

THE INFLUENCE OF EXPERIMENTAL ARTERIOVENOUS FISTULA ON THE DEVELOPMENT OF THE COLLATERAL CIRCULATION AND ON THE DEVASCULARIZED LIMB*

RYÔHEI KATO

*1st Department of Surgery, Nagoya University School of Medicine
(Director: Associate Prof. Itsuro Fukukei)*

ABSTRACT

The complicated features of congenital arteriovenous fistulas have emphasized the necessity for further study of collateral circulation to be developed around the fistulas.

Influence of an arteriovenous fistula on the collateral circulation and on the distal circulation in the involved extremity was investigated by means of angiography, electromagnetic flow meter, and venous occlusive plethysmography, in dogs with an experimental arteriovenous fistula created by side-to-side anastomosis between the femoral artery and vein. The results showed that the collateral development is rapid, requiring only one week to be significant. The distal circulation is reduced early in the postoperative period but later tends to be restored rapidly and sufficiently to 80% of the normal value concurrently with development of collateral arteries.

When an arteriovenous fistula is constructed just distal to the femoral arterial occlusion, the development of collateral arteries is more rapid and effective for the distal circulation than in the limb with arterial occlusion only. The dilated arteries of collateral pathways remain effective after closure of the fistula.

The beneficial and detrimental effects of arteriovenous fistulas on the devascularized limb were discussed.

INTRODUCTION

Arteriovenous fistula occurs as two types, congenital and acquired. The congenital type has usually multiple communications between the involved arteries and veins. The acquired arteriovenous fistula is due usually to trauma from bullet or puncture and has generally a single abnormal communication between artery and vein, but it can be induced surgically. This paper will concern the acquired arteriovenous fistula, since an understanding of the collateral circulation that develops in an acquired fistula can serve as a basis for understanding the complicated features of congenital fistulas.

加藤量平

Received for publication December 25, 1969.

* The summary of this investigation was presented at the 10th Congress of Japanese Angiological Society in 1969.

We have recently reported the hemodynamics of regional circulation which followed the establishment of femoral arteriovenous fistula^{1,2}. It was indicated that a femoral fistula brought about an increase in blood flow in arteries and veins proximal to the fistula, heavy networks of collateral vessels around it, and the impairment of circulation in the limb distal to the fistula. Increase in blood flow in proximal vessels has clinically been applied for maintenance of the patency of small arterial revascularizations and venous reconstructions. However, until recently, it was difficult to study the development of collaterals and distal circulation. The introduction of a new type of electromagnetic flow meter and mercury in silastic strain gauge plethysmography into this field has made it possible to evaluate quantitatively the influence of collateral vessels on the distal circulation in the limb with an experimental chronic fistula.

This experimental study was designed to deal with two problems; pathological physiology of collateral arterial vessels around the fistula, and effects of an arteriovenous fistula on the devascularized extremity.

I. Experimental Studies on Arteriovenous Fistula with Regard to the Development of Collateral Vessels and the Distal Circulation

METHODS

Ten adult mongrel dogs were used under sodium pentobarbital anesthesia (30 mg per kilogram of body weight). A side-to-side anastomosis, 10 mm in length, was made between femoral artery and vein using arterial 7-0 nylon sutures.

The morphological changes were observed by aortography carried out by injecting Urografin (Diatrizoate) via the contralateral femoral artery, immediately after surgery and then at certain intervals up to 15 weeks postoperatively. By means of angiographic studies on dogs with a femoral arteriovenous fistula, we have determined the patterns of development of collateral vessels.

Arterial blood flow distal to the fistula was determined by the electromagnetic flow meter with non-cannulating probes (made by Senko Med. Inst. Co.). Each probe was calibrated using a segment of artery previously excised, through which saline was irrigated at several flow rates.

Circulation in the lower extremity distal to the fistula was determined by the plethysmographic method described by K. Ito³. The plethysmography consisted of mercury in silastic strain gauge which was fitted around the paw, and a pressure cuff which was applied just below the knee, proximal to the strain gauge but distal to the site of arteriovenous fistula. Inflation of this venous collecting cuff was controlled by an electrically operated solenoid valve which permitted the passage of the air pressure from a large reservoir into the cuff. The average value from a series of several consecutive flow

measurements, each two minutes apart, was taken for comparison.

RESULTS

In this series, there were no instances of infection nor of occlusion of fistulas. The majority of dogs exhibited several typical signs of the fistula; dilatation and tortuosity of superficial veins, continuous bruit with systolic accentuation, palpable thrill, and some venous congestion and moderate edema of the extremity. The venous congestion and edema subsided gradually in 2 postoperative weeks.

