A STUDY OF DIRECT CORONARY SURGERY

FLOW STUDIES OF THE INTERNAL MAMMARY ARTERY-CIRCUMFLEX ARTERY ANASTOMOSIS AND THE AORTO-CIRCUMFLEX ARTERY BYPASS GRAFT, AND A REPORT OF TWO CLINICAL CASES

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ABSTRACT

The hemodynamic characteristics and differences after the internal mammary artery-circumflex artery anastomosis and the aorto-circumflex artery bypass graft were evaluated in dogs to determine the indication of these two procedures for clinical application. As a graft, the femoral artery, femoral vein or the cephalic vein was utilized.

In acute experiments, compared to the normal circumflex artery, there were no differences in flow rate and reactive hyperemia between these two procedures. But flow pattern of the internal mammary artery anastomosis was characteristic. In early systolic period the flow increased to the maximal level and decreased in relatively early period of diastole.

In chronic experiments, resting flow rate was almost comparable with the normal circumflex flow, but reactive hyperemic augmentation was not sufficient. This may be due to scar formation surrounding the vessels or their intimal thickening. Flow pattern of the internal mammary artery anastomosed to the circumflex artery changed from the immediate postoperative pattern to that resembling that of the normal circumflex artery.

Histological examination revealed a little thicker intimal proliferation in the vein graft than in the internal mammary artery or artery graft.

Presently, the method of the two procedures in which the diameter of the vessel matches the coronary artery proposed the anastomosis, should be utilized in the clinical cases.

Two clinical cases where the right coronary artery was bypassed from the aorta by a saphenous vein graft are reported.

INTRODUCTION

Atherosclerotic occlusion of the coronary arteries is a prevalent and devastating disease. Although the efficacy of medical management of its clinical manifestation is unquestioned, there is no satisfactory preventive or

curative therapy available at present.   The demand for adequate surgical measures to be applied to such patients is becoming more urgent.

Whereas the indirect method for the revascularization of the ischemic myocardium, implantation of the internal mammary artery, originally described by Vineberg, is now accepted as an effective treatment for angina pectoris by many cardiac surgeons, it takes at least three months until communicating collaterals between the implant and coronary vessels can be demonstrated angiographically.

Sabiston[1] indicated that the most advanced lesions and sites of stenosis or occlusions were most often located in the proximal third or half of the coronary arteries.   Moreover, these data indicated that the frequency and severity of occlusions were greatest in the anterior descending, the left circumflex and the left main coronary arteries, and least of all in the right posterior descending coronary artery.

Direct surgical intervention of the coronary arteries appears to promise more success, in so far as segmental stenoses of main branches are concerned, and direct reconstructive vascular surgery should provide immediate and adequate coronary artery blood flow.   In addition to methods toward removing stenosis by curettage, endoarterectomy and dilatation of the stenotic ring by means of a patch graft, numerous experiments have been aimed at overcoming the segmental narrowing by creating an anastomosis between a branch of the aortic arch and the coronary stem beyond the stenosis.

The direct anastomosis of systemic-to-coronary artery, as the first trial of direct surgical approach to coronary disease, was performed by Murray and coworkers[3] in 1954.   Since then, many experiments of direct systemic-to-coronary artery anastomosis have been reported.   The shunting was made through mobilized arteries, arterial or venous vascular grafts, or prosthetic vessels.

The mobilized arteries were the internal mammary[4]~[22], or subclavian artery[3][23]~[25]; while arterial grafts were the carotid[3], internal mammary[26][27], femoral[27][28], common or external iliac[30], axillar or humoral artery[30]; and, venous grafts were the external jugular[31][32], femoral[28], or saphenous vein[27]. As prosthesis, Dacron[33] or Ivaron vessel[34] was used.

The suture techniques utilized in experiments are categorized into two groups; 1) nonsuture technique such as with Tantalum ring[10][19], Polyethylen ring[9][18], Nylon[12][16][18], Polyethylen[12], or stainless stent[12], or Nakayama's[4], NCR Vogelfanger[8], American[35], or Roussian stapling device[35], gelatin tube[28] and 2) direct suture.

Patency rate of the nonsuture group was better than that of the direct suture group, but the pathological changes of atherosclerotic coronary arteries disturbed clinical application of the nonsuture technique.

Recently, direct coronary surgery has increasingly been employed in the treatment of coronary arterial occlusive disease, and many clinical experiences have been reported[36)~47)]. Green and coworkers[48)] reported that the late patency was 95% and the internal mammary artery-coronary artery anastomosis was better in patency than the aorto-coronary artery bypass graft. Effler and coworkers[53)] reported 2,000 clinical cases and stated the late patency of the bypass graft to be 85%. In Japan, the direct coronary surgery, mainly the aorto-coronary bypass graft and the internal mammary artery-coronary artery anastomosis, began to be undertaken in clinical cases[50)~53)].

In this study, mongrel dogs were utilized and the aorto-coronary bypass graft and the internal mammary artery-coronary artery anastomosis were carried out to evaluate the characteristics and hemodynamic findings of these two methods, and to justify their clinical application.

In addition, two clinical cases of an aorto-right coronary artery bypass graft by reversed saphenous vein are reported.

MATERIALS AND METHODS

The studies were performed with 73 mongrel dogs weighing 10 to 23 kg. Anesthesia was induced with thiopental sodium intravenously (30 mg/kg of body weight). The trachea was intubated, and the animal was connected to a Bird respirator and ventilated with room air. Left thoracotomy was carried out through the 4th intercostal space.

Then, the animals were divided into two groups according to the experimental methods; the left internal mammary artery to the circumflex artery anastomosis and the bypass graft from the ascending aorta to the circumflex artery.

Operative Technique

1) Left Internal Mammary Artery-Circumflex Artery Anastomosis

After thoracotomy, the left internal mammary artery was dissected proximally to the subclavian artery and distally to the 5th intercostal space. Then the pericardium was opened longitudinally, and the circumflex artery was exposed to about 2 cm distally from its origin sparing all branches carefully. Two turniquets were applied to the artery for occlusion. A small arteriotomy was made between the two, and the distal end of the internal mammary artery dissected already was anastomosed in a side-to-end fashion. The distal portion of the circumflex artery was perfused with blood from the femoral artery through a small vinyl catheter inserted at the incision site. At the end of the procedure, the shunt tube was removed and the last stitch was tied.

2) Aorto-Circumflex Artery Bypass Graft

After dissection of the circumflex artery, the fat tissue at the root of the

aorta was removed and the aortic wall was exposed.   Simultaneously, the graft was taken from either the femoral artery, femoral vein or cephalic vein and irrigated with heparinized normal saline.   After a small triangular hole was punched out on the aortic wall, the aorto-graft anastomosis was performed in a side-to-end fashion under a partial clamp of the aorta.   Then the proposed site of anastomosis of the circumflex artery was incised, and a small vinyl tube connected to the femoral artery was inserted via a branch of the graft to perfuse the distal portion of the artery (intraluminal shunt).   The distal end of the graft was anastomosed to the circumflex artery in a side-to-end fashion.

All these anastomoses described above were carried out by continuous over-and-over sutures with 6-0 monofilament nylon threads.   The use of a binocular loupe of two magnifications facilitated the meticulous anastomoses very much.   All these procedures were applied to the normally beating heart. After the anastomosis was completed, the circumflex artery was ligated proximal to the anastomosis.

In acute experiments, evaluation was made soon after the operation.   In the long-term follow-up group, animals were let to live and antibiotics were given for a week postoperatively.   They were sacrificed and evaluated at various intervals.

Methods for Evaluation

Two electromagnetic flow probes were used, one on the ascending aorta and the other on either the circumflex, left internal mammary artery, arterial or venous graft, for measurement of phasic and mean cardiac output and coronary blood flow.   A cannula was inserted into the left ventricle through its anterior wall.   The flow probes were connected to individual channels of a two channeled squarewave electromagnetic flow meter, and the ventricular cannula to a pressure transducer.   Flows, pressure, dp/dt and ECG were recorded on a direct writing poligraph.

