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SELECTIVE ANGIOGRAPHY OF COLLATERAL VESSELS IN LIMBS WITH AN EXPERIMENTAL ARTERIOVENOUS FISTULA[1]

By

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The present investigations were undertaken in correlation with studies of the changes induced by arteriovenous fistulas in the growth and structure of immature canine bone (9). The overgrowth produced by an arteriovenous fistula appears to be a function of the local changes in hemodynamics. Nonetheless, there is still confusion as to the exact nature of these changes. In vivo angiograms of arteriovenous fistula presented in the literature to date represent the combined image of the arterial and venous vascular trees, which opacify simultaneously because of the fistula. Exceptions are angiograms presented by *Boscher and co-workers* and by *Doumanian*. We have performed selective and bilateral phlebography and arteriography in dogs with a femoral or iliac arteriovenous fistula. We wish to stress a few controversial observations that we made with this method and to point out that the hemodynamics of arteriovenous fistula deserve further consideration.

METHOD

A side-to-side arteriovenous fistula (AVF) was induced between the right superficial femoral vessels in seven puppies 3 to 4 months old and in four adult dogs. One additional puppy had a right iliac AVF. The fistulas were identical, each measuring 1.5 cm. in diameter. The anasto-

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mosis was secured with 00000 silk while the vessels were bathed in heparin solution. All four branches of the AVF were patent at the end of the procedure. The presence of a thrill was observed at weekly intervals. With the AVF functioning, aorto-arteriography and saphenous phlebography were performed at times ranging from 1 to 18 weeks after creation of the AVF. Dogs were anesthetized and a catheter was threaded under fluoroscopic control through the left carotid artery to a level in the aorta a little above the iliac bifurcation. Then 30 ml. of methylglucamine diatrizoate (Renografin) was injected under a pressure of 100 pounds per square inch and a roentgenogram taken 1 to 3 seconds after completion of the injection.

Phlebography was performed in both legs simultaneously with the aid of a T-shaped catheter inserted in both saphenous veins. On four occasions the needles were oriented distally in order to direct the opaque medium toward the deep veins of the foot.

Each AVF was then closed surgically by transvenous arteriorrhaphy and aorto-arteriography was repeated 15 minutes after closure or 1 to 3 weeks later in the manner described above.

Fig. 1.

Angiogram made 2 seconds after injection of opaque medium into abdominal aorta. Arterial tree is visible in both limbs. At site of AVF (top arrow) medium has passed into venous tree and has already reached distal end of tibia (double arrow).

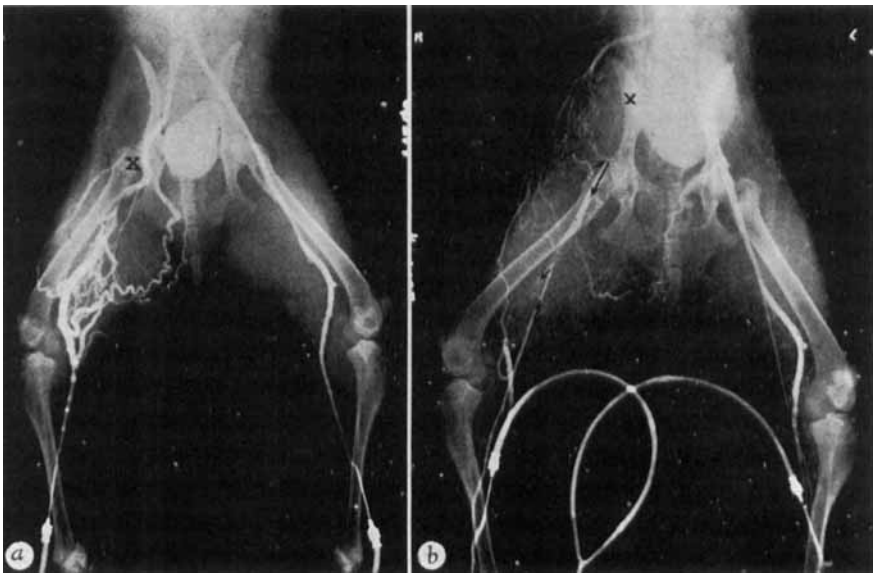

Fig. 2.