Immediately after construction of a femoral arteriovenous fistula, angiograms revealed narrowing of the arteries both proximal and distal to the fistula and marked dilatation of the proximal vein. No collateral pathways were demonstrated (Photo. I. 1). One week after operation, there was well demonstrated a heavy network of dilated tortuous vessels, composed in part of smaller and finer arteries but mostly of larger veins in the thigh, where the fistula was produced, but the lower leg and foot did not have any such distended vessels (Photo. I. 2). Collateral arteries and veins were in parallel together and seemed to be pre-existing vessels. After 2 weeks, the arterial channels in tortuous collateral vessels developed more markedly than the venous, since there was a marked increase in diameters of arterial channels, contrary to a slight decrease in numbers of venous channels (Photo. I. 3). These extensive collateral arteries originated from the branches of lumbar, internal iliac, deep femoral and cranial femoral arteries, and ended to caudal femoral and genicular arteries. Angiography failed to show that the duration of the fistula stimulates strongly the development of collateral vessels up to 15 weeks postoperatively (Photo. I. 4). Therefore, the collateral arterial channels that in turn were the true collateral circulation and the part of the distal circulation, were established almost in two weeks. Furthermore, there was no regression of the collateral arterial trees, till several weeks after quadruple ligations of chronic fistula, in 3 dogs of this series (Photo. I. 5).

Blood flow in the collateral arteries was presumed by measuring the distal arterial flow with an electromagnetic flow meter, since the most portion of the blood in collateral arteries delivered from the proximal artery returned to the fistula by way of the distal artery. Blood flow in the distal artery was retrograde and toward the fistula, when the diameter of fistula was sufficiently large (10 mm). The results of the distal artery flow are charted in Fig. 1. Immediately after creation of a fistula, flow rates of the distal arteries in 5 dogs averaged 55 ml/min, ranging from 35 to 75 ml/min. In chronic fistula with abundant collateral vessels, the flow increased to an average of 310 ml/min, ranging from 200 to 500 ml/min. In every experiment, a dramatic increase in the flow through the collateral arteries was demonstrated. The flow increment appeared to depend upon the development of collateral vessels

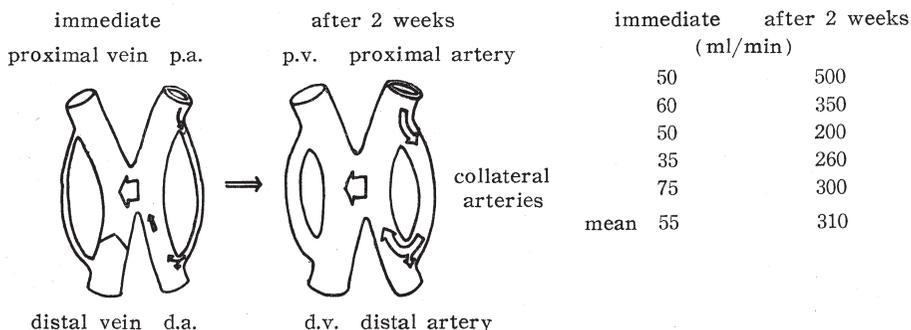
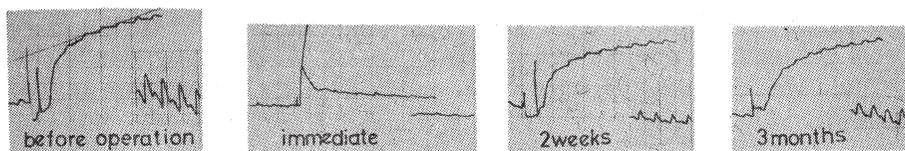


FIG. 1. Blood flow through the collateral arteries.

A) Plethysmogram



B) Blood flow (ml/min/100 ml of tissue)

1. Immediately after operation						mean
normal leg	12.0	18.0	15.0	16.0	8.0	13.9 ml
fistulous leg	—	5.5	3.0	3.0	—	— ml
% fist./norm.	—	30.5	19.4	18.7	—	— %
2. 2 weeks after operation						mean
normal leg	10.0	16.7	8.7	18.0	14.0	14.0 ml
fistulous leg	6.0	12.5	10.0	13.3	12.2	10.8 ml
% fist./norm.	64.0	75.0	115.0	74.0	87.0	78.5 %
3. 3 months after operation						mean
normal leg	10.0	15.5	14.2	10.0	13.3	12.5 ml
fistulous leg	8.2	10.6	11.0	9.2	10.0	9.8 ml
% fist./norm.	82.0	70.6	77.5	92.0	75.5	79.5 %

FIG. 2. Influence of arteriovenous fistula on the distal circulation.

as revealed by angiography.

