	Acute dilatation of heart
29	3/11/17	Right coronary artery	4/14/17	28	Anesthetized
30	8/17/17	Right coronary artery	3/20/17	3	Sepsis
31	3/21/17	Right coronary artery	3/31/17	10	Anesthetized; bronchopneumonia
32	3/24/17	Right coronary artery	4/13/17	20	Bronchopneumonia
33	3/27/17	Right coronary artery	3/22/17	Died following night	Acute dilatation of heart

pathologic changes, we are not prepared to accept in its entirety their "arborization block" explanation of the electrocardiographic phenomena seen in such cases. We feel that further study of this feature is necessary.

Anastomosis

The question of an anastomosis between the right and left coronary arteries has been often discussed. Our observations on these dogs lead us to the belief that while the degree of anastomosis is variable, there must often be a fairly free communication between the branches of the right and left arteries or between the smaller branches of the same artery. Otherwise it is difficult to explain the survival of dogs where extensive ligation has been made, the variations in extent of the lesions produced by the obstruction of the same vessel and the comparatively small size of the lesion which frequently results from the occlusion of a large artery.

The same conclusions, we believe, can be drawn with regard to the anastomosis of the coronary arteries in man. In a case that we recently studied, although the ramus descendens anterior sinister and the large anterior descending branch of the circumflexus sinister were completely occluded by thrombi, the only external change was a small depression the size of a fifty cent piece on the anterior wall of the left ventricle. Similar observations have been made by Thorel, Chiari, Merkel, Dock,

Herrick⁴ and others, in which a fairly rich collateral circulation, capable of functioning, must be assumed to exist as an explanation of the survival of the patient with such a comparatively small area of myocardial involvement after an extensive obstruction of a larger vessel.

Electrocardiograph Study

The various types of premature contractions, the appearing of these in runs of three to eight, with an occasional onset of tachycardia, have been recorded by Lewis⁵ in his work on tachycardia produced by the ligation of the coronary arteries. He observed tachycardia very frequently following the ligation of the right coronary artery, and in one instance following the ligation of the ramus descendens anterior. The majority of these tachycardias described by Lewis did not develop until after one hour subsequent to the ligation. He concluded that even a large number of his dogs would have developed the normal rhythm if he had observed them over a longer period of time. Six out of ten of his animals regained the normal rhythm after developing tachycardia; the remaining four went into ventricular fibrillation and died. In our series, four dogs in which the ramus circumflexus sinister was ligated, developed, within forty minutes, tachycardia which ended in ventricular fibrillation and death. Dog 18, in which the ramus circumflexus sinister was ligated, was observed on two different

Table 4. Summary of Results Following the Ligation of Various Branches of the Ramus Descendens Anterior and Circumflexus Sinister

Dog No.	Date of Operation	Vessel Ligated	Date of Necropsy	Duration of Life, Days	Cause of Death
34	4/9/17	Ramus descendens anterior sinister and first descending branch of circumflexus sinister	7/21/17	89	Anesthesia
35	4/11/17	Ramus descendens anterior sinister and first descending branch of circumflexus sinister	4/4/17	Died 10 minutes after ligation	Acute dilatation of heart
36	4/12/17	Ramus descendens anterior sinister and first descending branch of circumflexus sinister	4/12/17	Died following night	Acute dilatation of heart
37	4/14/17	Ramus descendens anterior sinister and first descending branch of circumflexus sinister	4/14/17	Died 30 minutes following ligation	Ventricular fibrillation; acute dilatation of heart
38	4/16/17	Ramus descendens anterior sinister and first descending branch of circumflexus sinister	4/17/17	Died 24 hours following operation	Acute dilatation of heart
39	4/18/17	Ramus descendens anterior sinister and first descending branch of circumflexus sinister	7/5/17	78	Failling heart
40	4/21/17	Ramus descendens anterior sinister and first descending branch of circumflexus sinister	4/21/17	Died 20 minutes following ligation	Ventricular fibrillation; acute dilatation of heart
41	4/23/17	Ramus descendens anterior sinister and first descending branch of circumflexus sinister	8/15/17	83	Anesthesia
42	4/25/17	Lateral branch of ramus descendens anterior and posterior descending portion of circumflexus sinister	4/25/17	Died following night	Acute dilatation of heart
43	4/28/17	Large anterior descending branch and posterior portion of ramus circumflexus sinister	6/9/17	42	Anesthetized
44	4/30/17	Large anterior descending branch and posterior portion of ramus circumflexus sinister	5/12/17	5	Empyema
45	5/2/17	Large anterior descending branch and posterior portion of ramus circumflexus sinister	5/23/17	21	Empyema
46	5/14/17	Large anterior descending branch and posterior portion of ramus circumflexus sinister	5/14/17	Died following night	Acute dilatation of heart
47	5/11/17	Large anterior descending branch and posterior portion of ramus circumflexus sinister	5/16/17	Died following night	Acute dilatation of heart

