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THE VASCULARIZATION IN THE AMPUTATION STUMPS OF RABBITS

A Microangiographic Study

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With the aid of microangiography the vascularization in the amputation stumps of 108 rabbits was studied, both in extremities with normal circulation and in those supplied with collaterals. It was found that the vascularization of the normal leg was altered by amputation, with the development of newly-formed, pathological, spirally-twisted vessels. Closure of the stump with myoplasty, however, counteracted this vessel formation, and hypervascularization took place through normal arteries. After amputation of extremities supplied with collaterals, the influence of amputation on collateral function and vascularization in the amputation stump was dependent on the time interval between arterial occlusion and amputation.

Key words: amputation; collateral circulation; microangiography; myoplasty

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The vascularization in the operated extremity is altered by amputation, primarily because of amputation trauma and secondarily because of the change in muscle function (Hansen-Leth & Karle 1978a). Utilization of various technical procedures during amputation can improve the vascular conditions in the amputation stump. This is of particular importance in amputations on extremities supplied by collaterals, where the preoperative blood flow is reduced at the level of the amputation.

In this work the morphological changes in the vascular structure after amputation were investigated by the use of microangiography in rabbits with normal circulation and in rabbits supplied with collateral circulation in the operated extremity.

MATERIAL AND METHODS

The experimental animals were 108 adult rabbits of both sexes weighing 3–4 kg. Sixty animals had normal vascular anatomy in the leg before amputation. The amputation techniques and the amputation levels are presented in Table 1. Ligation of the femoral artery was carried out on 48 rabbits, of which 34 were subsequently amputated on the crus on the same side of the body after varying time intervals (Table 1).

The operations were performed on animals anaesthetized with Nembutal. In proximal crus amputation the bone was sawn through at the tibiofibular synostosis and the muscles were severed 1 cm distal to the bone stump. In myoplastic closure the muscles were sewn together over the bone stump, whereas in the absence of myoplasty they were excised at the level of the bone stump. When amputations were performed distally on the crus the muscles were severed distal to the muscle-tendon transition of the triceps surae, and the bone stump was closed myoplastically. In osseous plugging the medullary cavity was plugged with cortex obtained from amputated bone. The femur was amputated at the midbone and was closed with myoplasty. The femoral artery was located proximally, isolated from the vein and femoral nerve and double-ligated with silk thread. Minor defects on the tips of the amputation stumps due to stress developed

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Table 1. The amputation techniques and the amputation levels

Rabbits with undisturbed vascularization				
Amputation level	Cases	+ myoplasty	− myoplasty	+ medullary plugging
Amp. prox. cruris	34	18	16	(9)
Amp. distalis cruris	14	14		
Amputatio femoris	12	12		(3)
	60	44	16	(12)

Rabbits with collateral circulation in the amputated leg					
Operation	Cases	Time interval between ligation and amputation			
		1 hour	3 days	2–4 weeks	7–18 weeks
Ligatura art. femoralis	48				
Ligatura art. fem. + amp. prox. cruris	34	3	12	11	8

in 16 animals, but no infection was detected in any of these cases.

The animals were sacrificed from 1 hour to 130 days, postoperatively, and microangiography was performed. After heparinization, a catheter was implanted in the abdominal aorta, the hind-quarters were perfused with saline under a pressure of 1 m water, followed by an infusion of 25 per cent Micropaque, 10 per cent Formalin and ½ per cent Berlinerblue for about three-quarters of an hour. After removal of the skin the hind-quarters were fixed in 10 per cent formalin and then photographed with a Machlett A.E.G. X-ray tube at a distance of 40 cm. Industry film Gevaert Structurix D7 and Kodak PE 4006 was used (exposure time 1 minute, 7 mAmp/24 Kv).