The plethysmographic findings concerning the blood flow, pulse wave, and segmental pressure at the paw distal to the fistula, before and after induction of the fistula, are given in Fig. 2. Immediately after creation of the fistula, the blood flow below the knee of the involved extremity was reduced down to 0 to 30% of the control value obtained in the normal leg. Pulse contour was almost flat and the segmental pressure was too low to be measured. In the fistula of 2 weeks old, the blood flow in the distal part of the fistula returned to 78% of the control value, on the average, ranging from 64 to 115%. Pulse contour had a notch resembling that seen with the normal femoral artery, but it was lower in amplitude with a delayed peak time. Blood pressure in paw

rose also to 80 mmHg, as compared with 120 mmHg in normal. Serial plethysmographic investigation to 15 weeks revealed no remarkable progression in blood flow with the passing of the time.

COMMENTS

It has been noted that the collateral arterial response is rapid, requiring only one week to be significant and in somewhat limited extent. This observation is in contradiction to the classically accepted opinion that the passing of time is a most strong stimulant for the development of the collaterals, which is constantly progressive and extensive.

It is evident from the studies of blood flow in the lower extremities distal to the fistula that the distal circulation is reduced early in the postoperative period but tends to be restored rapidly and sufficiently 80% of the normal circulation.

II. Experimental Studies on Effects of Arteriovenous Fistula on the Devascularized Limb

The unique development of collateral circulation in the presence of an arteriovenous fistula in comparing with the paucity of its development in simple arterial occlusion has enabled surgeons to excise an arteriovenous fistula and thus to interrupt the main arterial channel without resulting gangrene. Consequently, it is difficult to escape the belief that the arterial collateral circulation developed around the fistula may contribute to revascularize the limb involved in obliterative vascular lesions.

METHODS

Fifteen mongrel dogs of either sex, weighing 10 to 20 kg, were anesthetized with sodium pentobarbital. Through a ventral thigh incision, femoral artery and its all branches (deep femoral, cranial femoral, caudal femoral and muscular arteries)⁴ were bilaterally exposed. The femoral artery (proximal to the ramification of the deep femoral and distal to the caudal femoral artery) was occluded by multiple ligations. Then, the deep femoral and cranial femoral arteries were ligated and divided. In the right leg a side-to-side 10 mm arteriovenous fistula was created between femoral artery and vein just distal to the end of the occlusion described above. The left leg of the occluded femoral artery without an arteriovenous fistula was control (Fig. 3). Two weeks

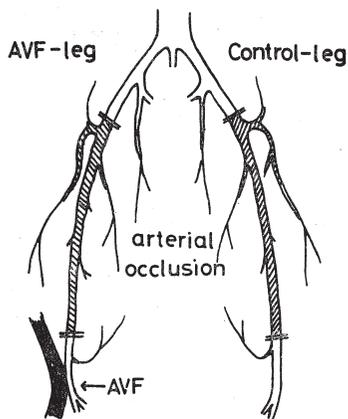


FIG. 3. Procedures of experiment II.

after the procedures, the right femoral fistula was re-explored and closed by triple ligations of fistulous limbs.

All animals were observed on the development of collateral vessels and improvement of distal circulation for 4 weeks. Formation of collateral vessels was studied angiographically. The arterial blood flow was measured in five dogs with the electromagnetic flow meter and the distal circulation was determined by the plethysmography prepared as described above.

RESULTS

In four of 15 dogs, the fistulas had been occluded at the time when they were re-explored 2 weeks after operation. In others, patency of fistula was proved by palpation for thrill at the site of fistula. Edema was more evident in the legs with the functioning fistula than in the control legs without the fistula. Venous congestion and edema subsided gradually after closure of the fistula, but one of the edematous legs developed a congestive ulcer.

Aortograms taken immediately after operation, showed no arterial trees in the thigh only except the internal iliac artery, and thus made sure of the completeness of femoral arterial occlusion. No difference was seen between in the fistulous legs and in the control legs angiographically (Phot. II. 1). After 2 weeks, there was a significant difference of the development of collateral vessels between the fistulous leg and the control. The fistulous thigh had abundant and tortuous collaterals and had the dilated popliteal and iliac arteries. The distinct visualization of the popliteal artery distal to the fistula indicated that the functioning collateral pathways were beneficial for the distal circulation. Collateral arterial channels originated from the internal iliac artery made a short cut by way of the popliteal artery to the venous system through the fistula (Photo. II. 2). Following closure of the fistula, aortograms showed no regression of the collateral bed nor decrease in the collateral circulation, and revealed a more widely dilated popliteal artery in the fistulous legs than in the control (Photo. II. 3).

