An Experimental Study on the Effect of Crossing Anastomosis Between Femoral Artery and Vein

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Introduction

The treatment of peripheral circulatory disturbances, especially of the occlusive nature, has not been accomplished satisfactorily. Amputation of the affected limb secondly to demarcation of necrotic tissue had been believed to be the only effective treatment for those occlusive diseases for years, but rapid growth of vascular surgery after World War II made it possible to attempt direct surgical approach to the vascular system itself. E. Key is the surgeon who made the first successful embolectomy on acute occlusive arterial disease in 1923. Since then numerous experiments and attempts concerning the direct surgical approach to the peripheral vascular system have been reported. Thus embolectomy has now become one of the most common and reliable surgical treatments for such occlusive diseases with relatively good results. It must be remembered, however, that there are many unsolved problems remaining in the treatment of peripheral vascular diseases.

For the treatment of acute and chronic arterial occlusive disease, high or low lumbar sympathectomy has been attempted in order to increase collateral circulation, which turned out to be quite effective in some cases. Other surgical methods employed for the treatment of occlusive arterial disease are as follows: transplantation of autogenous vessels or synthetic tube grafts, thromboendarterectomy, vascular suturing, etc. The above mentioned surgical approaches are not always possible technically, especially when the vessels are not big enough, as in peripheral regions. They usually run into difficulty if the affected regions are found below the popliteal artery. Here it becomes important to analyze why surgical approach to the small vessels are not easy, and to consider how this problem can be resolved.

First of all, the low flow rates through the graft caused by small capacity of the vascular bed usually results in clotting. In order to avoid clotting, it is important to
make proper choice of surgical equipment, especially suturing materials and type of
scissors in addition to unerring skill to reconstruct the small vessels. Secondly, synthetic
tubes used for repairing peripheral vessels cause more or less foreign body reactions,
which result in clotting. Long-term follow up data on use of synthetic tube grafts in small
sized arteries have been proven to be less indicative of longterm patency. Thirdly,
occlusive arterial diseases are usually progressive in symptoms, and their clinical courses
become prolonged. It is of course much more desirable, if the disease can be treated
and cured less traumatically without transplanting foreign bodies such as synthetic tube
grafts.

The above mentioned problems can be overcome to some extent by improving materials,
instruments and surgical techniques, but it seems to be almost impossible to ameliorate
synthetic tubes so that they might cause absolutely no antigen-antibody reaction. Although
there are still some problems which require further investigation, statistical studies on
experimental and clinical reports and evidences so far available have led us to the conclu-
sion that autogenous tissues are more suitable for the material of anastomosis than any
kind of synthetic products.

Based upon the above described idea, "the reconstructive bypass operation" has been considered. The outline of the
technique of an arteriovenous anastomo-
sis using the great saphenous vein
is shown in Fig. 1 and 2.

In an attempt to avoid clotting which
may occur in the attached vein, two
different techniques are employed: one
is to connect the distal end of the great
saphenous vein with the proximal end
of the femoral artery, and the proximal
end of the former with the distal end
of the latter. The other is to remove
all the valves located in the dissected
piece of the vein by turning the vessel inside out. (Fig. 1 & 2). Various other techniques
have also been tried, but other reconstructive bypass methods of the vessels have been
proven to be inadequate because they require a long skin incision.

In 1962, K.V. Hall made the first improvement in this connection, which is known as

![Fig. 1 Blood circulation](image1.png) ![](image2.png) ![](image3.png)
the "modern reconstructive femorotibial bypass operation". His method is characterized by using autogenous vein graft \textit{in situ} instead of synthetic tube graft. The follow up data was compiled with fairly good results in 1963. Every one of the deep communicating branches in the region was tied up, and end to side anastomosis between the anterior tibial artery and autogenous vein graft \textit{in situ} was performed, which resulted in normal blood flow in the capillaries from the arterial side. It is to be noted that M. E. DeBarkey, \textit{et al.} criticized Hall's method. Their arguments are concentrated in two points, that it would tend to produce arteriovenous fistula and that functional disturbances of the lower extremities might be caused after such a big surgical invasion.

I have decided, therefore, that it will be worthwhile to consider the possibility of the direct femoral arteriovenous anastomosis (AVA). In this connection, A. K. Amir-Jahed, in Canada, reported a paper in 1966 on his experiment, in which it is reported that the reversal of flow was achieved by an end to end arteriovenous anastomosis between the superficial femoral artery and vein with or without rupturing the venous valves, and with or without lumbar sympathectomy. He performed the experiment on 44 dogs and each case presented a definitive reversal of the flow in the veins and venules.