After the dissipation of the effects of the operative maneuvers, measurements were made.   The internal mammary artery, the arterial or venous graft was occluded temporarily for 1 to 5 minutes until distinct ischemic changes were seen and then released.

Data obtained from each group were compared with control values prior to the anastomosis.   Zero coronary blood flow was obtained by temporary occlusion of the coronary artery distal to the flow probe.   For the aortic flow measurement, a flat portion of the tracing in the diastolic phase of the cardiac cycle was assumed to be zero.

Patency of the survival cases was evaluated by angiography or postmortem angiography.   In angiography, a catheter was inserted from the femoral artery to the left subclavian artery or the ascending aorta and 76% Urografin® (Sodium

and Meglumine Diatrizoate) was injected.   In postmortem angiogram, a thin barium solution was injected through a small polyethylen catheter inserted into the internal mammary artery or the graft, and X-ray photos were taken.

In cases of the surviving group, in which the anastomosis was patent, the same measurements as in the acute experiment were applied at various intervals and histological examination was performed.   Tissue blocks were cut from the anastomotic site of the extirpated heart and burried in paraffin to prepare sections.   Hematoxylin and eosin, and elastica Van Gieson stainings were employed.

RESULTS

Acute Experiment

(a) Internal Mammary Artery-Circumflex Artery Anastomosis

This group consisted of 6 dogs, one of which, however, was excluded, since the animal developed ventricular fibrillation during anastomosis and died of brain damage six hours after successful resuscitation.   Results of the 5 dogs were as follow;

Flow Rate: The mean flow of the anastomosed internal mammary artery ranged from 15 to 25 ml/min. (average 24), which was well compared with that of the preanastomotic circumflex artery ranging from 15 to 25 ml/min. (average 21) (Table 1).

Flow Pattern: In early systolic phase, the flow showed the maximum to produce the initial spike which corresponded to the peak of output.   Then it decreased rapidly.   At the onset of diastole, the flow increased once to form the diastolic spike but decreased after a short period.   Presystolic augumentation was noted (Fig. 1).

Effects of Occlusion: Occlusion of the internal mammary artery induced ischemia in the left ventricular myocardium perfused by the artery.   After a

TABLE 1. Flow Rates of the Preanastomotic Circumflex
Artery (CFA) and the Internal Mammary Artery (IMA)
Anastomosed to the Circumflex Artery in Acute
Experiment. BW: Body Weight

No.	BW (kg)	Flow	
		CFA (ml/min.)	IMA (ml/min.)
1	20	15	15
2	12	25	25
3	12	25	25
4	17	25	25
5	17	15	30

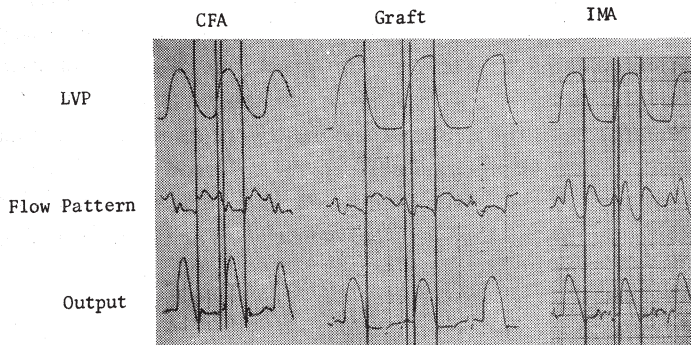These values may be accepted as almost the same.

FIG. 1. Flow pattern of the normal circumflex artery (CFA), the aorto-circumflex artery bypass graft and the internal mammary artery anastomosed to the circumflex artery, simultaneously recorded left ventricular pressure (LVP) and output. As graft, the femoral artery was utilized. The flow pattern of the bypass graft resembles to that of the circumflex artery, but the internal mammary anastomosis has the characteristic flow pattern, in which the early systolic spike is maximal flow.

minute and a half a distinct elevation of the ST segment was visible in ECG, and left ventricular pressure and dp/dt decreased gradually. After release of the occlusion, ECG returned to normal in a minute and a half. dp/dt and left ventricular pressure improved beyond the preocclusion level. Internal mammary arterial flow increased up to 383% of the preocclusion control level, from 30 to 115 ml/min. (Fig. 2).

(b) Aorto-Circumflex Artery Bypass Graft

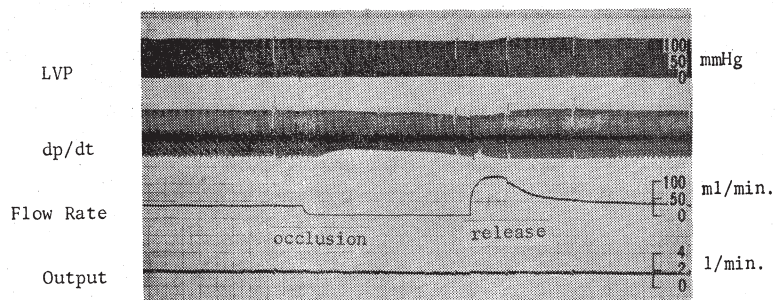In this group, the autogenous femoral artery was used as a bypass graft,

FIG. 2. Continuous recording of left ventricular pressure (LVP), dp/dt of LVP, flow rate of the internal mammary artery anastomosed to the circumflex artery and output, during occlusion and release of the internal mammary artery. Remarkable augumentation of flow of the internal mammary artery after release (reactive hyperemia) is noted. Ratio of increased flow to resting flow rate is 383%.

and nine dogs were included. Of these dogs, 4 died in operation; 2 died of uncontrollable bleeding from the aorto-graft anastomosis, and the other two of ventricular fibrillation when the circumflex artery was occluded for an intraluminal shunt.

Flow Rate: The mean flow of the anastomosed bypass graft ranged from 10 to 50 ml/min. (average 31), which was well compared with that of the preanastomotic circumflex artery ranging from 15 to 50 ml/min. (average 32) (Table 2).

Flow Pattern: The early systolic flow was relatively low and decreased gradually until the end of the systolic phase. In diastolic phase, the flow increased to high level and formed a plateau which continued till the presystolic phase, when the presystolic augmentation appeared. The flow pattern was essentially the same as that of the intact circumflex artery (Fig. 1).

TABLE 2. Flow Rates of the Preanastomotic Circumflex Artery (CFA) and the Femoral Artery Bypass Graft between the Aorta and the Circumflex Artery in Acute Experiment. BW: Body Weight

No.	BW (kg)	Flow	
		CFA (ml/min.)	Graft (ml/min.)
1	15	37	36
2	13	25	25
3	19	50	50
4	12	15	22.5
5	20	35	20

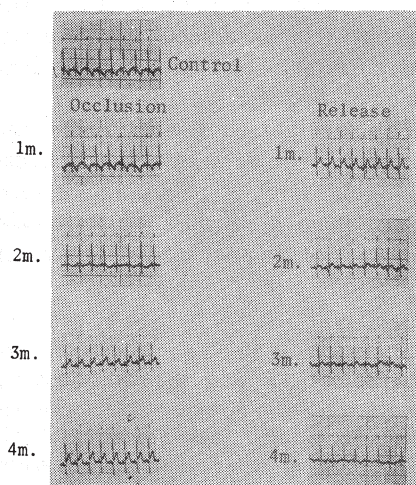These values may be accepted as almost the same.

FIG. 3. ECG (aVf) changes after occlusion and release of the aorto-circumflex artery bypass graft using the femoral artery immediately after operation. The ST segments elevated distinctly, and return after release.