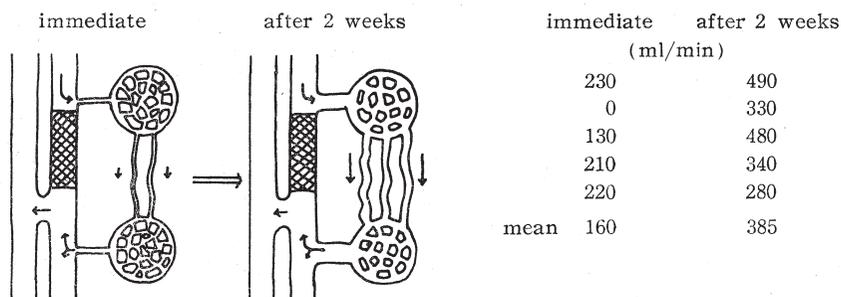


FIG. 4. Blood flow through the collateral arteries.

The results of flow studies using an electromagnetic flow meter on five dogs are shown in Fig. 4. Blood flow rate through the collaterals is equal to that through the artery distal to the fistula, since blood in distal artery is driven, on the whole, from the collateral channels, as far as the artery is ligated proximal to the fistula. Following creation of fistula, the distal artery was opened to flow toward the fistula. Early in the postoperative period, during which time the angiography noted no collateral channels, the flow rate in the distal artery averaged 160 ml/min. It was greater than the value obtained from the distal artery with the simple arteriovenous fistula as described in experiment I. Two weeks after opening off an arteriovenous fistula, the flow through the collaterals averaged 385 ml/min (the greatest value being 490 ml/min and the smallest 280 ml/min). Therefore, the collateral blood flow increased as much as several times during 2 weeks. While in the control legs, the arteries distal to the occlusion were thrombosed as far as the first branch of the popliteal artery and the flow rate remained so small as not to be measured.

The alterations in the distal circulation are charted in Figs. 5 and 6. Occlusion of the femoral artery reduced the blood flow in the lower extremity below the knee. The flow in the control legs averaged 5.3

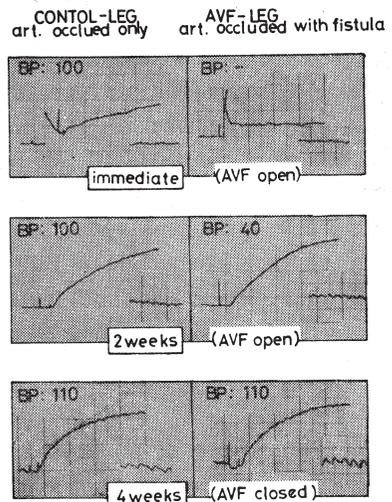


FIG. 5. Plethysmograms in devascularized limbs.

blood flow ml/min/100 ml of tissue						
1. Before operation						mean
normal leg	19.0	17.0	13.0	20.0	16.0	17.0 ml
2. Immediately after operation (fistula open)						mean
control leg	8.0	4.0	3.0	7.0	4.5	5.3 ml
fistulous leg	3.0	—	—	3.0	—	— ml
%, fist./cont.	37.5	—	—	42.9	—	— %
3. 2 weeks after operation (fistula open)						mean
control leg	11.0	8.0	12.0	15.5	7.5	10.4 ml
fistulous leg	13.0	7.0	18.5	17.0	12.5	12.9 ml
%, fist./cont.	109.0	87.5	154.0	109.6	166.7	123.9 %
4. 4 weeks after operation (fistula closed)						mean
control leg	11.0	7.0	15.5	11.3	9.4	11.0 ml
fistulous leg	12.0	13.0	18.0	18.6	14.0	15.1 ml
%, fist./cont.	109.0	186.0	116.2	164.5	149.0	144.9 %

FIG. 6. Distal circulation in devascularized limbs.

ml/min/100 ml of tissue (range 8.0 to 3.0) in comparing with the preoperative average 17.0 ml/min/100 ml of tissue. The addition of a fistula to the occluded femoral artery caused a significant decrease in the flow in the lower leg. The amount of flow was too small to be evaluate. After 2 weeks, when collaterals developed enough to take good function for the distal circulation, the distal blood flow in the fistulous leg increased in every instance except for one, ranging from 7.0 to 18.5 ml (average 12.9 ml). It was an increase by an average of 24% of the value obtained in the control legs. The development of collaterals in the control legs was poor and slow as shown angiographically. Segmental arterial pressure in the lower extremity below the knee was 100 mmHg in the control leg, but was 40 mmHg in the fistulous leg. The significant pressure gradient was originated from the additional fistula. Pulse contour became prominent in 2 weeks, but it showed still a lower systolic peak in both legs. After closure of the additional fistula, the distal pressure in the fistulous leg rose to 110 mmHg as same as in the control leg. Pulse contour in the fistulous side had a higher amplitude than in the other. The flow increment appeared to be progressive, regardless of closure of the fistula, in all experiments during this study. Moreover, the difference of the distal circulation in both sites became more significant. The average flow rate in the fistulous leg was 15.1 ml and 145% in the control leg.