Looking at the anatomical, physiological and pharmacological point of view, however, there are many questions left over being unresolved with regard to the venous system. For instance, the question as to whether or not the venular wall has an active contractility has not yet been settled, although, there is a general agreement as to the fact that the vascular wall in the venous system is thinner than that in the arterial system.

The aims of the present experiment are: (1) to discover whether arterialization in peripheral small veins has an effect of hemodynamic changes in its controlled area, and (2) to investigate the histological and histochemical changes from the femoral vein to the capillaries after a given period in order to find a key for surgical treatment of arteriosclerosis and Böger's disease.

\textbf{Experimental methods and materials}

Twenty healthy adult mongrel dogs, each weighing 8 to 18 kilograms, were used for this experiment.

Left single end to end AVA was performed on fifteen dogs between the proximal end of the superficial femoral vein and distal end of the femoral artery. The proximal end of the vein and the distal end of the artery were ligated. Contralateral femoral artery and vein were not touched, and the venous valves were left intact in all cases.

There were five dogs, on which a left superficial femoral artery and vein were ligated,
The right hind limb is kept intact for control. The left limb is operated to complete single AVA (arteriovenous-anastomosis).

Fig. 3

The left superficial femoral artery and vein were ligated individually in the left hind limb.

Fig. 4

and right superficial artery and vein were left intact because of the technical failures of the end to end anastomosis. The study plan and procedures used were shown in Figures 3 and 4. Anesthesia was attained with 30 mg pentobarbital sodium per kilogram injected intravenously, and no artificial respiration was attempted. In all cases we used the Elp-needle, and nylon thread which is usually used in plastic surgery for anastomosis. Heparin was used locally during the surgical procedure of anastomosis. For each case, postoperative angiography was performed by retrograde catheterization of the superficial femoral arteries of the control side within 2 months of the operation.

The angiography was taken under the following condition. Puls : 7/120, 51 Kvp, 100 mA, using 76% Urografin 10 cc; time : 5’, 10’, 15’.

Histological study was also done with the arterialized segments of veins and muscles lying below the parts of anastomosis from both extremities one or two months after the operation. Specimens were stained using Hematoxlin Eosin stain, Azan’s stain, Van Gieson’s stain and Elastica VanGieson’s methods.

In order to ascertain the gross changes observed, we used simple circumferential measurements to indicate degree of swelling or edema at the following four levels; knee, ankle, the uppermost part of the thigh and the middle part of the thigh. Before performing end to end AVA, the diameter of the vessels were measured in order to ascertain the relationship between the blood circulation and the diameter of the vessels. The greatest diameter of ecchymosis and necrosis in the lower extremities was also measured when such pathological changes were observed. As the basis for comparisons, the control limbs were measured preoperatively as well as postoperatively and later references were made to the circumferences of the control limb.

The following data was checked with each experimental adult dog: (1) the femoral arterial pressure, (2) the pressure in the lowest distal region of the great saphenous
vein, (3) the pressure at the lowest distal part of the great saphenous vein which was blocked at the femoral vein, (4) the pressure in the distal part of the great saphenous vein after the blockage of the femoral artery and vein was accomplished, (5) the pressure in the distal part of the great saphenous vein soon after the AVA was made, (6) the pressure in the distal part of the great saphenous vein after forming the stricture in the part of AVA.

Results

Figure 5' offers a synopsis of the results arranged according to the circumference of the operated limb and the postoperative days. Figure 9 shows the relationship between postoperative symptoms and frequency.

Thirty limbs (15 dogs) were available for complete investigation. Three out of the earlier 20 dogs died by anesthetic failure and two dogs also had to be eliminated because of deaths on the second postoperative day. In these cases, marked swelling of the operated limbs were observed.

Swelling: As judged from the increased circumference of the limbs on the operated side, swelling of variable degree was present in all cases with AVA. Swelling of variable degree generally increased day after day for the first three postoperative days, but it disappeared almost completely between the seventh to ninth postoperative days. The maximum swelling was observed either on the second or third postoperative day.

