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AMPUTATION AFTER DEVELOPMENT OF COLLATERAL CIRCULATION

An Arteriographic Study in Rabbits

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The vascular changes in the amputation stump after amputation on an extremity which is vascularized by collaterals were studied by arteriography in adult rabbits.

Amputation on the crus immediately after ligature of the femoral artery caused a retardation in the development of collaterals and a protracted vasoconstriction in the amputation stump. Osseous plugging of the medullary cavity in the amputation stump counteracted the vasoconstriction, and the development of collaterals was improved. When amputation on the crus was performed 3-6 days after ligature of the femoral artery, immediate function of the collaterals and a rapid dilatation of the arteries in the below knee amputation stump were seen, and 3–4 weeks postoperatively arteriovenous shunts developed in the stump. Amputation 7–10 weeks after ligature of the artery involved a more pronounced shunt development in the amputation stump.

After amputation on the femur only slight differences were observed in the development of collaterals and the vascularization in the amputation stump compared with findings after amputation on the crus.

Key words: amputation; arteriovenous shunt; collateral circulation; intracardial arteriography; vascular spasm

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The vascular changes occurring after amputation may influence the healing process in the amputation stump, especially if the amputation is performed on an extremity with reduced arterial supply. In earlier experimental investigations arteriography has shown that amputation initially induces vasospasm (Erikson & Olerud 1966) and secondarily causes arteriovenous shunts to develop in the stump (Hansen-Leth & Karle 1978). When amputation is performed on an extremity supplied by collaterals formed because of occlusion of the femoral artery, the muscle blood flow to the stump will depend on the time interval between the occlusion and the amputation (Hansen-Leth 1978).

The aim of this investigation was to elucidate the arteriographic changes occurring after amputation on extremities supplied by collaterals. Arteriography was performed after intracardial injection of contrast as in an earlier investigation (Hansen-Leth & Karle 1978).

MATERIALS AND METHOD

The studies were performed in 23 adult rabbits weighing 3–4 kg. Ligation was carried out on the

Table 1. Examples of repeated arteriographic investigations on the same rabbit

Operations	Time of arteriography			
	Rabbit N 62		Rabbit N 70	
Ligature of the femoral artery	Preoperative 1 hour after ligature 1 week after ligature			
Ligature of the femoral artery + amp. on crus	10 weeks — — — — — — — —	+ 1 hour + 2 weeks + 4 + 10 + 13	½ week — — — — — —	+ 1 day + 1 week + 3 s + 5 s
Ligature of the femoral artery + amp. on femur			10 weeks — — — — — —	+ 1 hour + 1 week + 6 weeks + 8

proximal part of the left femoral artery, and the amputation stumps were in all cases closed by myoplasty. In nine rabbits amputation proximally on the left crus was performed immediately after the ligature – in three of these, myoplasty was combined with osseous plugging of the marrow cavity. In five animals amputation on the crus was carried out 3–6 days and in a further five animals 7–10 weeks after the ligature. Finally, in two animals previously amputated on the crus – amputation on the femur was performed 1 week and 10 weeks after the ligature. Two animals were not amputated at all.

All the operations were performed under Nembutal anaesthesia. The femoral artery was double-ligated with silk and the stump was closed by silk knots in the muscles and nylon in the skin. The marrow cavity was plugged with cortex obtained from the removed bone.

Arteriography was carried out as previously described (Hansen-Leth & Karle 1978). Under Nembutal anaesthesia a lumbar needle (90 × 0.9 mm) was inserted through the skin at the tip of the xiphoid process and thrust into the heart. The needle was kept open with heparin-saline solution and a bolus of 6 cm^3 76 per cent Urographin was injected manually for a period of 1.5 seconds. Six pictures were taken immediately thereafter (1 exposure every 2 seconds). This procedure clearly portrayed the arterial and venous phase, and the transit-time through the arteries and the appearance of the venous phase could be determined.

The degree of change in arterial diameter was measured on subtraction films at corresponding levels by the use of a magnifying glass and a scale permitting readings with a precision of 0.1 mm. The magnification factor was so small that it could be ignored (measured with a lead striped ruler placed across the pelvic area of the rabbit).