COMMENTS

The effects of an arteriovenous fistula on the devascularized limbs were studied. It has been noted that the development of collateral arteries in the devascularized limbs with an arteriovenous fistula was more rapid and effective in the distal circulation than in the limbs without the fistula, and that the dilated arteries of collateral pathways remained effective after closure of the fistula. The pressure gradient induced by an arteriovenous fistula can increase the flow in collaterals and dilate the arterial trees. The increase in flow and the dilatation of artery can compensate the distal circulation more effectively.

DISCUSSION

1. Collateral Circulation

A most intriguing feature of an arteriovenous fistula is the abundant collateral circulation that develops around it.

What is the stimulus to the development of the arterial collateral circulation? Ried⁵⁾ proposed that the collaterals developed in response to the need of tissue distal to the fistula. Lewis⁶⁾ suggested that "a chemical stimulant" produced locally by the tissues deprived of adequate blood flow, affected the collateral vessels, resulting in further growth. Holman⁷⁾⁸⁾ had examined extensively on this problem, by constructing the fistula in limbs which had

been amputated distal to the fistula or by ligating the distal artery. He eliminated the possibility of stimulation by ischemic tissue and established the importance of retrograde flow in the distal artery. These mechanistic stimulation theories were supported by the studies of John and Warren⁹⁾, who suggested that the pressure gradient was the most important factor in developing the collaterals.

For the most part, the collateral arteries that respond to arterial occlusion in the human legs are pre-existing pathways. They are distributing branches from the large and medium sized arteries. It is only by virtue of the normal communications which exist between these arteries that viability is retained after an occlusion. Longland¹⁰⁾, separating the major components of collaterals into the stem, midzone, and reentry vessels, observed that at first relatively large stem and reentrant vessels anastomosed with fine straight vessels in the midzone, which are non-visible initially. As the collateral circulation improved, the greatest change in the arterial diameter occurred in the midzone arteries.

The major factors involved in volume flow across the collateral are the proximal driving pressure, the peripheral resistance, and the viscosity of the fluid. The viscosity and proximal driving pressure are critically not important for the flow through the collateral arteries. Induction of an arteriovenous fistula reduces the resistance of the reentry artery and brings out the greatest pressure gradient. The extent of the flow across the collaterals is determined by the resistance offered by the collaterals and the arterioles distal to the reentrant vessels. Therefore, an arteriovenous fistula increases the flow and spreads the extent of the collateral circulation most definitively.

Regardless of the underlying mechanisms, neural factors must in some way influence the physical factors that govern fluid flow. Deterling *et al.*¹¹⁾¹²⁾ pointed out that the sympathetic denervation in the limb involved in an arteriovenous fistula had greater effect in opening up collateral circulation than the elapsing of time alone.

Generally, in the presence of large fistulas, the collateral channels function as part of the fistulous circuit, which includes the distal artery. The stimulus for opening the collaterals and their continued development is the maintenance of large pressure gradient across the collateral circuit.

2. Distal Circulation

To quote Holman, "All avenues of approach to the fistula open to appease, as it were, the thirst of the fistula"¹³⁾. Hence with the flow in collateral channels directed towards the region of low resistance the distal tissues may be deprived more effectively of active circulation by large peripheral fistula in a lower extremity, than that would be following ligation.

To gain a better understanding of the circulation distal to the fistula, some measurements have been made for the comparison between the fistulous and

non-fistulous legs. Using venous occlusion plethysmography, Robertson *et al.*¹⁴⁾ studied the distal circulation in the limbs involving 2 weeks to 7 months old fistulas. As the fistulas were opened, the limb flows became lower than the normal, but when the fistulas were occluded, it showed a striking increase to the level above the normal, establishing the collateral circulation. Wakim and Janes¹⁵⁾, using venous occlusive plethysmography, studied the distal circulation in 4 patients after repair of acquired fistulas and in 7 patients before and after creation of femoral arteriovenous fistulas for the treatment of short extremities. After the fistulas were constructed, blood flow below the knee was reduced by 5% to 56%. After repair, blood flow increased by 9 to 53%. Strandness *et al.*¹⁶⁾ used a mercury in silastic strain gauge to study the digit volume pulse and segmental limb pressure gradient in 3 patients with acquired arteriovenous fistulas. There was distinct pressure drop across the fistula and diminution of amplitude of the digit volume pulse.