![Swelling Graph](attachment:image)

**Fig. 5'** shows the change of circumference of the operated limbs after completion of AVA. Swelling was higher in large stoma of AVA than small sized AVA, however, swelling subsided 4 days after surgery and returned to preoperative level between the 10th and 11th postoperative days. + represent good patency and large sized stoma of AVA, • represent small sized or obstructed cases of AVA.

<table>
<thead>
<tr>
<th>Compare</th>
<th>No.</th>
<th>%</th>
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<tr>
<td>Swelling</td>
<td>C ≥ 1.2 c</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>≥ 1/5C</td>
<td>1</td>
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<tr>
<td></td>
<td>≥ 1/4C</td>
<td>1</td>
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**Fig. 9** C : Postoperative circumference of the limb  
c : Preoperative circumference of the limb

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The maximum increase reached about 1.5 times the postoperative circumference. Although it is generally believed that contralateral limbs will not be affected by the operation, we observed temporary postoperative swelling of contralateral limbs lasting for three days in several cases.

**Diameter of the vessels to be anastomosed:** When the vessels to be anastomosed measured more than 4 mm in diameter maximum swelling of the limbs was observed, and 2 dogs weighing 18 Kg each died on the first postoperative day. With small dogs whose vessels measured less than 2 mm in diameter stricture at a part of AVA was noted in all cases, but no mortality was recorded as the result of stricture.

The experiment was most successful with medium-sized dogs whose femoral vessels measured between 4 mm and 2 mm in diameter. Satisfactory blood circulation to the periphery through the reconstructed bypass was observed with each case.

**Effect on walking:** Some difficulty on walking was naturally observed in all cases, as being expected preoperatively, which was particularly true with the dogs whose limbs were badly swollen for the first three days after surgery. This disadvantage, however, disappeared gradually.

**Necrosis of the skin:** Necrosis of the skin at the lower part of the leg near the ankle was observed with one case, but the necrotic skin had nothing to do with the operative wound. No evidence of necrosis was observed with the rest of the experimental dogs.

**Ecchymosis:** No evidence of ecchymosis was proved with any dogs except for one which died on the first postoperative day.

**Skin temperature:** No significant changes of skin temperature measured at the lower extremities were recorded in all cases after the AVA was completed.

**Blood pressure:** Changes of blood pressure at the lowest distal region of the great saphenous vein were as follows.

1. The femoral arterial pressure of the adult dog was 120/80 mmHg (see Fig. 11).
2. The femoral venous pressure was 11/9 mmHg (see Fig. 12).
3. The pressure at the lowest distal region of the great saphenous vein after the blockage of the unilateral femoral vein showed 70 mmHg.
4. The pressure at the lowest distal region of the great saphenous vein after the blockage of the unilateral femoral artery showed 70 mmHg to 25-30 mmHg (see Fig. 13).
5. The pressure at the lowest distal region of the great saphenous vein immediately after the AVA showed 70 mmHg and then shifted down to 20 mmHg after a while; the pressure then rose finally reaching a plateau of 70-60 mmHg (see Fig. 14.
6. The pressure at the venous segment when AVA was closed recorded 12-13 mmHg line (Fig. 16).

Venous pressure was always measured at the lowest peripheral region of the great saphenous vein. Upon ligating (or blocking) unilaterally the femoral vein, the pressure jumped from the usual level of 9-11 mmHg to 70 mmHg and then the pressure was kept at the same level. When the blood flow of the femoral artery was cut off, the pressure then leveled down from 70 to 25-30 mmHg.

Upon completion of the AVA immediately the pressure elevated to 70 mmHg, which was close to the lowest range of normal pressure 80 mmHg. The pressure, however, dipped down to 20 mmHg five or six minutes after the completion, but it again elevated up to the level of 60-70 mmHg, where the pressure was stabilized henceforth. The peripheral venous pressure of the obstructed blood vessel after the AVA showed 12-13 mmHg, which showed a reading 2-3 mmHg higher than the normal pressure.

**Angiogram**: An angiogram taken 2 months after surgery proved it to be a good blood flow through the AVA to the venous field. It was observed that the subcutaneous venules in the thigh had been markedly developed, forming a plexus, and they looked as if they had been arterialized. (see Fig. 17) These small vessels were spread over the muscular layers supplying nourishment. The development of these vessels were seen more in number at the thigh than at the leg, where it was not so intensive as to form a plexus. The circulation of the blood, therefore, was less intensive in the leg. In the venous field, the blood return depended on the small vessels developed in the lower extremities and on the vein which had not been influenced by the AVA.