Effects of Occlusion: ECG indicated distinct elevation of the ST segment three minutes after occlusion, which returned to normal about four minutes after release (Fig. 3). Continuous recordings showed suppression of left ventricular pressure and dp/dt by occlusion, and recovery and increase over the control value after release. Bypass graft flow increased to 400% of the control level, from 20 to 80 ml/min. by reactive hyperemia after release.

Chronic Experiment

(a) Internal Mammary Artery-Circumflex Artery Anastomosis

Of 16 dogs subjected to this group, 7 died in operation; 4 due to ventricular fibrillation which occurred during the anastomosis in spite of application of

TABLE 3. Results of Long-Term Survivors of the Internal Mammary Artery-Circumflex Artery Anastomosis. BW: Body Weight

No.	BW (kg)	Survival time (days)	Cause of death	Result
1	13	7	sacrificed	patent
2	18	2	brain damage	patent
3	11	28	sacrificed	occluded
4	20	21	sacrificed	patent
5	12	1	cardiac arrest	patent
6	12	153	sacrificed	occluded
7	16	7	pyothorax	patent
8	17	3	thrombosis	occluded
9	20	122	sacrificed	patent

The longest patent survival time is 122 days.
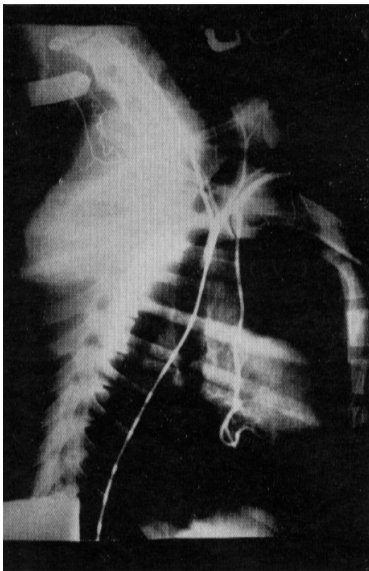
the femoro-coronary shunt, and 2 due to ventricular fibrillation at reaccomplishment of blood flow after the anastomosis. Another animal was sacrificed immediately after the operation. The period of survival ranged from 1 to 153 days (Table 3).

Six of 9 survivors had a patent anastomosis proved by angiography or postmortem angiography. The patency rate was 66.6%. Two dogs died of thrombus formation at the site of anastomosis on

FIG. 4. Angiogram through the femoral artery in the dog No. 4 after 21 days survival, whose internal mammary artery was anastomosed to the circumflex artery. No narrowing of the anastomosis and good filling of the branches are noted.

the 2nd and 3rd postoperative day and one dog was sacrificed on the 153rd postoperative day, in which the anastomosis was occluded by thrombus. Three animals died of brain damage, cardiac arrest and pyothorax, 1, 2 and 7 days after operation, respectively, though the anastomosis of each dog was patent.

Fig. 4 shows an internal mammary arteriogram of a patent case taken on the 21st postoperative day. The anastomosis was not narrowed and blood flow was sufficient with a good filling of the distal circumflex artery.

Flow Rate: In 2 cases flow study was carried out on the 21st and 122nd postoperative day. The dog No. 4 had preanastomotic circumflex arterial flow of 25 ml/min. No changes in the flow rate were observed between immediately after the anastomosis and after 21 days' survival. In dog No. 9, the flow rate, on the 122nd postoperative day, was 30 ml/min. and increased to 50 ml/min. (167%) by reactive hyperemia (Fig. 5).
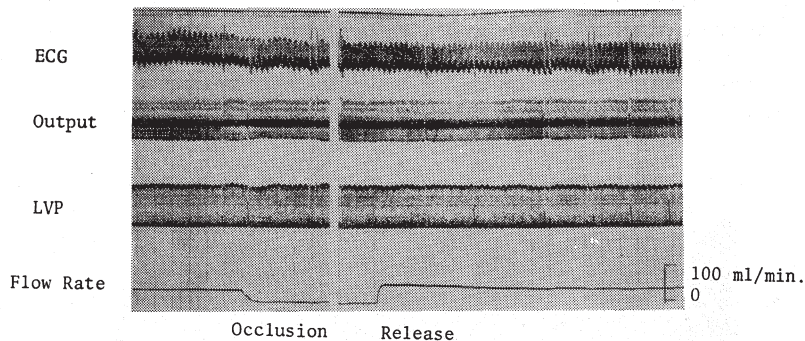

FIG. 5. Continuous recording of ECG, left ventricular pressure (LVP) and flow rate of the internal mammary artery anastomosed to the circumflex artery after 122 days survival in dog No. 9. Blood flow augmentation by reactive hyperemia is relatively low (167%).

Flow Pattern: A characteristic flow pattern was seen in long-term survivors. Decrease of flow introduced by isovolumetric contraction, continued beyond the onset of ejection. At the early systolic phase, the flow decreased to reach the lowest level, below the level at onset of ejection of the heart, and then increased to form a spike, which corresponded to the peak of cardiac output. But the spike was not the maximum flow in the whole pattern. In the diastolic phase, the flow increased to the maximum level, halted relatively steady, and began to decrease at the beginning of ventricular contraction (Fig. 6).

Histological Findings: At the junction of the internal mammary and circumflex arteries, a small fibrocollagenous mass was noted, which seemed to be the secondary changes from organization of localized fibrin deposits. The structure did not project into the lumen and apparently served to smooth out the lumen at the anastomosis. There was no foreign body reaction, nor
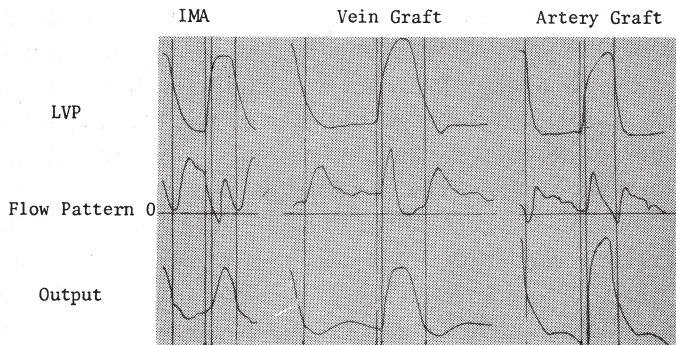
FIG. 6. Flow patterns of the internal mammary artery anastomosed to the circumflex artery, aorto-circumflex artery bypass grafts using the cephalic vein and the femoral artery after some periods of survival, left ventricular pressure (LVP) and output simultaneously recorded. The flow pattern of the internal mammary artery anastomosis is characteristic and differs from that immediately after the anastomosis, and came to resemble that of the coronary artery. Flow patterns of the bypass grafts are essentially the same as that of the coronary artery but early systolic spike is prominent.
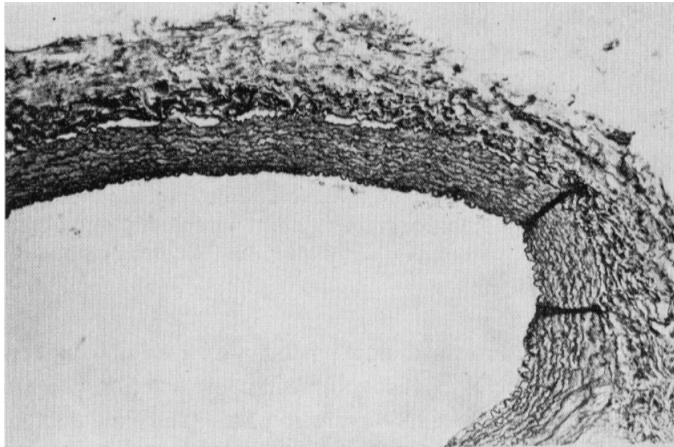

FIG. 7. Section of the internal mammary artery anastomosed to the circumflex artery after 122 days suyvival. No intimal thickening is noted. Elastica Van Gieson stain (×100).

cellular infiltration.