Using I¹³¹ rose bengal, Poupart *et al.*¹⁷⁾ found that blood turnover rates in the tibia of dogs with femoral arteriovenous fistulas were reduced after creation of the fistula. The larger the fistula was, the less the tibial flow was. Eight weeks after the operation, the values increased approaching normal. Henrie *et al.*¹⁹⁾ by monitoring the equilibration curves of radioactive iodinated human serum albumin concluded that the arterial blood supply was reduced in limbs distal to iliac arteriovenous fistulas.

Skin and muscle temperatures serve as indirect indices of the blood supply distal to the fistula. The skin temperature¹²⁾ in the region of the fistula is usually elevated. Distal to the fistula, the temperature tends to be lower. The temperature within the calf muscle¹⁸⁾ in the limb involved in chronic femoral arteriovenous fistulas may rise above normal, it is due probably to the dilated venous collaterals and, to a lesser extent, the arterial collaterals in the vicinity of the fistula.

3. Clinical Use of an Arteriovenous Fistula

Peripheral arteriovenous fistulas have been used for a number of years in children to decrease a discrepancy of leg length due to childhood disease^{20) 21)}. More recently fistulas have been utilized for increasing the blood flow through the replacements and for maintaining the patency in vascular reconstruction^{22) -27)}. The use of specially designed small peripheral arteriovenous shunts as an aid to the chronic dialysis of uremic patients is now in common^{28) 29)}.

As a result of circulatory alterations by an arteriovenous fistula—especially high flow rate^{30) 31)} and abundant collateral formation, some benefits for the revascularization of ischemic extremities³²⁾ would seem to be expected. As the first attempt, the effect of high rate of flow on the patency of small arterial reconstruction has previously been investigated in our laboratory by

using an arteriovenous fistula in the repair¹⁾³³⁾. A significant improvement in the immediate and late success rate of the procedure was obtained.

As the second attempt, an arteriovenous fistula has been constructed with an effort to provide the beneficial effects of collateral growth for the distal circulation in the devascularized limbs. The theoretic disadvantage of this technics is that blood flow can be directed into the venous system at the expense of distal arterial circulation. This technics aggravates rather than relieves the ischemic changes. Experiment I studies on the development of collaterals around the fistula, however, indicates that the distal circulation is restored to 80% of the control, concurrently with the development of collaterals early in the postoperative period. Furthermore, an arteriovenous fistula distal to the arterial occlusion induces more abundant and effective collateral arteries in the devascularized limbs, as reported in our experiment II. These works offer the evidence for supporting the clinical application of an arteriovenous fistula for the treatment of ischemic and unreconstructable arterial occlusive disease.

The challenge, then, in the clinical use of this technics of revascularizing the ischemic limbs is threefold, for 1, maintaining the perfusion of the arterial bed distal to the fistula, 2, avoiding hypertension of the venous system, and 3, avoiding the regression of collateral circulation after closure of the fistula. Immediately after induction of a fistula, the fistula deprives the blood from the distal tissue, which is not yet compensated by the collateral flow. Impairment of distal circulation is a detrimental effect of an arteriovenous fistula, but is very short in duration, probably less than a few days. Consequently, it must be ingeniously examined to restore the distal circulation disturbed shortly after the operation, for example, controlling of shunting volume by the fistula-size, reduction of the peripheral resistance induced by sympathectomy, oxygenated hyperbaric treatment³⁴⁾, and some others.

Venous congestive edema is one of the complications of an arteriovenous fistula. Clinically, the greater saphenous vein is the ideal drainage system and it can be sacrificed with impunity. If it is ligated distal to the fistula or anastomosed by the mode of Y, no hypertension should be produced in the venous system of the lower part of leg. The utilization of subcutaneous vein for the fistula permits ready control by digit pressure or ready exposure for closure of the fistula.

Bosher³⁵⁾ had demonstrated that following excision of an arteriovenous fistula, there was a regression of the collateral bed over a period of months in some instances. This would seem logical in view of the decreased demand for blood flow through these collateral vessels following excision of the fistula. The present study, however, indicated that the fistula decreased the most part of pressure gradient, but occlusion of the proximal artery retained the rest part of it maintaining the demand for blood flow in the distal tissues. If the

regression takes place slowly over a period of months, it will allow for a more gradual adjustment of needs of the circulation and will be less likely to produce a sudden effect. It must be pointed out that the changes, herein reported, up to two weeks after closure of the fistula do not mean final and stable values. Five dogs in this experiment are still alive and will be used for further study.