**Histological changes**: Fibrous thickening of the tunica media was observed histologically with some of the medium and small sized arteries six months after the operation if good patency had been obtained. Not in any case could evidence of intimal thickening be detected in the artery, but a thrombus had been formed in some of the medium and small sized arteries with complete recanalization through the center of the thrombus. Growth of the vaso vasolum and the revascularization of the capillaries were seen in the connective tissue, particularly in the subcutaneous connective tissue of the thigh.

In regard to the medium or small sized veins; no thickening of the tunica intima was detected, but hypertrophy and thickening of the smooth muscle in the tunica media were observed. Thickening of the intima and the increase of endothelial nuclei were found to be true with venules. It was also noted that many capillaries were proven to exist in the connective tissues around the small veins. The muscular tissues in the thigh appeared
normal throughout, but a portion of the muscles in the leg demonstrated some dystrophic changes (see Fig. 18, 18a, 18b, 19, 20, and 21).

In the obstructed cases, growth of the subcutaneous capillaries was seen in the thigh and in the peripheral field, but it was smaller than nonobstructed cases. Bleeding in a part of the connective tissue was also observed.

The table of histological changes in artery and vein after AVA

<table>
<thead>
<tr>
<th>histological changes</th>
<th>medium sized artery</th>
<th>small artery</th>
<th>arterioles</th>
<th>medium sized vein</th>
<th>small vein</th>
<th>venules</th>
<th>capillary</th>
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</thead>
<tbody>
<tr>
<td>increase of endothelial nuclei</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>#</td>
<td>#</td>
</tr>
<tr>
<td>hypertrophy and thickening of tunica intima</td>
<td>–</td>
<td>–</td>
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<td>#</td>
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<tr>
<td>hypertrophy and thickening of tunica media</td>
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<td>+</td>
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<td>+</td>
<td>+</td>
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<tr>
<td>hypertrophy and thickening of tunica adventitia</td>
<td>–</td>
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<td>–</td>
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<tr>
<td>increase of vaso vasolum</td>
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<td>#</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>–</td>
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</tr>
<tr>
<td>bleeding in the connective tissue</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>#</td>
<td>#</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>bleeding in the intravascular wall</td>
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<td>–</td>
<td>–</td>
<td>#</td>
<td>#</td>
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<tr>
<td>thrombus in the vascular cavity</td>
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<td>#</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>#</td>
<td>–</td>
</tr>
<tr>
<td>recanalization of the vessels</td>
<td>#</td>
<td>#</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>increase of capillaries in the connective tissue</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>#</td>
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Fig. 10 Remarks:  
– no significant change, + some minor change,  
# considerable change,  # marked change.

Histological investigation of the femoral artery measuring more than 4 mm in diameter demonstrated intimal thickening and the increase of endothelial nuclei. The external elastic layer had been torn off together with part of the intima and the tunica media, which resulted in hemorrhaging in the intra-wall space as well as in the external space of the vessels (see Fig. 22, 23). The thrombus in the internal surface of the vessels was gradually organized pathologically. No abnormalities of the vessels were reported in the medium or small sized vessels or the capillaries.

As for the muscular tissues of the lower extremities, some muscular atrophy or muscular degeneration was detected in all the cases, but, of course, the severity of the pathological changes were different individually (see Fig. 24, 25.).
Discussion

The significance and purpose of making the AVA is to supply more blood to the peripheral ischemic tissues and organs below the obstruction. Therefore it is most important to keep good patency throughout the AVA in order to assure good blood circulation to the periphery.

There are three major factors for the formation of thrombus in the AVA:

1. Changes in velocity of the blood flow.
2. Changes of the vascular form.
3. Changes of the blood contents.

In regard to changes of the blood flow, it is absolutely impossible to avoid the influence, because the AVA itself causes considerable changes of the blood flow, but it is possible to eliminate the influence to the minimum if the utmost effort is paid not to cause any unnecessary changes of the blood flow by constructing AVA gently and carefully. For example, attentions must be paid not to compress the operative field, particularly the part of the AVA so that a compression thrombus may be avoided. It is basically required to block natural blood flow for a short while in order to complete the anastomosis during the procedure, but Chatteergée's method, the temporary bypass method using teflon tube in AVA seems to be effective to shorten the time of blocking the natural circulation.

As for changes of the vascular form, it is quite natural that the vessels of large bore do not make stenosis in the part of AVA, since excessive suture bites and tissue trauma would not easily affect the larger vessels.