Section of the internal mammary artery apart from the anastomosis revealed no intimal thickening nor inflammatory findings, and normal arterial structures were observed (Fig. 7).

(b) Aorto-Circumflex Artery Bypass Graft

Of 23 dogs in this group, 14 died in operation; 9 died of ventricular fibril-

lation at occlusion of the circumflex artery before anastomosis, 2 of ventricular fibrillation at the time of reaccomplishment of blood flow after anastomosis, 2 due to uncontrollable bleeding from the aorto-graft anastomosis and 1 because of kinking of the graft immediately after the anastomosis. Consequently, 9 dogs were subjected to evaluation and the survival time ranged from 1 to 92 days (Table 4).

TABLE 4. Results of Long-Term Survivors of the Aorto-Circumflex Artery Bypass Graft

No.	BW (kg)	Graft	Survival time (days)	Cause of death	Result
1	15	FA	7	sacrificed	patent
2	13	FA	3	sacrificed	occluded
3	19	FA	1	shock	patent
4	20	FA	2	unclear	patent
5	16	FA	33	sacrificed	patent
6	17	FA	92	living	patent
7	12	FV	2	thrombosis	occluded
8	13	CV	17	sacrificed	patent
9	15	CV	91	sacrificed	patent

As graft, the femoral artery (FA), the femoral vein (FV) or the cephalic vein (CV) were utilized. The longest patent survival time is 92 days in the femoral artery graft and 91 days in the cephalic vein graft.
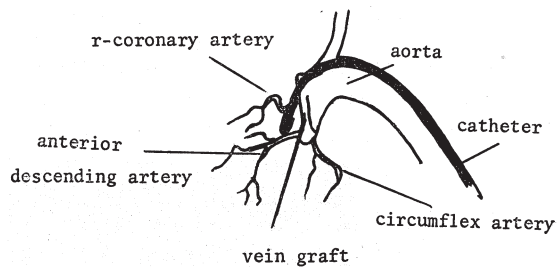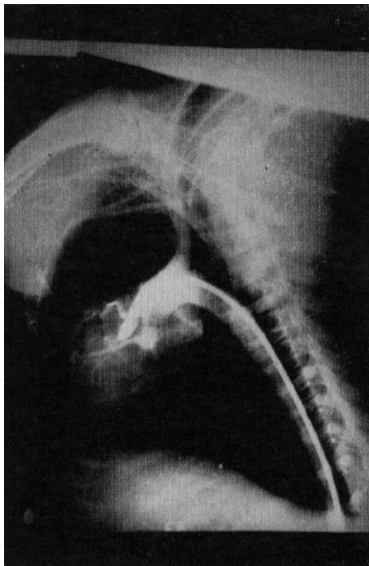

FIG. 8. Aortogram of the aorto-circumflex artery bypass graft using the cephalic vein after 91 days survival. Graft is opacified, and good filling of the distal circumflex artery is noted.

Seven of the 9 survived animals had a patent anastomosis at death or sacrifice. The patency rate was 77.7%.

One dog died of thrombus formation at the graft-circumflex artery anastomosis on the 2nd postoperative day. Another animal sacrificed after 3 days revealed occlusion of the graft-circumflex anastomosis caused possibly by intimal injury to the graft during operation. Otherwise all animals had a patent anastomosis after various periods of survival.

Fig. 8 shows a retrograde aortogram of a patent case taken on the 92nd postoperative day. Good filling of the distal portion of the circumflex artery is visualized.

Flow Rate: In 2 cases, flow study was performed. In dog No. 5 weighing 16 kg, the flow rate of the femoral artery graft was 50 ml/min. on the 30th postoperative day, and in dog No. 8 weighing 13 kg, the flow rate of the cephalic vein graft was 35 ml/min. 17 days after operation. By reactive hyperemia, the flow rate increased to 125 ml/min. (250%) and 80 ml/min. (228%) respectively (Fig. 9).
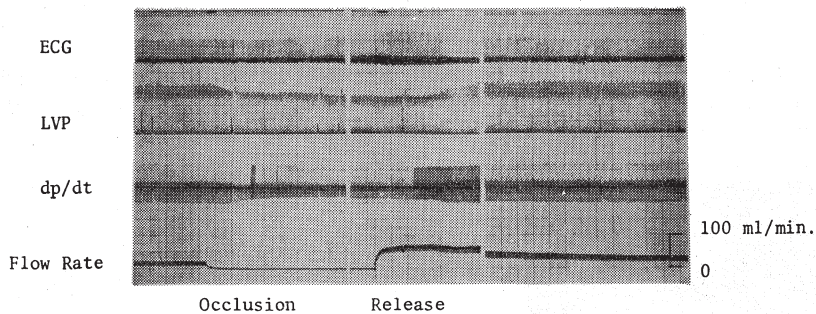

FIG. 9. Continuous recording of ECG, left ventricular pressure (LVP), dp/dt and flow rate of the aorto-circumflex artery bypass graft using the cephalic vein after 17 days survival in the dog No. 8. Augumentation of blood flow by reactive hyperemia is relatively low (228%).
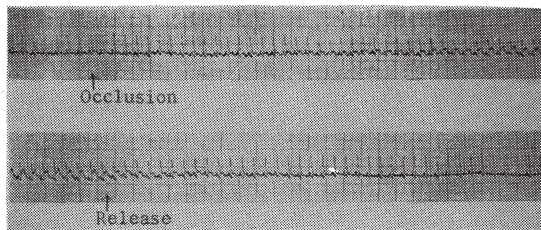

FIG. 10. Distinct elevation and return of the ST segment of ECG (aVf) by occlusion and release of the aorto-circumflex artery bypass graft using the femoral artery after 33 days survival in dog No. 5.

ECG changed distinctly by occlusion or release of the graft; a remarkable ST segment elevation was visible by occlusion and disappeared after release (Fig. 10).

Flow Pattern: A typical flow pattern of a long-term survival dog is shown in Fig. 6. In the vein graft, in systolic phase the flow once increased sharply corresonding to output, then decreased by left ventricular contraction to form a spike, the highest flow in the whole pattern, and remained relatively flat till the beginning of the diastolic phase. In diastolic phase, flow increased initially and decreased gradually. On the other hand flow pattern of the femoral artery graft showed almost the same as that of the vein graft except that flow decreased sharply below the zero level and formed a biphasic pattern at the end of the systolic phase.

Histological Findings: Sections were prepared from the aortograft anastomosis, the midportion of the graft and the graft-circumflex artery anastomosis.

In the femoral artery graft, intimal thickening and cellular infiltration were minimal, if any. At the anastomotic site there was minimal intimal thickening (Fig. 11).

In the vein graft, on the other hand, the intimal thickening of fibrocollagenous tissue was observed. Especially, the cephalic vein graft revealed rather thickened intimal layer 3 months following operation. But there was no cellular infiltration in any portion (Fig. 12).
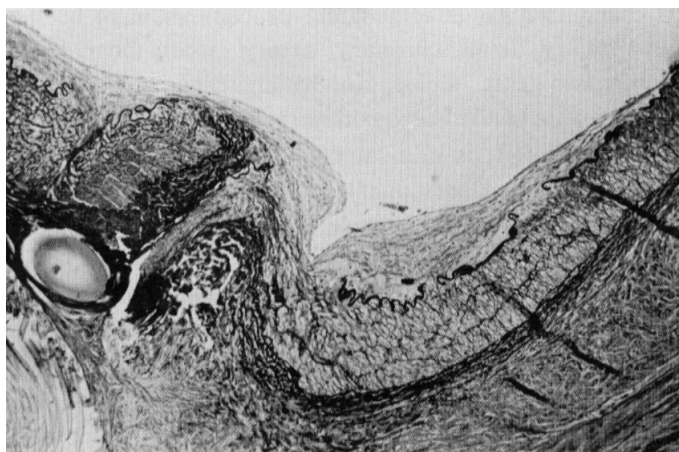