a. Bilateral phlebogram made 3 seconds after injection of opaque medium through a T-shaped catheter. Medium cannot reach site of AVF (X) but bypasses it through deep femoral vein and reaches vena cava practically at same time as on normal side. *b.* Bilateral phlebogram made 5 seconds after injection of opaque medium with needles oriented distally in animal with 1-week-old iliac AVF (X). Again medium cannot reach AVF in femoral veins but is stopped at knee level. However, it is delivered to the femoral vein at higher levels through collaterals and then is immediately washed out by arterial backflow in a cascade-like phenomenon (arrows). Runoff finally occurs through deep circumflex iliac vein, abdominal epigastric collateral veins and contralateral pelvic veins.

RESULTS

Per-Aortic Angiograms With Functioning AVF (Fig. 1).—In one of five animals the opaque medium perfusing the veins through the fistula instantaneously filled the saphenous veins down to the ankle (Fig. 1). In the other four, arterial backflow in the veins stopped at knee level where it looped upward through collateral veins bypassing the AVF.

Bilateral Phlebograms With Functioning AVF (Fig. 2).—In all of these phlebograms the opaque medium injected near the foot reached the vena cava through collateral veins on the side of the AVF. These were fully effective by the end of 1 week (Fig. 2b). The opaque medium, bypassing the AVF, reached the vena cava as soon as that flowing through the normal veins on the left side.

Fig. 3.
Aorto-arteriogram made immediately after closure of AVF (arrow). (Tip of catheter accidentally oriented toward normal iliac artery.) Note hypertrophy of iliac, deep femoral and superficial femoral arteries down to knee.

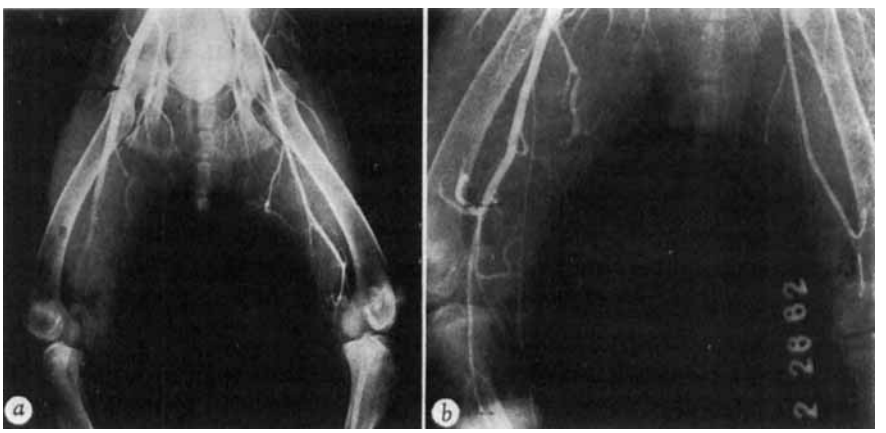

Fig. 4.
a. Aorto-arteriogram made 15 minutes after closure of AVF (arrow). (Catheter oriented away from side of body on which fistula was situated.) Note arterial hypertrophy proximal to AVF.
b. Same animal, second injection. Note hypertrophy of arteries distal to AVF.