W. Andrew-Dale reported a paper in which he made careful and worthwhile investigation on the reasons causing postoperative vascular obstruction in cases of anastomosis. He pointed out many technical errors committed unconsciously during surgery such as; stretching too tightly, twisting, constricting, making too small stoma, causing stenosis below graft, and so on.

The vessels measuring between 2 and 4 mm in diameter kept good patency of AVA as mentioned previously. In some cases, however, obstruction developed but those obstructive changes took place immediately after the operation.

It is presumed that the vessels with a caliber of less than 4 mm may be coated inevitably with a fibrin lining sooner or later.

Arthur N. Thomas contended that tubes less than 4 mm in diameter were unsatisfactory, and that at the six month follow-up examination, the venous segment of the fistula was closed in all instances. But in six out of eight cases followed up that far, the
proximal arterial segment had remained patent functional. On the other hand, Karl Viktor Hall\textsuperscript{11}, concluded that ten thrombosed bypass veins had a caliber of less than 4 mm and the rate of success would have been higher if saphenous veins with a caliber of less than 4 mm had not been employed. I presume that the vessel with a caliber of 4 mm is the smallest in performing AVA if ordinary operative techniques are used.

The vessels less than 2 mm in diameter are technically inadequate for anastomosis. It is technically difficult to perform anastomosis with ordinary suturing methods, and even if the AVA is technically successful, an obstruction by clotting can not be avoided. The obstruction or stricture in the vessels resulting in poor peripheral flow rate which inevitably will form a thrombus. Another important problem is to find out how the venous valves act in the formation of thrombus when AVA is completed.

J.K. Amir-Jahedi\textsuperscript{1} noted in his experiments that the presence of the intact venous valves did not seem to be a permanent obstacle to reversal flow. He reported that rupturing the venous valves was not only unnecessary but even harmful, since it would damage the intima of the vessel. I, therefore, did not rupture the venous valves in this series of experiments.

Swelling or edema in the extremity after the operation is another important consideration in making the femoral artery-vein crossing anastomosis \textit{in situ} and it is necessary to analyze it from various points.

In an attempt to know the relationship between the blood flow and the diameter of the vessels, we measured preoperatively the diameter of the vessels on which AVA was to be performed. The dogs with vessels measuring more than 4.5 mm in diameter died within 24 hours of the surgery with a high degree of swelling on the operated side as shown in Figure 5'.

From the theorem of Bernoulli, the blood flow $Q$ is in proportion to the product of

\[
S_1V_1 = S_2V_2
\]

$1/2 \rho v^2 + \rho gh + P = \text{constant}$

(from the theorem of Bernoulli)

Flow $Q = S_1S_2 \sqrt{2 (P_1 - P_2)/(S_1^2 - S_2^2)}$

Fig. 28
blood velocity $V$ and the cross section of the vessel $S$ ($Q = VS$). On the contrary, the blood flow $Q$ is in inverse proportion to the peripheral resistance of the blood flow $R$. $P$ is the blood pressure, and $\rho$ is the density of the blood flow (Fig. 28).

If the blood pressure is 150 mmHg and the cross section of the vessel is 4 or 5 millimeter in diameter, the blood flow is within the limits of 500 to 1000 ml per minutes. We can then assume that the peripheral resistance in the venous system in less than that of the peripheral arterial system as the elasticity of the arterial wall is greater than that of the venous wall. Then, the blood flowing into the venous segment will probably circulate more rapidly because the peripheral venous resistance is decreased and the expansion of the venous cross section with AVA may be done.

The excessive arterial blood flow in the venous segment naturally predispose swelling of high degree in the periphery. This venous stasis of high degree in the lower extremities causes imbalance of blood circulation and exerts considerable influence on the heart. I presume that some dogs died of shock caused by this.

In conclusion, it is necessary to study further on problems of metabolic and circulatory balance immediately after the operation lest imbalance of circulation should arise.

In several cases, temporary swelling was observed on the contralateral limb. This phenomenon is explained as a result of an alteration of relative increase and decrease in blood flow circulation, because such an alteration of blood flow in one limb exerted much influence upon the opposite limb.

It is interesting to know that G. Johnson and others reported in 1966 that venous occlusion caused a significant increase in flow in the other non-occluded side of limbs, and that the venous system gave a marked influence upon the arterial flow.