ACKNOWLEDGEMENTS

The author wishes to express his thanks to Associate Prof. I. Fukukei for criticism, Dr. T. Takao for kind guidance, K. Ota for cooperation, and K. Ito for technical assistance.

REFERENCES

- 1) Takao, T., Kumagai, T., Iino, S., Osuga, N., Naiki, K., Oiwa, S., Hibi, Y., Kondo, M., Onogi, H., Kidokoro, H., Matsunaga, Y., Takeuchi, T., Yamashita, H., Yamada, Y., Asai, T., Ito, K., Kato, R., Tarumi, H., Ota, K., Nishiwaki, T., Yano, T., Koike, R., Kachi, N., and Tsai, B., Experimental studies on arteriovenous fistula, *J. Jap. Coll. Angiol.*, **9**, 71, 1969 (in Japanese).
- 2) Ota, K., to be issued.
- 3) Ito, K., to be issued.
- 4) Miller, M. E., *Anatomy of the dog*, W. B. Saunders Company, Philadelphia, 1964, p. 370.
- 5) Ried, M. R., Abnormal arteriovenous communications, acquired and congenital, *Arch. Surg.*, **10**, 601, 996, 1925, **11**, 25, 237, 1925.
- 6) Lewis, T., The adjustment of blood flow to affected limb in arteriovenous fistula, *Clin. Sci.*, **4**, 277, 1940.
- 7) Holman, E., Problems in the dynamics of blood flow. 1. Conditions controlling collateral circulation in the presence of an arteriovenous fistula, following the ligation of an artery, *Surgery*, **26**, 889, 1949.
- 8) Holman, E., *Abnormal arteriovenous communications, peripheral and intracardiac, acquired and congenital*, Charles C. Thomas, Springfield, Ill. 2nd ed., 1968, p. 90.
- 9) John, H. T. and Warren, R., The stimulus to collateral circulation, *Surg.*, **49**, 14, 1961.
- 10) Longland, C. J., The collateral circulation of the limb, *Ann. Roy. Coll. Surg. Eng.*, **13**, 161, 1953.
- 11) Deterling, R. A., Essex, H. E., and Waugh, J. M., Arteriovenous fistula; Experimental study of influence of sympathetic nervous system on development of collateral circulation, *Surg. Gynec. Obstet.*, **84**, 629, 1947.
- 12) Deterling, R. A., Essex, H. E. and Waugh, J. M., Experimental studies of arteriovenous fistula with regard to the development of collateral circulation, *Proc. Staff. Meet. Mayo Clin.*, **22**, 495, 1947.
- 13) Holman, E., Arteriovenous fistula; dilatation of artery distal to the abnormal communication, *Arch. Surg.*, **18**, 1672, 1929.
- 14) Robertson, R. L., Dennis, E. W. and Elkin, D. C., Collateral circulation in the presence of experimental arteriovenous fistula, determination by direct measurement of extremity blood flow, *Surgery*, **27**, 1, 1950.
- 15) Wakim, K. G. and Janes, J. M., Influence of arteriovenous fistula on the distal circulation in the involved extremity, *Arch. Phys. Med.*, **39**, 431, 1958.
- 16) Strandness, D. E. Jr., Gibbons, G. E. and Bell, J. W., Mercury strain gauge plethysmography, evaluation of patients with acquired arteriovenous fistula, *Arch. Surg.*, **85**,