A total of 57 arteriographs were performed, two preoperative, seven after arterial ligature and 48 after amputation from 1 hour to 4 months postoperatively. Two animals were arteriographed 8 times (Table 1) one 4 times, five 3 times, seven twice and eight once.

RESULTS

When arteriography was performed immediately after ligature of the femoral artery, function of the collaterals from the circumflex femoral arteries and contrast filling of the distal part of the femoral artery were seen, but no filling of the crural vessels. From 1 to 10 weeks after ligature of the femoral artery, arteriography showed a moderate increase in the prominence of the collaterals and only a slight amount of contrast in the crural arteries (Figure 1).

If amputation on the crus was performed immediately after the arterial occlusion only a few collaterals were seen in the amputated leg in the first 4 weeks after the operation and the contrast filling in the stump vessels was minimal up to 6 weeks (Figure 2). When 7 weeks had passed a dilatation of the

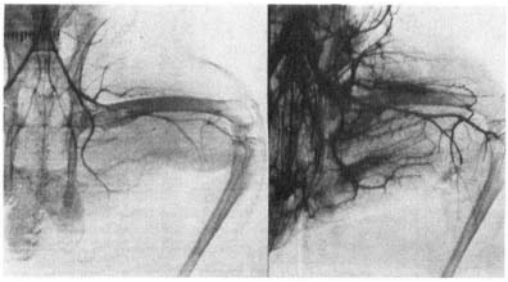

Figure 1. (a) Ten weeks after ligature of the left femoral artery. Note the moderately prominent collaterals and almost no contrast filling of the crural arteries (b) Postmortem angiography performed on the same rabbit through a catheter placed in the aorta. Rabbit N69.

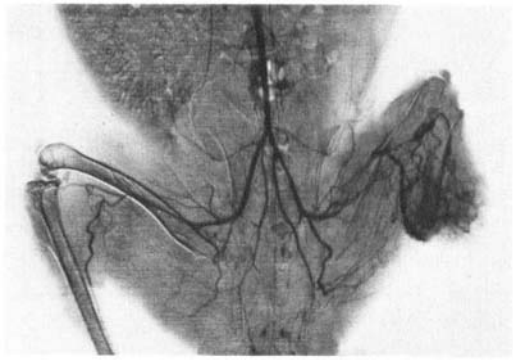

Figure 3. Two weeks after simultaneous ligature of the femoral artery and amputation on the crus combined with plugging of the medullary cavity. (N_{55}).

supplying arteries and slight filling of the veins was observed (Table 2).

However, if amputation was combined with plugging of the medullary cavity, dilatation of the collaterals and the arteries in the stump was seen 1 week postoperatively (Figure 3).

After a time interval of from 3 to 6 days between ligature of the artery and amputation, arteriography showed an immediate contrast filling of the collaterals; dilatation of the arteries in the stump was seen 2 days later (Figures 4, 5). Four weeks postoperatively there was filling of the superficial and deep veins in the stump and the superficial veins in the contralateral extremity.

Figure 2. Ten weeks after ligature of the femoral artery and amputation on the crus performed simultaneously. (N_{64}).

In experiments with 7 to 10 weeks interval between ligature and amputation, arteriography immediately after amputation showed little contrast filling of the collaterals and the vessels in the stump (Figure 6). Two weeks later more collaterals were seen (Figure 7) and there was simultaneous vein filling on both sides.

Table 2 illustrates that the flow rate in the arteries was almost constant (4–6 seconds) and independent of the time interval between artery ligature and amputation, whereas vein filling increased 2–3 weeks postoperatively, and was most noticeable when a long time interval (7–10 weeks) was introduced between artery occlusion and amputation.

Contrast filling of the veins occurred simultaneously on both sides, but on the contralateral extremity only the superficial veins were seen, and they disappeared when a tourniquet was placed on the distal part of

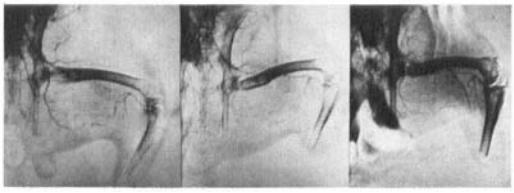

Figure 4. (a) Five days after ligature of the femoral artery. (b) One hour after subsequent amputation. (c) Two days after the amputation. (N_{74}).