Table 4. *(Continued)*

Dog No.	Date of Operation	Vessel Ligated	Date of Necropsy	Duration of Life, Days	Cause of Death
48	5/19/17	Lateral branch of ramus descendens anterior and first descending branch of ramus circumflexus sinister	7/1/17	61	Anesthesia
49	5/23/17	Lateral branch of ramus descendens anterior and first descending branch of ramus circumflexus sinister	5/25/17	2 ^{1/2}	Empyema
50	5/26/17	Lateral branch of ramus descendens anterior and first descending branch of ramus circumflexus sinister	5/30/17	4	Falling heart
51	5/30/17	Lateral branch of ramus descendens anterior and first descending branch of ramus circumflexus sinister	6/6/17	6	Meningitis
52	6/2/17	Lateral branch of ramus descendens anterior and first descending branch of ramus circumflexus sinister	8/21/17	49	Anesthesia
53	6/6/17	Lateral branch of ramus descendens anterior and first descending branch of ramus circumflexus sinister	6/14/17	8	Sepsis
54	6/23/17	Lateral branch of ramus descendens anterior and first descending branch of ramus circumflexus sinister	6/23/17	Died 1 hour after operation	Acute dilatation of heart
55	6/25/17	Lateral branch of ramus descendens anterior and posterior portion of ramus circumflexus sinister	7/21/17	26	Anesthesia
56	6/27/17	Lateral branch of ramus descendens anterior and posterior portion of ramus circumflexus sinister	6/27/17	Died following night	Acute dilatation of heart
57	6/30/17	Anterior descending branch and the posterior portion of ramus circumflexus sinister	7/6/17	7	Sepsis
58	7/7/17	Anterior descending branch and the posterior portion of ramus circumflexus sinister	10/6/17	91	Anesthetized
59	7/12/17	Two lateral branches of ramus descendens anterior and descending portion of ramus circumflexus sinister	7/12/17	1 hour following operation the heart	Tachycardia and acute dilatation of

Table 4. (Continued)

Dog No.	Date of Operation	Vessel Ligated	Date of Necropsy	Duration of Life, Days	Cause of Death
60	7/14/17	Two lateral branches of ramus descendens anterior and descending portion of ramus circumflexus sinister	7/14/17	20 minutes following operation	Hemorrhage from surgical error
61	7/16/17	Large anterior descending branch and posterior portion of ramus circumflexus sinister	10/6/17	82	Anesthetized
62	7/18/17	Large anterior descending branch and posterior portion of ramus circumflexus sinister	9/30/17	74	Anesthetized
63	7/20/17	Large anterior descending branch and posterior portion of ramus circumflexus sinister	10/6/17	77	Anesthetized
64	7/26/17	First lateral branch of ramus descendens anterior sinister and first descending branch of ramus circumflexus sinister	7/28/17	2	Sepsis
65	7/28/17	Two lateral branches of ramus descendens anterior and posterior portion of circumflexus sinister	10/6/17	70	Anesthetized
66	7/29/17	Two lateral branches of ramus descendens anterior and posterior portion of circumflexus sinister	7/29/17	Died following night	Acute dilatation of heart

occasions in an attack of tachycardia weeks following the operation. The animal was in fine condition at the necropsy which was fifty-nine days from the time of ligation. We have previously stated that the frequency with which paroxysmal tachycardia developed subsequent to the ligation of the ramus circumflexus sinister and the right coronary artery may explain the death of many of these animals the night following the operation. This supposition is made even more plausible by the fact that we observed one animal die in one of these attacks twenty-four hours following operation.

Ventricular fibrillation was observed in six cases. In four instances this abnormal rhythm was preceded by tachycardia and in the remaining two by auricular fibrillation and auricular flutter. Ventricular fibrillation in the dog invariably ended in death. We observed one case in which we believe

the normal rhythm was reestablished. Recovery in small animals is very common. Gunn⁶ observed this feature in rats. MacWilliams⁷ reported recovery in dogs, and recently Robinson and Bredeck⁸ have described a case in man in which the normal rhythm returned after a ventricular fibrillation had been well established.

The changes in the T-wave we have already described. If confirmed, these observations may be of considerable value from a diagnostic point of view, at least as concerns the left coronary artery. The early exaggeration of the T-wave, its marked negative drop below the line within twenty-four hours and its more gradual return to its positive position and its final iso-electric or negative location were so characteristic in dogs watched for several days, that similar changes in the wave in man might reasonably be supposed to be due to similar lesions. In

fact, one case in man, which will be reported later, was observed in which a clinical diagnosis of coronary thrombosis was made by Dr. James B. Herrick which was verified later at necropsy. The T-wave of the electrocardiogram of the patient ran a course similar to that of the dogs previously described. In other cases believed to be coronary thrombosis similar changes in the electrodiagram have been seen but no verification of the diagnosis has been made, the patients either living or no necropsy having been obtained.

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