FIG. 11. Section of the anastomotic site between the femoral artery graft and the circumflex artery after 33 days survival in the dog No. 5. Minimal intimal proliferation is noted, but it seems to be caused by fibrin deposits at the anastomosis. At the midportion of the femoral artery graft no intimal thickening is noted. Elastica Van Gieson stain (× 100).
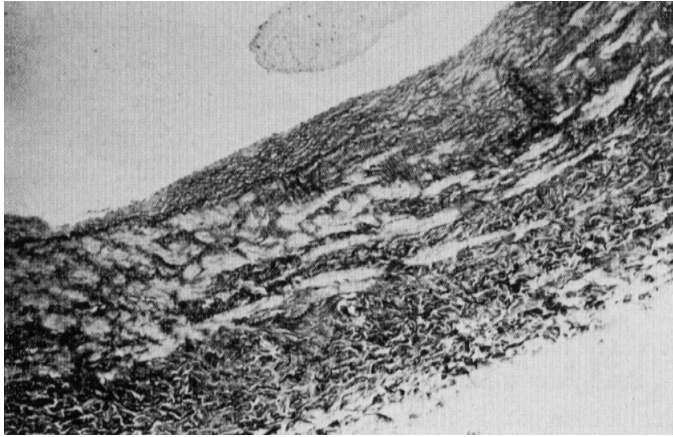
FIG. 12. Section of the midportion of the cephalic vein graft after 91 days survival in dog No. 9. Some intimal thickening is noted but thin. Venous structure is fairly preserved. Elastica Van Gieson stain (×100).

DISCUSSION

Recently, numerous clinical cases of direct coronary surgery were reported and evaluated. The results were almost acceptable clinically with relatively good patency rate and relief of preoperative symptoms [53][54].

In clinical cases, two kinds of surgical procedures have been carried out; the internal mammary artery-coronary artery anastomosis and the aorto-coronary artery bypass graft. Effler, Mundth and their coworkers [53][56] preferred the combined procedure of the aorto-coronary bypass graft with the Vineberg's implantation, and indicated its clinical usefulness. They avoided the internal mammary artery-coronary artery anastomosis for combined implantation.

On the contrary, Green and coworkers [11][57] indicated the absence of arteriosclerotic changes at small coronary arteries and have been using the internal mammary artery-coronary artery anastomosis in many clinical cases, and, recently, the procedure began to be applied to clinical cases in Cleveland Clinic, also [58].

In the internal mammary artery-coronary artery anastomosis, the anastomosis is carried out between two arteries, and only one anastomosis is necessary. On the other hand, in the aorto-coronary bypass, the anastomosis is carried out either between two arteries or between artery and vein according to the graft used and two anastomoses are necessary. Otherwise, there should be definite differences between these two procedures, and the main purpose of this report is to clarify these differences from a hemodynamical viewpoint.

Method of Anastomosis

As the method of anastomosis, direct suture or nonsuture technique has been undertaken in almost all reports. Davies and coworkers[59] reported a new method of "onlay graft" without intimal approximation, in which the coronary artery was severed and not sutured nor fixed to open the end of the vessel. As preliminary method, a modified Davies' method, shown in Fig. 13, was undertaken, in which four stitches were placed to open the incision site. Fourteen dogs were subjected to this procedure and only one case revealed patency in postmortem angiogram.

Direct systemic to coronary artery anastomosis in the dog was first reported by Murray and coworkers[3] in 1954. Direct systemic to the left circumflex artery anastomosis in the dog was first reported by Absolon and coworkers[34] in 1956. After then, many investigators have reported on various techniques. With these techniques, however, there has been considerable immediate operative mortality (38%) and only 28% of long-term survivors had a patent anastomosis[5) 6) 17) 20) 22) 25) 26) 29) 34)]. When nonsuture techniques were used in this procedure, the immediate operative mortality decreased to 24%, and the late patency rate improved to 44% [9) 10) 12) 18) 19) 30)].

There have been limited experiences with the interpolation of a graft between a systemic artery and the left circumflex artery in the dog. Only 36% of the animals were immediate survivors with only 7% of late patency of the graft[25) 29) 32) 34)]. Nonsuture techniques, though superior in patency, are difficult to utilize in the arteriosclerotic artery, most likely to be encountered clinically. Therefore, almost all cardiac surgeons have been performing direct coronary surgery with direct suture technique.

In the present study, operative mortality of the internal mammary artery anastomosis was 36% (8 of 22 dogs), and that of the bypass operation was 56% (18 of 32 dogs).

Acute occlusion of the canine left circumflex artery at its origin resulted in ventricular fibrillation in 85% or more of animals within 3 minutes, if no supportive measures are utilized[13]. The utilization of a nonsuture technique may permit construction of shunt in such a brief period. Construction of shunt with a suture technique, however, necessitates the use of some temporary supportive measures. Systemic hypothermia[31) 32)], selective cardiac hypo-
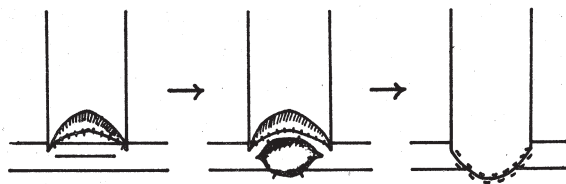

FIG. 13. New method of anastomosis without intimal approximation.

thermia[30], cardiopulmonary bypass[25][29][60], cardiopulmonary bypass with hypo-thermic cardiac arrest[26], and temporary internal bypass shunt[5][6][22][29][34] have been utilized with varying degrees of success.   Of the supportive measures described, the indwelling internal or temporary external shunt, as utilized in the present study, has been one of the most widely tested.   Actually, in clinical case, Arbulu[61] utilizes a "femoro-coronary shunt".

There appeared fatal ventricular fibrillations in relatively many dogs, either during the use of an internal shunt or just after removal of a clamp. Ventricular fibrillation during use of the shunt may be due to an inadequacy of coronary perfusion rate, while that at the removal of a clamp from the graft or the internal mammary artery seemed to be curious. This phenomenon, however, occurred very often and always under similar situations, generally when the anastomosis had taken a long time and the myocardium became possibly ischemic. Swell and coworkers[62] reported that ventricular fibrillation developed within twenty seconds after release of the artery in 6 of the 31 dogs, in which the flow was restored suddenly. Arnulf[30] said that the accident may be due to introduction of a highly oxygenated current of blood into an anoxic myocardial territory.   In the present study 4 animals fibrillated at reaccomplishment of blood flow.

Green and coworkers[48] said that the use of the operating microscope at 16 magnifications was essential to these anastomoses, and many other authors [63]~[65] recommended the use of binocular loupe of 2 to 4 magnifications.   In this experiment a loupe of 2 magnifications was used. The construction of a systemic to coronary artery anastomosis deep in a thoracotomy wound with a moving operative field (caused by the beating heart) hampers the use of the operating microscope, and a loupe fascilitated the meticulous anastomosis satisfactorily.

Sauvage and coworkers[32] reported occlusion rate of 81% (39 of 48 dogs) using the external jugular vein as a graft. This high incidence of thrombosis was thought to reflect technical problems associated with the use of an over sized venous graft.   Parenthetically, should such bypass grafts be considered clinically, a segment of the saphenous vein would be a logical choice, as this vein has a thick wall and is of about proper size.   In this experiment, dog No. 7, in which the femoral vein was used as a graft, revealed occlusion at the anastomosis which seemed to be caused by disproportion of the graft and the coronary artery. Since then the cephalic vein was used as grafts.

Perhaps the major obstacle to performing the systemic to coronary artery anastomosis is suture line thrombosis. An approach to prevention of thrombosis of the anastomotic site is anticoagulant therapy. In this study animals were heparinized immediately prior to performance of the anastomosis.   At the termination of the procedure, no neutralization was achieved. Post operative heparinization was not considered.