Table 2. Transit-time. Rate of contrast filling in the vessels in the operated leg. (One sign means one single picture = 2 seconds.)

TRANSIT-TIME

OPERATION	1 HOUR	1/2 WEEK	1 WEEK	2-3 WEEKS	4-5 WEEKS	6-10 WEEKS	>10 WEEKS
LIGATURA ART. FEMORALIS	x x	x x x	x x x x x	x x x		x x	x x x
SIMULTANEOUS LIG. AND AMP. CRURIS	x x	x x x x	x x	x x x x x x	x x	x x △ △ △ △ x x o o o	x x △ △ x x △ △
SIMULTANEOUS LIG. AND AMP. + PLUGGING		x x △ △ △	x x △ △	x x o o x x △ △ △	x x x x		
INTERVAL 3-6 DAYS	x x x x x	x x x x x x	x x △ △ x x x x	x x △ △ x x △ △ △ △	x x ● ● ● x x o o o o	x x △ △ △ x x o o o	x x x ● ● ● ● x x o o o o o x x △ △ △
INTERVAL 7-10 WEEKS	x x x x x x	x x x x		x x △ △ △ x x x o o o x x x ● ●	x x x ● ● ● x x ● ● ● ●	x x ● ● ● ● ●	x x o o o o x x x △ △ △
LIG. AND AMP. FEMORIS	x x x		x x	x △ △	x x	x x	

x ARTERY OCCURRENCE
△ VEIN SLIGHT OCCURRENCE
o VEIN MODERATE OCCURRENCE
● VEIN MARKED OCCURRENCE

the crus, indicating that the vein filling was caused by arteriovenous shunts distally in the extremity. In the amputated extremity contrast filling of the superficial as well as the deep veins was observed; the superficial veins were especially noticeable after a long time interval between artery occlusion and amputation.

The dilatation of the suppling arteries is illustrated by the diameter of the aorta (Figure 8). The degree of dilatation with 3–6 days interval between artery occlusion and amputation was greater than after 7–10 weeks interval, and remained unchanged in the investigation period, while the diameter of the aorta increased after the longer time interval.

The secondary dilatation of the suppling arteries and the increased occurrence of superficial veins in the stump, especially after a long time interval between artery occlusion and amputation, could be explained by the formation of arteriovenous shunts in the amputation stump.

If amputation on the femur was performed 1 and 10 weeks after artery occlusion

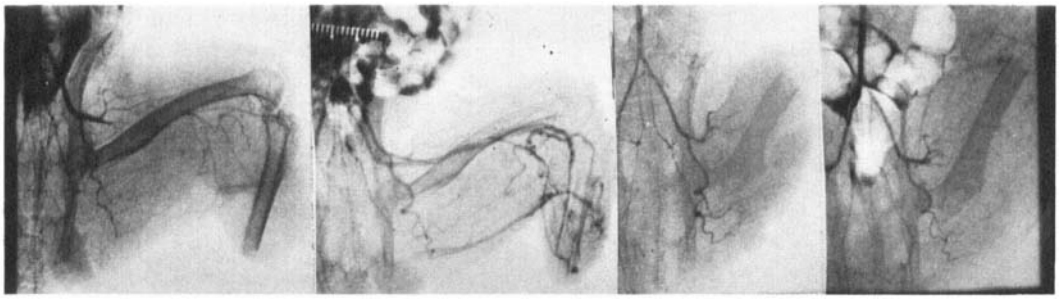

Figure 5. Amputation on the crus and later on the femur performed on the same rabbit. (a) Three days after ligature and 1 hour after amputation. (b) Three days after ligature and 5 weeks after amputation. (c) Ten weeks after ligature and 1 hour after amputation on the femur, (d) 10 days later. (N_{70}).

no contrast filling of the distal part of the femoral artery was seen; the circumflex arteries were dilated, but the collaterals in the stump were only slightly so, and no vein filling occurred (Figure 5). However dilatation of the arteries and rapid filling of the veins were seen in the contralateral extremity.

DISCUSSION

Using intracardial arteriography it is possible to perform repeated investigations on the same animal and, in this way, to follow the development of collaterals after ligature of the femoral artery, and the vascular changes following subsequent amputation.