RESULTS

The vascularization of the amputation stumps after *amputation in extremities with normal circulation* is presented in Figure 1. It can be seen that amputation was accompanied by vascular changes, partly dependent on the level of amputation and partly dependent on the nature of stump closure. *Proximal amputation of the crus closed with myoplasty* caused hypervascularization for from ½–10 weeks, postoperatively (Figure 2), whereas *amputation* at the same level *without myoplasty,* as well as *distal amputation of the crus,* resulted in transient hypervascularization; the vascularization of the stump in these latter cases was implemented predominantly by newly-formed, spirally-twisted vessels (Figures 3 and 4). Increased vascularization of the stump of quite short duration was similarly observed after *amputation of the femur,* without contrast filling of the large arteries, and spirally-twisted vessels were seen 3 weeks after surgery. A decrease in vascularization of the stumps was found in all of the amputated animals 10 weeks after amputation, and this was accompanied by the appearance of contrast filling of irregularly-dilated, twisted veins. Osseous plugging of the medullary cavity produced no distinct change in these vascular conditions.

Ligation of the femoral artery prior to amputation caused an initial reduction of vascularization of the crus musculature (Figure 5), but a moderate hypervascularization through collaterals, as well as the appearance of newly-formed, spirally-twisted vessels, occurred 1 week later. Hypervascularization declined after 5 weeks, whereas the collaterals were functional until 16 weeks after arterial occlusion.

When amputation was performed proximally on the crus 1 hour after ligation of the femoral artery, only slight collateral develop-

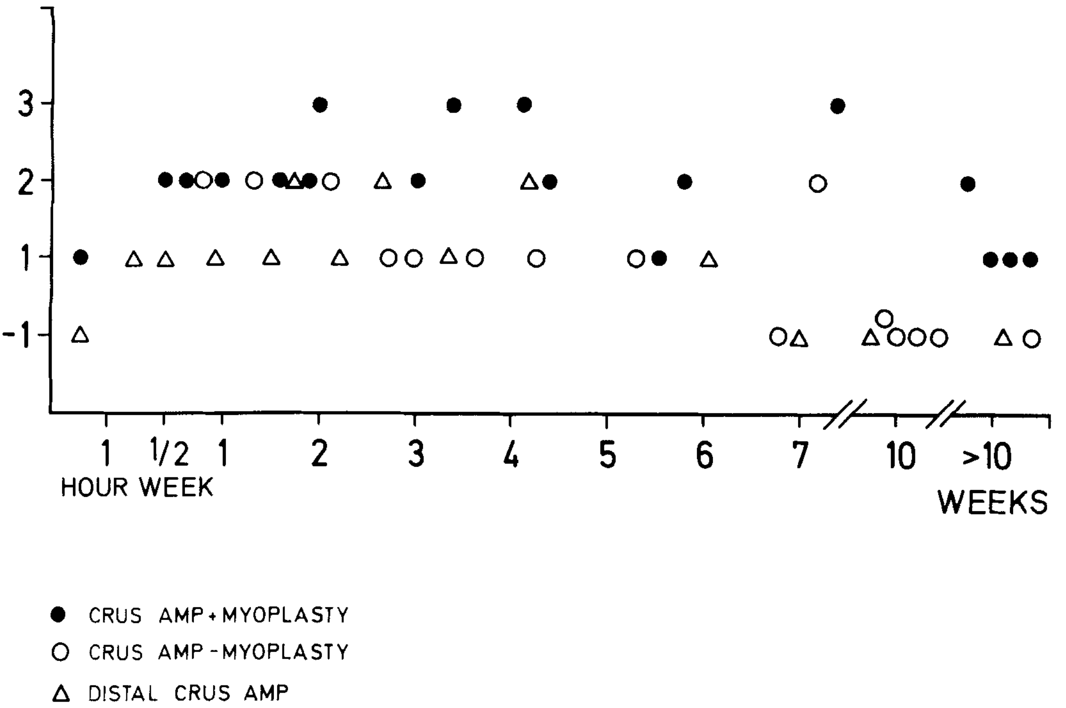

Figure 1. Vascularization in the amputation stump. Explanation of numbers on the ordinate: 1 = Same as at the corresponding level on the unoperated leg. 2 = Moderately increased. 3 = Markedly increased. −1 = Less than at the corresponding level on the intact leg.