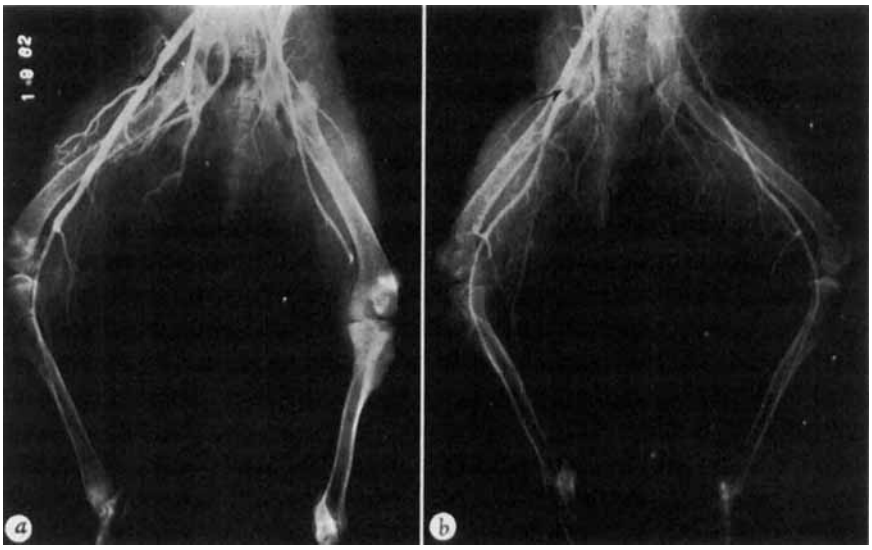

Fig. 5.

a. Aorto-arteriogram made 15 minutes after closure of AVF (arrow), showing enormous tortuous arteries.

b. Similar arteriogram in an adult dog. Note increase in length and number of small arteries in thighs.

Figure 2b (arrows) demonstrates how opaque medium and venous blood are repeatedly mixed with arterial blood in the femoral vein below the AVF. It is delivered there by collateral veins, then is washed out by the arterial backflow and loops back through other collateral veins in a cascade-like phenomenon.

When needles were directed distally, 20 ml. of opaque medium completely disappeared from the foot on both sides within 4 seconds.

Per-Aortic Arteriograms After Closure of AVF (Figs. 3, 4 and 5).— Immediately after repair of the fistula in six of eight animals the arteries on the side of the AVF were hypertrophic. This was true of the right iliac artery (whose diameter was twice that of the normal left one), the femoral artery distal to the AVF, and the deep femoral and hypogastric arteries bypassing the AVF. (Complete filling of the vessels of one limb or the other is an artifact resulting from the orientation of the tip of the catheter.) Aortograms made 1 week after those shown in Figures 3, 4 and 5 showed that the arteries had shrunk back to normal size and were identical to the left ones.

COMMENT

Condition of the Arterial Tree.—Six of the eight bilateral arteriograms made immediately after occlusion of the AVF showed all the arteries of the limb, including the distal fistulized artery itself, to be hypertrophic. The magnitude this hypertrophy can assume has not been fully appreciated in the past (2, 4, 5) except by *Bosher and co-workers* who reported the same findings concerning the arteries that we do. *Robertson and colleagues* found that inflow in dog's limbs with an AVF was more than normal upon acute occlusion of the shunt. They thought that the large collateral arteries accounted for this. By microangiographic examination of femurs that had been subjected to the influence of an AVF, *Kelly and co-workers* observed hypervascularity of the distal and proximal parts of the femur. In our series of eight puppies, two that did not show much hypertrophy of the arteries around the AVF had the weakest response in bone growth. *Holman,* in his excellent description of AVF, has stressed the dilatation of the proximal artery. He demonstrated that the arteries and veins involved in the short circuit of an AVF and the heart itself were dilated somewhat proportionally to the size of the fistula.

Condition of the Venous Tree.—Adequate collateral veins develop around the AVF within a week. We were struck by the fact that edema never developed in one third of the puppies after formation of the AVF. In those in which edema did develop, it always disappeared within a week, as collateral veins formed. This runoff passage was then sufficient to drain the blood from the foot or leg beyond the AVF as fast as was the passage on the normal side. It has been shown that, if a side-to-end AVF is created in a limb of a dog wherein experimental venous insufficiency has been produced by deep venous ligation and then the AVF is closed, the venous pressure in the limb diminishes because of the large size of collateral veins the fistula has produced (3).