This study has demonstrated immediate function of collaterals after ligature of the femoral artery. Similarly Schoop & Jahn (1961) showed immediate contrast filling of preexisting "primary" collaterals after ligature of the femoral artery on dogs, while "secondary" collaterals developed in the course of the following weeks. In clinical investigations Shepherd (1950) and Dornhorst & Sharpey-Schafer (1951) showed that the resistance in the collateral vessels diminished already 1 minute after acute arterial occlusion.

In the present study there was no contrast filling of the crural arteries before 1 week after the occlusion despite the development of collaterals. This is in accordance with the findings of Barnes & Trueta (1942) and Jaya (1958), who found that ligature of the femoral

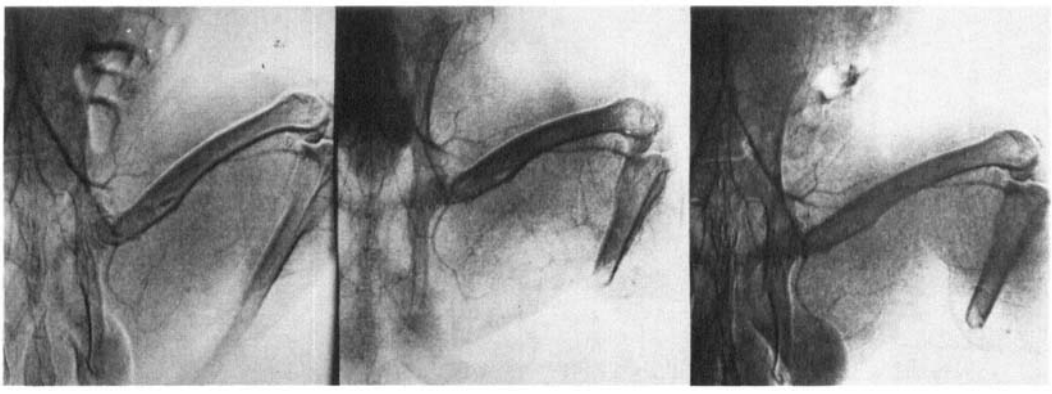

Figure 6. (a) Seven weeks after ligature. (b) Amputation performed at this time and the arteriography 1 hour later. (c) Three days later. (N_{71}).

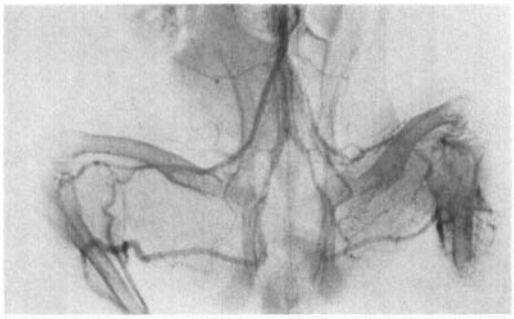

Figure 7. The amputation was performed 10 weeks after ligature and the arteriography 4 weeks later. (N_{58}).

artery induced a vasospasm of the peripheral arteries. Measurement of the muscle blood flow (Hansen-Leth 1978) has shown that after ligature of the femoral artery there is an immediate reduction in the blood flow to the crus.

In this study, amputation performed immediately after arterial occlusion counteracted the function of collaterals and induced a protracted vasoconstriction in the peripheral arteries in the amputated extremity. Measurement of the blood flow in muscles (Hansen-Leth 1978) has shown that the flow in the stump is decreased during the first week after simultaneous ligature of the femoral artery and amputation on the crus. This is in contrast to crus amputation on rabbits with intact circulation where an increase in blood flow was seen 1 day after operation (Hansen-Leth 1976).

When amputation is done on an extremity with intact circulation an initial vasospasm will always be the result (Erikson & Olerud 1966, Hansen-Leth & Karle 1978). However, if the amputation is performed 3–6 days after ligature of the femoral artery, an immediate dilatation of the supplying arteries and filling of the collaterals to the stump are seen. In accordance with this, determination of muscle blood flow (Hansen-Leth 1978) has shown an immediate increase in the blood flow to the stump, when amputation on the crus is performed 3 days after ligature of the femoral artery. The reason why amputation on an extremity supplied by collaterals does not provoke an initial vasospasm is not clear.