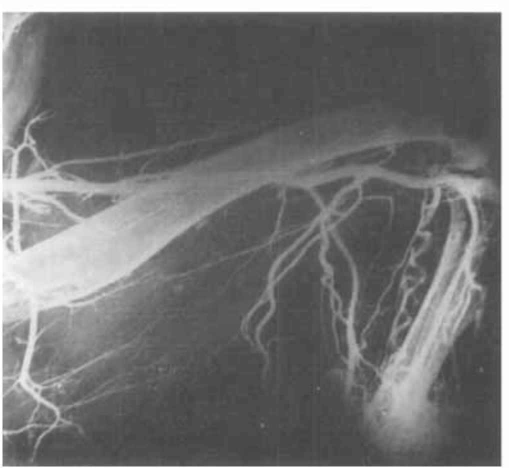

Figure 2. Proximal crus stump with myoplasty 9 weeks after amputation (rabbit R42).

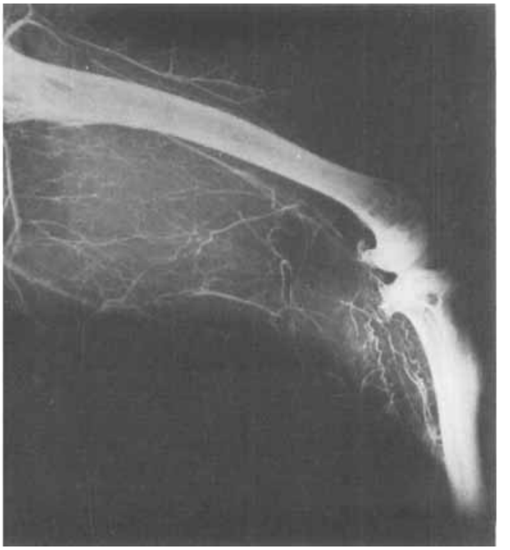

Figure 3. Proximal crus stump without myoplasty 6 weeks after amputation (rabbit P9).

Figure 4. Distal crus stump with myoplasty 14 weeks after amputation (rabbit R31).

ment and vascularization of the stump were seen, but if the amputation was combined with osseous plugging of the medullary cavity a dilation of the collaterals and hypervascularization of the amputation stump were observed (Figure 6). If crus amputation was undertaken 3 days after arterial ligation the collaterals immediately became functional after amputation, and an initial hypervascularization of the stump was seen (Figure 7). After 10 weeks the circulation was dominated by dilated veins and increasing numbers of spirally-twisted vessels (Figure 8). When amputation was carried out 2–4 weeks after arterial occlusion no clear initial hypervascularization of the amputation stump was found, and the manifestation of stump hypervascularization declined with increasing time intervals between arterial occlusion and amputation, despite the occurrence of dilated, twisted collaterals on the femur (Figure 9).

The results of this investigation therefore indicate that amputation of an extremity