In serial roentgenograms the opaque medium is seen to remain longer in the vicinity of the AVF than in the corresponding part of the opposite (normal) thigh. This does not represent stasis, but active cascade-like recycling as shown in Figure 2b. It is proposed that this be termed "active" rather than "passive" venous congestion or venous stasis.

Two of the eight puppies had typical arterial flow in the veins down to the foot; only one was subjected to phlebography (Fig. 1). The saphenous veins had a definite arterial supply, and red, pulsing blood flowed from the right saphenous vein (side of the AVF) toward the

left one through the T-shaped catheter used for phlebography. More often, though, this arterial perfusion of the venous tree was arrested at knee level by competent valves. This backflow always reaches the knee.

SUMMARY AND CONCLUSIONS

In puppies with an induced arteriovenous fistula of the upper part of a limb, selective angiography showed the following local circulatory changes: (1) arterial backflow in the veins, reaching the knee in all cases and the foot in two of eight cases; (2) development of sufficient collateral vessels within 1 week to ensure a normal rate of venous return from below the knee in the fistulized limb; and (3) pronounced hypertrophy of the arterial tree in the fistulized limb of six of eight dogs studied; included in this hypertrophy were the fistulized artery proximal and distal to the fistula and the collateral arteries bypassing the fistula; the presence of the fistula was necessary for this to occur, the hypertrophy disappearing within a week after repair of the fistula.

The classic conception of an arteriovenous fistula as a mere shunt is incomplete. Such a fistula is a double system consisting of a shunt and of large arterial and venous vessels bypassing this shunt.

RESUME

Chez de jeunes chiens auxquels il avait été pratiqué une fistule artérioveineuse dans la parie supérieure d'un membre, une angiographie sélective a montré les changements suivants de circulation locale: (1) reflux artériel dans les veines atteignant le genou dans tous les cas et le pied dans deux sur huit cas; (2) développement de vaisseaux collatéraux suffisants dans l'espace d'une semaine pour assurer un taux normal de retour veineux depuis la partie inférieure au genou dans le membre fistulisé; et (3) hypertrophie prononcée du tronc artériel dans le membre fistulisé chez six des huit chiens étudiés; touchées par cette hypertrophie se trouvaient l'artère fistulisée, proximalement et distalement à la fistule, et les artères collatérales traversant la fistule; la présence de la fistule était nécessaire pour provoquer cet état. L'hypertrophie disparut dans l'espace d'une semaine après la réparation de la fistule.

La conception classique d'une fistule artérioveineuse plutôt comme un shunt est incomplète. Une telle fistule est un double système consistant en un shunt et un large passage des vaisseaux artériels et veineux par ce shunt.

ZUSAMMENFASSUNG

Bei Welpen mit einer im oberen Anteil der Gliedmasse angebrachten arterio-venösen Fistel zeigte die selektive Angiographie folgende örtliche Kreislaufsveränderungen: (1) Arteriellen Rückfluss in die Venen, der das Knie in allen und den Fuss in zwei von acht Fällen erreichte. (2) Entwicklung von hinreichend kollateralen Gefässen innerhalb einer Woche um das normale Mass von venösem Rückfluss von unterhalb des Kniees in die Gliedmasse mit der Fistel zu sichern und (3) ausgesprochene Hypertrophie der arteriellen Verzweigung in der Fistelgliedmasse bei sechs der acht untersuchten Hunde. Inbegriffen in diese Hypertrophie war die Arterie mit der Fistel proximal und distal zur Fistel und die Kollateralarterien, welche die Fistel umgingen. Das Vorhandensein der Fistel war die Vorbedingung für die Entstehung dieses Geschehens indem die Hypertrophie innerhalb einer Woche nach der Reparatur der Fistel verschwandt.

Die klassische Auffassung einer arterio-venösen Fistel als ein blosser Nebenanschluss ist unvollständig. Eine derartige Fistel stellt ein Doppelsystem dar, das aus einem Nebenanschluss und grossen arteriellen und venösen Gefässen besteht, die diesen Nebenanschluss umgehen.

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