Selection of the canine left circumflex artery serves as a good test preparation for the construction of a systemic to coronary artery anastomosis for several reasons. This artery is the largest of the easily accessible coronary arteries in the dog, and it carries more blood than either the anterior descending artery or the main right coronary artery. The large size of this artery makes it preferable to other canine coronary arteries as a site for construction of such an anastomosis, for the technical difficulties of the anastomosis and the tendency to suture line thrombosis are minimized. Because of the relatively high flow rate of the left circumflex artery, its utilization is a more severer test of the patency of the anastomosis. Acute occlusion of the canine left circumflex artery within 0.7 cm of its origin results in death in 89% of animals; ligation of the artery 0.7 to 2 cm from its origin is fatal in 45% of animals[13]. It is apparent that postoperative failure of a systemic to left circumflex artery anastomosis becomes manifest readily in a majority of animals. In the present study anastomotic thrombosis resulted in death in one of nine animals of the internal mammary artery anastomosis group and one of nine animals of the bypass group. But nevertheless, two dogs survived for 28 and 153 days in spite of occlusion of the anastomosed internal mammary artery, and one dog in the bypass group for 3 days with a blocked graft.

Flow Study

As control, flow study was achieved with the normal circumflex artery in five dogs weighing between 12 and 18 kg. Flow rate ranged from 15 to 40 ml/min., and averaged 30 ml/min. Increment of flow rate by reactive hyperemia was 60 to 150 ml/min., and averaged 86 ml/min., that was 200 to 400% (averaged 292%).

Flow Rate: According to Ross[66], the circumflex artery carries 43% of the total coronary flow and its flow rate was 46 ± 4 ml/min. in the dogs weighing 25 to 30 kg. According to Hall and coworkers[12], blood flow through the internal mammary artery-circumflex artery anastomosis by nonsuture technique ranged from 31 to 118 ml/min. (average 68). In their reports, however, big dogs weighing 19.5 to 36.4 kg were used. Wakabayashi and coworkers[68] reported that average mean flow of the arterial grafts was 23 ml/min., whereas that of the saphenous vein grafts was 45 ml/min. But they did not describe body weight of dogs used. In the present study, flow rate of the internal mammary artery group was 15 to 30 ml/min. (average 24), while that of the bypass group ranged 20 to 50 ml/min. (average 31). These values were almost the same as each of the preanastomotic circumflex artery flow rate. In long-term follow-up study of the internal mammary artery anastomosis, flow rates of two dogs weighing 12 and 20 kg, were 25 and 30 ml/min., respectively. In the bypass group, 35 and 50 ml/min. were recorded in two animals weighing 13 and 16 kg. Previous reports indicated greater flow rate than in this ex-

periment.   The discrepancy would be due to differences in the body weight.
Actually, when the comparison is made at the same level of body weight,
these flow rates were nearly equal.   There may be no significant differences
between these two operative procedures in flow rate.

Flow Pattern: During isovolumetric contraction, the blood flow through
the intramyocardial branches is so impeded as to decrease almost to zero
usually, and to reverse occasionally.   These findings were observed both in
the internal mammary artery anastomosis and in the bypass graft immediately
after operation.   But in the long-term follow-up animals, the deceleration was
absent in the vein and artery graft, while flow decreased beyond the onset
of ejection in the internal mammary artery anastomosis.   This is one of the
characteristic findings.

When the blood is ejected from the ventricle, flow in the intact circumflex
artery is accelerated, but shortly after that an almost equally rapid decelera-
tion occurs.   These changes produce a "spike" in the coronary flow record.
During the remainder of the systolic phase, flow continues at a relatively
steady rate, which is slightly higher than that prevailing at the end of the
isovolumetric contraction period [66] [69].   In the present study, there were no
differences between flow patterns of the intact circumflex artery and those
of the bypass graft in the systolic phase immediately postoperatively.   In the
internal mammary artery anastomosis, the spike was distinct and flow decreased
rather rapidly to form a biphasic pattern.   In follow-up groups, the flow
patterns of the vein and artery graft resembled the immediately postoperative
pattern of the internal mammary artery anastomosis, and a prominent systolic
spike was characteristic.   In the internal mammary artery anastomosis, the
onset of acceleration was delayed and the spike was not the maximal flow in
contrast that the systolic spike was the maximal flow immediately after op-
eration.

According to Ross and coworkers [66], following closure of the aortic valve,
a rebound of the aortic blood column impinging upon the aortic walls produces
a small rise of pressure.   In conjunction with the continuing relaxation of the
myocardium, this results in rapid acceleration of flow through the coronary
arteries after which flow continues at a relatively steady level until the onset
of the next systole.   Soon after operation, the diastolic flow patterns of both
the bypass graft and internal mammary artery anastomosis were essentially
equal to the intact circumflex arterial flow pattern except that in the latter
the diastolic spike was not the maximal flow.   In chronic cases of the internal
mammary artery anastomosis, a relatively steady flow was observed in the
diastolic phase, which resembled the flow pattern of the normal circumflex
artery, and the diastolic peak was the maximal flow.   Urshel and coworkers [69]
reported that there was no significant difference in the flow through either
graft, which was anastomosed proximally to the ascending aorta, or the left

subclavian artery. In both, the peak flow occurred at the end of diastole and prior to the onset of the systolic isometric phase.

Results of the present study showed that in the bypass graft the peak flow appeared in the diastolic phase immediately after surgery, while it appeared in the systolic phase in long-term survivals. In the internal mammary artery anastomosis, the peak flow was observed in the ejection period soon after operation, but after some period, it occurred in the diastolic phase. Although the peak flow was noted at systolic or diastolic phase according to the bypass graft or the internal mammary artery anastomosis, the whole flow pattern became similar to each other in the follow-up groups. The most characteristic finding in flow patterns was the delayed onset of acceleration of systolic flow in the follow-up group of the internal mammary artery anastomosis. The phenomenon seemed to be curious and interesting, but the cause could not be clarified. Further investigation should be carried out to clarify this phenomenon.

Reactive Hyperemia: The flow augmentation of blood flow following release of a complete arterial occlusion is well known as reactive hyperemia. The response is the most distinct in the heart and augmentation of blood flow is noted at the minimum changes in systemic pressure or output. According to Ross[67], the marginally hypoxic state provides a mechanism for sensitive local autoregulation. The hypoxic cell may release chemical byproduct "adenosine" which acts on the smooth muscle in the walls of arterioles adjacent to the cardiac muscle cells and causes vasodilatation. Occlusion of 5 to 7 sec, was sufficient to elicit the maximum increases in stroke coronary flow rate, and the absolute value was essentially constant for any animal at any length of occlusion greater than this lower limit[71]. These augmentations occur within 5 minutes and longer occlusion failed to reveal the maximum increase[68]. Matsuda[68] described that the maximum increase of reactive hyperemia was about 300%. Goldman and coworkers[73] reported upon release of the aortic clamp after 30 minutes of anoxic arrest, that total coronary blood flow rose 253% above control levels. In the present study, augmented flow by reactive hyperemia of the normal circumflex artery was 60 to 150 ml/min. (average 86), which corresponded to 200 to 400% (average 292%).

In acute experiments, flow rate through internal mammary artery anastomosis increased from 30 to 115 ml/min. (383%) by reactive hyperemia. In the bypass graft, flow rate through the graft increased from the control value of 20 to 80 ml/min. (400%). In long-term follow-up group of the internal mammary anastomosis, flow rate increased from the control value of 30 to 50 ml/min. (167%). And in the artery bypass graft flow rate increased from 50 to 125 ml/min. (250%); in the vein bypass graft from 35 to 80 ml/min. (228%).