Although his methods and materials are some what different from those of mine, Arthur N. Thomas pointed out that the flow rates through the arteriovenous fistula of 500 to 1000 ml per minutes were tolerated by dogs weighing 15 to 20 Kg and this rate was obtained by using a 4 mm tube for the venous segment of the fistula. Indeed, Thomas in another paper notes that a fistula measuring 5 mm in diameter can be tolerated without danger to the heart, and this is approximately the diameter of the great saphenous vein of the human being.

However, in my opinion, the vessels measuring about 5 mm in diameter in dogs, if they are used for transplantation, they may place too much burden on the heart of the animals. With respect to swelling in the lower extremities, all successful cases with satisfactory patency developed swelling of high degree on the operated side of the limbs. This
phenomenon was caused by the postoperative venous stasis secondary to the rapid arterial blood flowing into the venous segment. We then assume that a new bypass circulation will be created and completed in 7 to 8 days postoperatively, when swelling may almost completely subside.

Swelling in the lower extremities usually disappears within four to five days if good patency is secured. It is presumable that the circulation is resumed as a result of newly developed shuntings between the venules and the arterioles, numerous in number, and the development of the collateral ways of the venous system.

Henry Haimovici⁹ stated that the existence of the arteriovenous shunting was seen in many vascular diseases, and in the case of varicose vein shunting, it appeared to be rather a secondary growth than congenital. He also found that in the postphlebitic syndrome, short circuiting of the arterial blood might be responsible for ischemic disorders further complicated by venous stasis manifestation.

Ordinarily, the blood flows from the arterial segment to the venous segment, and the shunting is made as the form of arteriovenous shunting. But I presume that venous-arterial shunting in the capillary area will be completed as opposed to the arteriovenous...
shunting. V-A shunting is different from the case of the varicose vein (see Fig. 7 & 8).

In attempt to ascertain the above facts, I measured the blood pressure of the distal part of the great saphenous vein of dogs and found that it was kept constant at the range of 70 mmHg when we blocked the unilateral femoral vein alone. When AVA was completed, the blood flowed from artery to vein through AVA, and the pressure immediately jumped up to 70 mmHg. The blood pressure again receded to 20 mmHg, but after a while it gradually rose up and remained constant at 60-70 mmHg. This means that strong resistance is induced passively by the stasis of the blood flow until satisfactory collateral ways are established. The fact that the venous pressure immediately rises to 70 mmHg upon completion of AVA and then recedes temporarily to 20 mmHg indicates that the rapid outflow of the blood into the saphenous vein through the AVA causes sudden expansion of the vascular wall and massive stasis of the blood.

They consequently cause sudden elevation of the venous pressure, and that the establishment of collateral circulation after while takes the load off the venous wall resulting in the temporal decrease of the venous pressure. This relatively long period of low pressure is associated with (a) the combination of the elasticity of the venous wall which decreases the resistance against the blood flow, and the temporary stasis of blood circulation, and (b) the opening of collateral ways in one of the lower extremities.

The pressure again ascends from 20 mmHg to 70 mmHg as described previously, which is close to the pressure recorded immediately after the ligation of the femoral vein. This means that the blood circulates throughout the peripheral part of the lower limb maintaining the level of the systemic arterial pressure. When obstructions takes place at a part of the AVA, the pressure usually goes down to approximately 13 mmHg, which is close to the normal pressure of 11 to 13 mmHg on the distal part of the unaffected great saphenous vein. It means that sufficient collateral ways have been completed between the arterioles and the venules.

Necrosis and ecchymosis of the skin was observed only in one case. In that case the subcutaneous venules were extremely developed so as to form a plexal net work. Arterialization of those subcutaneous venules might have caused ecchymosis and necrosis of the skin. This was proven to be true at the time of postoperative angiogram and postmortem examination.

The small vessels were found to be more in number, as well as in density, in the thigh than in the legs, permeating into the tissues in order to supply nourishment (Fig. 26). The newly established and well organized plexal networks not only prevent the muscles of the thigh from atrophy, but even hypertrophy of the tissues of the thigh,
resulting in increased circumference of the affected limb.

Systemic review of what has been observed and studied so far allows us to present a hypothesis on the blood circulation circle after the completion of AVA as described below.

A chart of inferred blood circulation after establishment of AVA.