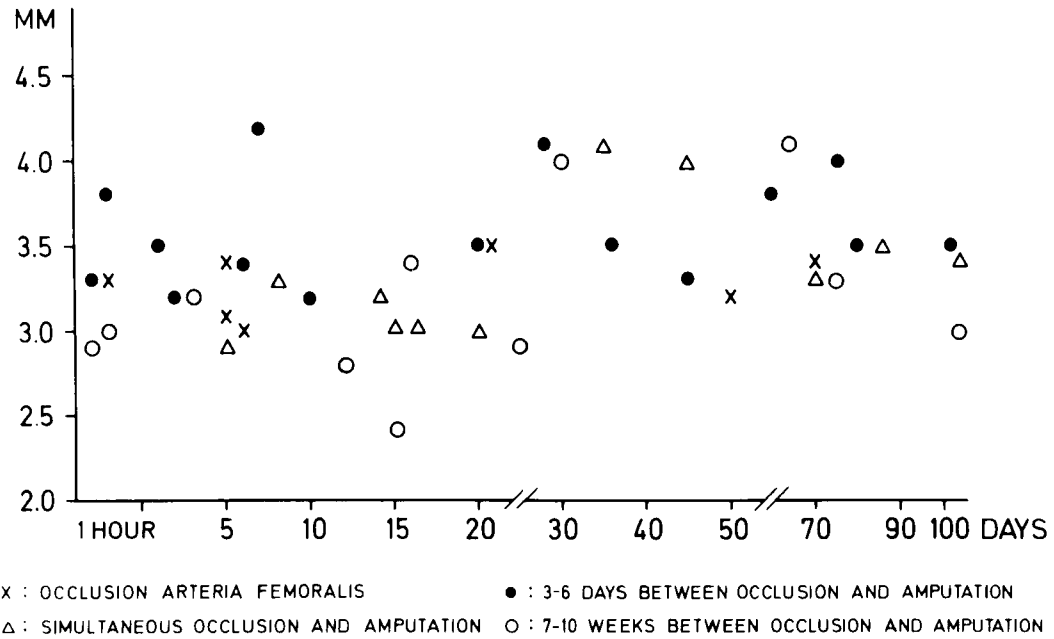

Figure 8. The diameter of the aorta. A secondary dilatation is observed 3–4 weeks after amputation, especially after a long interval between occlusion and amputation.

Erikson & Olerud (1966) suggested that the vasospasm after amputation could be caused by an increased sympathetic tone. From clinical investigations it is known that collaterals have a low sympathetic tone (Nielsen et al. 1973). A decreased sensitivity to the sympathetic impulses could be the cause of the immediate function of collaterals after amputation.

After an extended time interval between arterial occlusion and amputation a similar initial vasodilatation and collateral function was not seen. But secondary arterial dilatation was observed after 3–4 weeks simultaneously with the occurrence of contrast filling of the superficial veins. This might be due to the development of arteriovenous shunts in the stump, and these findings can explain the diminished muscle blood flow in the amputation stump seen when amputation was performed 10 weeks after arterial occlusion (Hansen-Leth 1978).

The occurrence of superficial veins can be due to arteriovenous shunts, whereas the contrast filling of deep veins means an improvement in the venous return from the stump (Loon 1960). In a previous investigation (Hansen-Leth & Karle 1978) the deep veins from the stump were only seen when amputation was combined with osseous plugging of the medullary cavity. Similarly, the present investigation has shown that plugging of the medullary cavity improved the vascularization in the stump. In accordance with this, determination of muscle blood flow (Hansen-Leth 1976) has shown that plugging of the marrow cavity induces a more rapid and greater blood flow in the stump.

Following amputation on the femur only a slight filling via the collaterals to the femoral stump was seen and there was no refilling of the femoral artery. After amputation on the femur the femoral artery must be considered as an end-artery, which is obliterated at the level where it joins with the circumflex femoral arteries. The vascularization of the amputation stump takes place only through small terminal branches; the fall in blood pressure through these is marked (Learmonth 1950) and the capillary blood flow in the stump will be diminished. In accordance with this, determination of muscle blood flow has shown no increase in the flow in the stump after amputation on the femur (Hansen-Leth 1977).

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