- 215, 1962.
- 17) Pauporte, J., Lowenstein, J. M., Richard, V. and Davison, R., Blood turnover rates distal to an arteriovenous fistula, *Surgery*, **43**, 823, 1958.
 - 18) Ingebrigtsen, R., Krog, J. and Lerraand, S., Circulation distal to experimental arteriovenous fistulas of the extremities; a polarographic study, *Acta Chir. Scand.*, **125**, 308, 1963.
 - 19) Henrie, J. N., Johnson, E. W. Jr., Wakim, K. G. and Oruis, A. L., The influence of experimental arteriovenous fistula on the healing of fractures and on the blood flow distal to the fistula, *Surg. Gynec. Obstet.*, **108**, 591, 1959.
 - 20) James, J. M., The effect of a surgically introduced arteriovenous fistula on bone growth, *Proc. Staff. Mayo Clin.*, **27**, 335, 1952.
 - 21) Bialostozky, L., Lazcano, M. A. and Barrón, J. O., Creacio de fistula arteriovenosa en el tratamiento de las de longited en miemvros inferiores, *Arch. Inst. Card. Mex.*, **37**, 276, 1967.
 - 22) Root, H. D. and Cruz, A. B., Effects of an ateriovenous fustula on the devascularized lirimb, *J.A.M.A.*, **191**, 645, 1965.
 - 23) Blaisdell, F. W., Lim, R. C., Hall, A. D. and Thomas, A. N., Revascularization of severely ischemic extremities with an arteriovenous fistula, *Amer. J. Surg.*, **112**, 166, 1966.
 - 24) Blaisdell, F. W., Lim, R. C., Hall, A. D. and Thomas, A. N., Reconstruction of small arteries with an arteriovenous fistula, *Arch. Surg.*, **92**, 206, 1966.
 - 25) Inokuchi, K., Yagi, H., Tanigawa, S., Kusaba, A. and Masuda, M., Femoropopliteal thromboendarterectomy with popliteo-saphenous arteriovenous shunt, *Operation*, **22**, 27, 1968 (in Japanese).
 - 26) Osselaer, G. V., Ponette, E., Geest, H. D. and Stalpaert, G., The influence of automatic vascular suturing and arteriovenous shunting on the patency of small dacron grafts in dogs, *J. Cardiovasc. Surg.*, **9**, 170, 1968.
 - 27) Bryant, M. F. Jr., Lazenby, W. D. and Howard, J. M., Experimental replacement of short segments of veins, *Arch. Surg.*, **76**, 289, 1958.
 - 28) Quinton, W., Dillard, D. and Scribner, B. H., Canulation of blood vessels for prolonged hemodialysis, *Trans. Amer. Soc. Artif. Inter. Organ.*, **6**, 104, 1960.
 - 29) Scribner, B. H., Burt, R., Cner, J. E. Z., Hegstrom, R. and Burnell, J. M., The treatment of chronic uremia by means of intermittent hemodialysis, a preliminary report, *Trans. Amer. Soc. Artif. Inter. Organ.*, **6**, 144, 1960.
 - 30) Shenk, W. G. Jr., Bahn, R. A., Cordell, A. R. and Stephens, J. G., The regional hemodynamics of experimental acute arteriovenous fistulas, *Surg. Gynec. Obstet.*, **105**, 733, 1957.
 - 31) Shenk, W. G. Jr., Martin, J. W., Leslie, M. B. and Portin, B. A., The regional hemodynamics of chronic experimental arteriovenous fistulas, *Surg. Gynec. Obstet.*, **110**, 44, 1960.
 - 32) Omura, Y., Experimental studies on the cross anastomosis of peripheral arteriovenous system, *J. Nagoya Med. Ass.*, **81**, 1, 1960 (in Japanese).
 - 33) Koike, R., Iino, S., Kumagai, T., Naiki, K., Oiwa, S., Hibi, Y., Kondo, M., Onogi, H., Matsunaga, Y., Kidokoro, H., Takeuchi, T., Asai, T., Ito, K., Kato, R., Nishiwaki, T., Ota, K., Tarumi, H., Yano, T., Tsai, B. and Takao, T., Significance of blood flow in reconstructive arterial surgery —Experimental studies—, *J. Jap. Coll. Angiol.*, **9**, 359, 1969 (in Japanese).
 - 34) Kidokoro, H., Clinical studies on hyperbaric oxygen therapy for peripheral vascular diseases, *J. Jap. Surg. Soc.*, **69**, 429, 1968 (in Japanese).
 - 35) Boshier, L. H. Jr., Harper, F. and Bigger, I. A., A study of the collateral circulation after excision of arteriovenous fistula, *Surgery*, **26**, 918, 1949.



1)



2)



3)



4)



5)

- 1) Immediately after operation: Note the visualizing of venous system, and no collateral vessels.
- 2) After one week: Showing a heavy network of collateral vessels, fine straight arteries and dilated veins.
- 3) After 2 weeks: Note the dilatation of arterial channels and the diminution of numbers of veous channels.
- 4) After 15 weeks: Indicating that the development of collateral circulation is not constantly progressive as the passing time.
- 5) After the quadruple ligations of a chronic fistula: Demonstrating that the closure of the fistula would not reduce the collateral circulation.

PHOTO. I

Experiment I. An arteriovenous fistula at the middle of the thigh.



1)



2)



3)

- 1) Immediately after surgery: Illustrating the completeness of the femoral arterial occlusion.
- 2) After 2 weeks: Note the development of tortuous and dilated collateral arteries and the dilatation of int. and ext. iliac arteries in fistulous leg (right), as compared with the control leg (left).
- 3) After closure of the fistula: Note the excellent filling of the dilated popliteal artery, and no regression of the collateral vessels.

PHOTO. II

Experiment II. An arteriovenous fistula distal to the femoral arterial occlusion.