Thrombus in small arteries — small arteries — arterioles
V-A shuntig tissue
Femoral artery — AVA — femoral vein — small vein — capillaries
Other veins — small vein — subcutaneous venules — tissue
                   tissue —— newly built plexal networks
                                          which seemed to be arterialized.

Fig. 6' Arrows indicate directions of blood flow.

It can be said that the presence of hypertrophy and thickening of the tunica media in medium and small sized arteries after completion of AVA indicates that short circuits between small arteries and small veins have been created. Angiographic examinations demonstrate evidence of blood flow even to peripheral small veins. Histologically approved increase of endothelial nucleus in venules and thickening of intima of veins substantiate presence of arterial blood flow into those small vessels of venous nature. Rejuvenescent capillaries in connective tissues suggest that circulating blood may flow from small veins to subcutaneously located venules and then from venules which have been arterialized back to the proximal.

Here it becomes a problem that absolute blood volume circulating through the newly built passageway is not sufficient to nourish the entire lower extremity if the blood pressure is kept low. A question may be raised, "How much blood volume and blood pressure are maintained in the capillary phase and in the field after flowing through the venous arterial fistulae?" We have observed a few cases of muscular atrophy of the legs. Further investigation is therefore required in order to resolve these problems.

In cases of secondary obstruction after completion of AVA, tissues in the lower extremity are nourished by two vessels, which are formed slowly over a long period of time; one is branched from the external iliac artery and the other from the internal iliac artery (see Fig. 27). These reconstructed vessels usually penetrate into tissues like plexal networks around the obstruction. The above mentioned is conjectured from the fact that development of subcutaneous arterioles, thickening of the intimal wall of capillaries and increase of endothelial nuclei are detected in the thigh.
In some cases bleeding was noted in the space of intravascular wall and in the extra-
vascular tissues (see Fig. 23, 24, & 25). The bleeding thus encountered was caused by
tearing of the vascular wall especially of the tunica media vasolum; that is, the vessels
could not stand against the sudden increase in pressure of circulating blood upon the
completion of AVA.

Laceration of the vascular wall was often encountered when the diameter of the anasto-
mosed vessels were larger than 5 mm because the blood rushing into the anastomosed
vessel was more in quantity and stronger in pressure. It was also observed that obstruc-
tion in a part of the AVA caused such an elevation in blood pressure that even a laceration
of the tunica media of the femoral artery in the neighboring area above the AVA
was brought about.

In all cases in which obstruction was encountered after AVA, other collateral vessels
were reconstructed in the thigh, but they were not enough in number and quality to
nourish the tissues in the thigh satisfactorily, and consequently muscular atrophy was
sometimes recognized.

Summary

The effect of femoral artery-vein crossing anastomosis on the peripheral circulation and
the venous wall was studied with dogs. The results are summarized as follows:

1. It is presumable that blood circulation after completion of AVA seems to flow rever-
sely from capillaries to venules and growth of some shuntis between arterioles and
venules is postulated.

2. Branches of external and internal iliac artery develop downward on the operated side
of the lower extremity forming a kind of plexal network after completion of AVA.
When good patency is obtained, the rate of growth and the area covered by new
vessels seems greater than otherwise.

3. It seems almost certain that the complete venous collateral ways may be established
within seven days of operation.

4. There is evidence, if good patency is secured, of blood circulation with reasonably
strong blood pressure from the part of AVA to the distal part of the great saphenous
vein.

5. The subcutaneous capillary phase in the lower extremity, especially in the thigh,
grows as compensation for the obstructed vessels. Consequently, the venular wall is
thickened and arterialized vessels function as arterioles.

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6. It usually depends upon diametral size of anastomosed vessels whether AVA is successfully completed or not; Vessels measuring 4 to 5 mm in diameter are found to be most adequate for this purpose. Those with a diameter of more than 5 mm seem to disturb peripheral blood circulation and often cause malfunctioning of the heart.

7. An attempt to make AVA of small vessels, especially when the caliber of the anastomosed vessels is less than 4 mm usually fails because of a low rate of blood flow, which most likely causes inevitable obstruction in the vascular lumen.

8. Operative results in AVA will be considerably improved if unnecessary physical or chemical irritation can be absolutely avoided during operative procedure and post operatively.

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References


The pressure in the femoral artery in dog is from 120mmHg to 80mmHg.

Fig. 11

In case of obstruction after AVA, the venous pressure in the great saphenous vein is from 12 to 14 mmHg.

Fig. 16

Fig. 14