Hall and coworkers[12] reported that internal mammary artery flow rate increased 1.9 to 5-fold (average 2.3) after internal mammary artery-circumflex

artery anastomosis by nonsuture technique.   Sabiston[1] said that reactive hyperemic response after temporary occlusion of the saphenous vein graft occurred with flows increasing double or triple of the control values in the majority of patients.

Compared the results of this experiment with these reported values, in acute experiment they are almost acceptable as the same.   But in chronic cases flow augmentation by reactive hyperemia was rather low.   This may be caused by scar formation surrounding the vessel, as observed frequently in the long survived dogs.   Loss of elasticity due to intimal proliferation revealed in histological examination may be one of other causes. Khouri and coworkers[74] presented reduction of the amplitude of the flow pattern and great decrease of the peak reactive hyperemia with no affection of the coronary flow rate by partial constriction of the circumflex artery.   This decrease in reactive hyperemia was the first dynamic change observed when gradual occlusion was slowly applied to a coronary artery.   Decrease in reactive hyperemia may suggest the presence of stenosis distal to the flow probe, though angiographic examination failed to show any localized narrowing.

By reactive hyperemia, the systolic and diastolic flows are equally increased[20], and the initial increase was observed in the systolic phase.   The increase in systolic flow may be due in part to decreased myocardial contractility[71] (Fig. 14).

Moran[76] and Grondin[75] and their coworkers measured flow rate of the graft after aorto-coronary bypass graft and calculated peripheral resistance from flow increase following papaverin injection to the graft.   They pointed out its usefulness to suspect early patency.   Since flow augmentation by reactive hyperemia was observed at the minimal change of heart rate or blood pressure, it will be more useful to speculate on the peripheral lesion or early
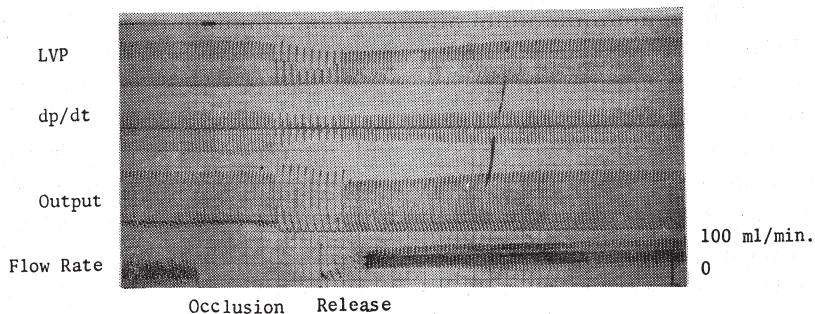

FIG. 14. Continuous recording of left ventricular pressure (LVP), *dp/dt*, output and flow rate of the aorto-circumflex artery bypass graft using the femoral artery.   Reactive hyperemic augumentation of blood flow is noted at first in systolic phase and later both in systolic and diastolic phases.

postoperative patency.

Histological Findings

In the internal mammary artery-circumflex artery anastomosis group and aorto-circumflex artery bypass group with femoral artery graft, the intimal proliferation was minimal. In the vein bypass group the intima became rather thick. Killen and coworker[13] reported complete healing of the suture line in dogs one year after the anastomosis of the internal mammary artery to the circumflex artery with direct suture. Good preservation of the internal mammary artery anastomosed to the coronary artery with nonsuture technique was reported by Hall[12] and Abe[4] and their coworkers. Wakabayashi and coworkers[68] reported minimal thickening of the intima both in artery and vein grafts. Dedomenico and coworkers[31] reported that the external jugular vein, used as graft, was found to show significant dilatation after a follow-up of $5\frac{1}{2}$ years. Sezai and coworkers[77] reported markedly fibroelastic hyperplasia in vein grafts of dogs. They used the femoral vein that is too large for coronary surgery. Disproportion of the coronary artery and the graft may be one of the causes.

This experimental study revealed rather thick intimal proliferation in the vein graft than in the artery graft or internal mammary artery anastomosis. Further investigation should be continued on these points. Since the fibro-muscular layer of the human saphenous vein is twelve times thicker than that of the canine vein[31], the dilatation of the vein would not be any greater and probably would be less. However, the intimal changes of clinically used saphenous vein should be evaluated in future.

CASE REPORT

Case 1. A 62-year-old man who had complained of anginal pain was admitted to University of Nagoya Medical Center on August 7, 1971. He had been treated medically and relieved from the complaint a year ago. He had been free from anginal pain prior to admission. On admission, there were almost no findings on physical and laboratory examinations except electrocardiographic changes suggestive of ischemia of the inferior wall. At that time, medical therapy did not relieve anginal pain. By selective coronary angiography the right coronary tree was found to be occluded at the main trunk. The left coronary artery was diffusely narrowed (Fig. 15). Soon after, ischemia advanced to infarction of the inferior wall while waiting operation.

On operation, February 15, 1972, the aorta and the right coronary artery were bypassed beyond the stenotic portion with a reversed autogenous saphenous vein graft. The proximal anastomosis was performed by continuous over and over suture with 5-0 monofilament nylon and the distal anastomosis by continuous suture on one side and intermittent on the other with 6-0
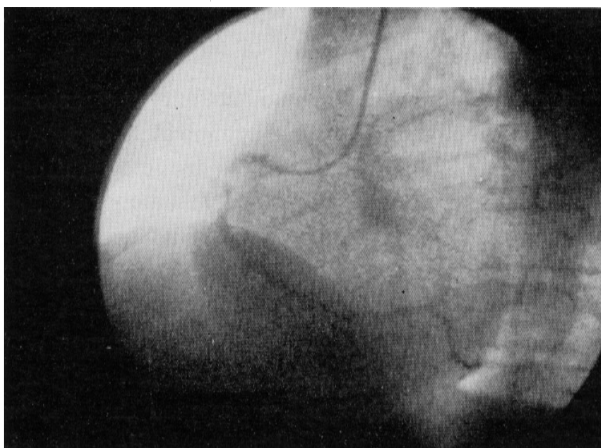
FIG. 15. Selective coronary angiogram by Sones' technique.
Proximal portion of the right coronary artery is occluded and
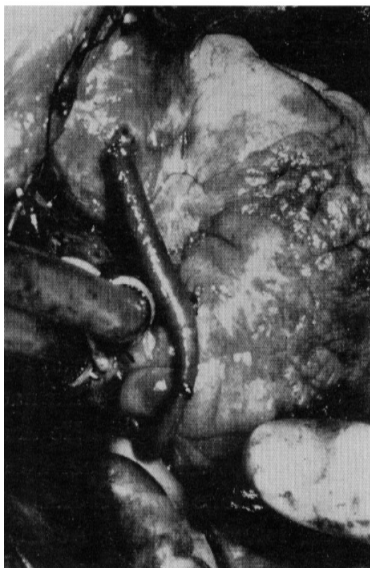good run-off is noted (case 1).

FIG. 16. Photograph in opera-
tion. The aorta and the right
coronary artery were bypassed
using the saphenous vein graft
(case 1).

monofilament nylon. All these procedures were performed under beating heart. There was no bleeding from incision of the right coronary artery and heart beat did not change by interruption of blood flow (Fig. 16).

Flow rate of the bypass graft was 30 ml/min. There were no complications in operation. On returning to the intensive care unit moderate hypotension and electrocardiographic changes of anteroseptal infarction were observed. Thereafter, the patient developed severe cardiogenic shock combined with bradycardia twice, which seemed to be due to atrioventricular block.

Marked acidosis was observed during the initial 12 hours postoperatively. Serum GOT increased markedly (482 u.) after operation and serum GPT and LDH also increased. Otherwise, the recovery was uneventful.

The electrocardiographic changes of antero-septal infarction improved gradually and old infarction pattern is visible at the present time. Chest pain has disappeared. He does not complain of heart.

Case 2. On August 16, 1972, a 44-year-old woman was admitted to University of Nagoya Medical Center for coronary surgery. She had been suffering from anginal attack for five monthes. Coronary angiography performed on June 19 revealed occlusion of the diaphragmatic portion of the right coronary artery. On admission, physical and laboratory examinations pointed out almost no findings. ECG during anginal attack showed depression of the ST segment in leads II, III and aVf. She experienced anginal attacks once or twice a day in spite of medical therapy.

On operation, September 5, 1972, the femoral artery, superior and inferior vena cavae were cannulated, and the extracorporeal circulation was achieved. After anoxic arrest, an induration was palpated on the right coronary artery about 2 cm proximal to the bifurcation of the posterior descending artery. The distal portion of the induration and the aorta were bypassed with a reversed autogenious saphenous vein. These two anastomoses were performed by interrupted suture with 5-0 and 6-0 monofilament nylon. Resuscitation was easy.

Flow rate of the bypass graft was 25 ml/min. and flow pattern of the bypass graft was the same as that of the coronary artery (Fig. 17).

Postoperative course was uneventful and serum GOT elevated slightly (94 u.) soon after surgery, and decreased gradually. ECG did not change. Chest pain disappeared, and she does not complain of heart at the present time.
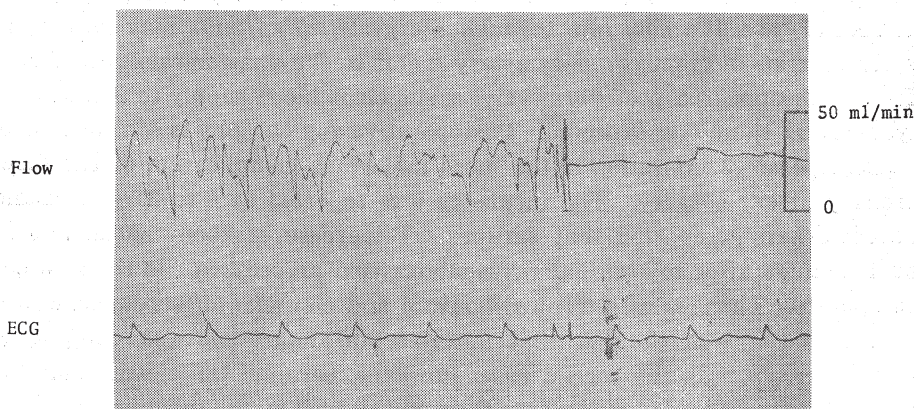

FIG. 17. Flow record in case 2. Flow rate of the bypass graft is 25 ml/min. and flow pattern of the bypass graft is the same as that of coronary artery.

COMMENT

In Japan, 23 cases of direct coronary artery surgery have been reported up to August 1972. One of them was the internal mammary artery-anterior

descending artery anastomosis[51], and the others were the aorto-coronary artery
bypass grafts[78]. In the present cases a reversed saphenous vein was used to
bypass the aorta and the right coronary artery. In case 1, the electrocardio-
gram at coronary angiography revealed only ischemic pattern of the inferior
wall, but while waiting operation Q wave appeared and ischemia advanced to
infarction. It might be more ideal for the operation to be performed before
infarction took place. Such cases have been reported[79][80], and direct coronary
operation is recommended as soon after coronary angiography. Lambert and
coworkers[80] said that cine-coronary angiography can be done safely in patients
with impending myocardial infarction. Emergency operations have not been
associated with any added mortality.

Of the graft anastomosed to the right coronary artery, flow rate was
reported as 9 to 165 ml/min.[48][76] Flow rates of 30 and 25 ml/min. measured
in the present cases, might be relatively low. According to Grondin and
coworkers[75], all grafts with flow of 20 ml/min. or less became occluded and
all grafts with flow greater than 45 ml remained patent. Johnson and co-
workers[54] said that the flow did not correlate closely with artery size but
rather with the disturbance of the recipient artery and the condition of the
myocardium. As the first patient developed hemiplegia possibly from cerebral
vascular accident on the 20th postoperative day, postoperative angiography
has not been done. Low flow rate in operation may show that vascular
resistance of distal artery was high and there were vast atherosclerotic changes,
althogh the distal portion was visualized well by coronary angiography. In
the second case, the flow rate through the graft, 25 ml/min., may be low due
partly to a small right coronary artery distal to the anastomosis. Since chest
pain has disappeared postoperatively, a sufficient blood supply to the ischemic
myocardium should be expected. Postoperative angiography is scheduled soon.

Postoperative infarction is the most important complication of the direct
coronary artery surgery. The incidence was reported as 9 to 20%[81]. Bailey
and coworkers[63] reported that serum GOT increase of about 130 u. was the
usual findings after myocardial revascularization procedures. In the first case
postoperative changes of electrocardiogram and elevation of serum GOT were
distinct and it was thought that antero-septal infarction was complicated
postoperatively. In the second case, however, serum GOT elevated slightly
soon after surgery and returned to the normal level by the third postoperative
day.

According to Favaloro[82], extracorporeal circulation is recently not used
in the bypass graft to the right coronary artery, and Mundth and coworkers[56]
insisted on the importance of use of the distal perfusion to decrease posto-
perative myocardial infarction[83]. But many surgeons who perform direct
coronary surgery under extracorporeal circulation do not use distal perfusion[38].
Reul and coworkers[84] reported safety of anoxic arrest in direct coronary

artery surgery. Arbulu[61] used a technique of "femoro-coronary shunt" that was used in this experimental study. If no electrocardiographic changes nor hypotension are observed after occlusion of coronary artery, it is thought better that bypass graft to the main trunk of the right coronary artery is performed under beating heart. In the second case, anoxic arrest was used and good result was achieved.

The cause of postoperative severe acidosis is not clear, but precise and careful postoperative care is necessary and indispensable. Especially in cases of the old age group, that are treated frequently, vascular lesion of central nervous system is an important complication.

SUMMARY

The internal mammary artery-circumflex artery anastomosis and the aorto-circumflex artery bypass graft with the femoral artery and vein, and the cephalic vein, were performed in dogs to evaluate hemodynamic characteristics and differences of these two procedures. These anastomoses were accomplished by direct suture technique under beating heart. To supply blood to the distal portion of the circumflex artery during occlusion for anastomosis, femoro-coronary shunt was utilized. Surgical results were evaluated immediately after operation and repeated at various intervals after operation.

Results from these experiments were as follows;

a) Immediately after operation, there were no differences in flow rate and reactive hyperemia between the internal mammary artery-circumflex artery anastomosis and the aorto-circumflex artery bypass graft.

b) In long-term survivors, the resting flow rate was comparable with normal circumflex arterial flow, but reactive hyperemic augmentation was less sufficient due possibly to scar formation surrounding the vessel or deficiency of elasticity of the vessel, as showen by histological examination.

c) Flow pattern of the bypass graft was essentially the same as that of the intact circumflex artery immediately after operation and even after long-term survival, though changed a little. On the contrary, flow pattern of the internal mammary artery anastomosed to the circumflex artery was characteristic and much different from that of the normal circumflex artery immediately after operation. In early systolic period, flow increased to the maximal level, and in diastolic phase, it stayed at a relatively low level. In long-term survivors, however, diastolic flow increased and the flow pattern came to resemble that of the normal circumflex artery.

d) Though there were some differences between these two procedures, no significant differences in hemodynamic effects were noted.

e) Reactive hyperemic examination of the vessel anastomosed to the coronary artery may be useful to estimate the pathological state of the distal

artery and prognosis of the anastomosis.

f) In clinical application of these procedures, the diameter of the internal mammary artery or the graft should match the diameter of the coronary artery, where anastomosis is proposed. Otherwise, thrombus formation at the site of anastomosis is most likely to occur.

Based on these results, the aorto-right coronary artery bypass graft technique was applied clinically to two cases with success.

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