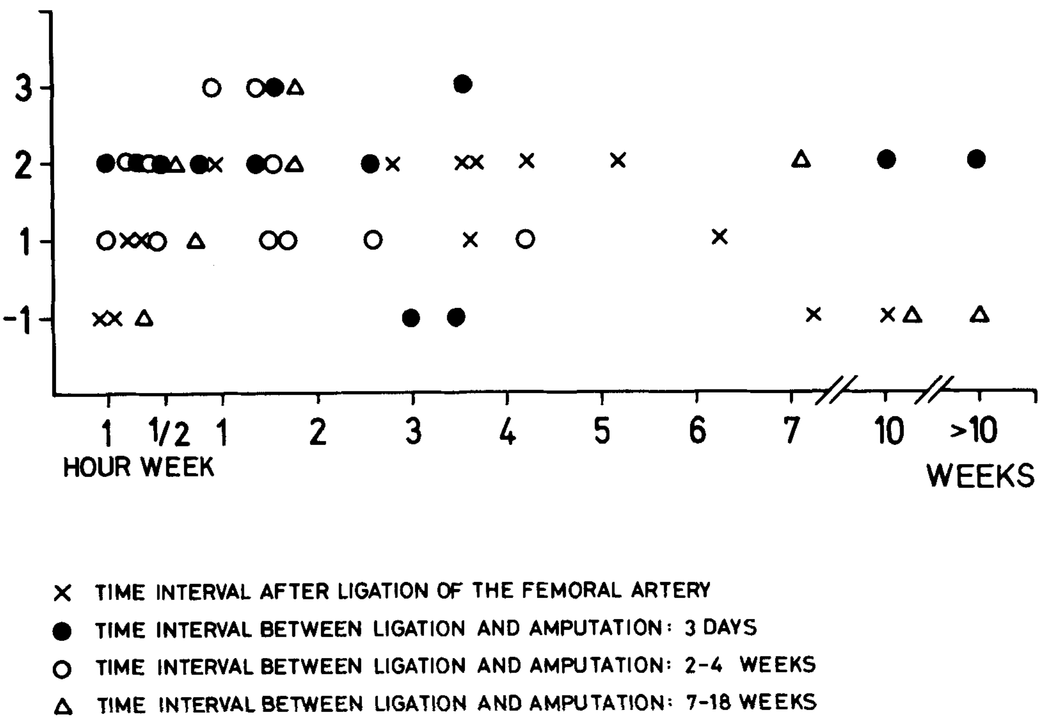

Figure 5. Vascularization in the amputation stump supplied with collaterals. (See text to Figure 1 for explanation.)

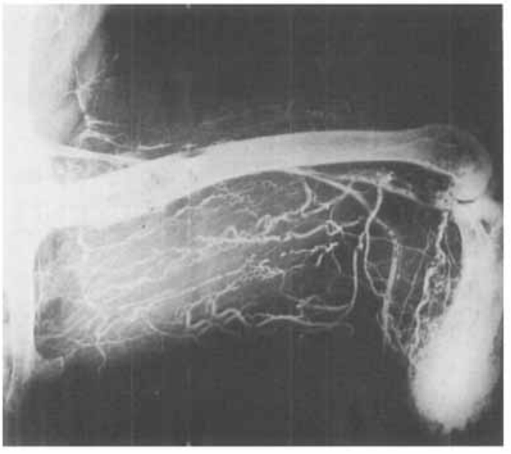

Figure 6. Crus amputation with myoplasty and medullary plugging 12 weeks after amputation (rabbit N55).

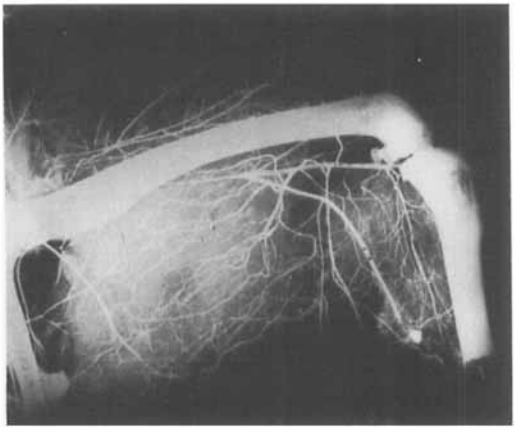

Figure 7. Crus amputation 3 days after femoral artery occlusion, photographed 1 hour after amputation (rabbit N4).

supplied with collaterals produces a hypervascularization of the amputation stump which is similar to that found after amputation of an extremity with a normal circulation, but that this effect is dependent on the time interval between arterial occlusion and amputation.

DISCUSSION

Previous investigations have shown that amputation evokes hypervascularization in the amputation stump, as well as the formation of newly-formed, spirally-twisted

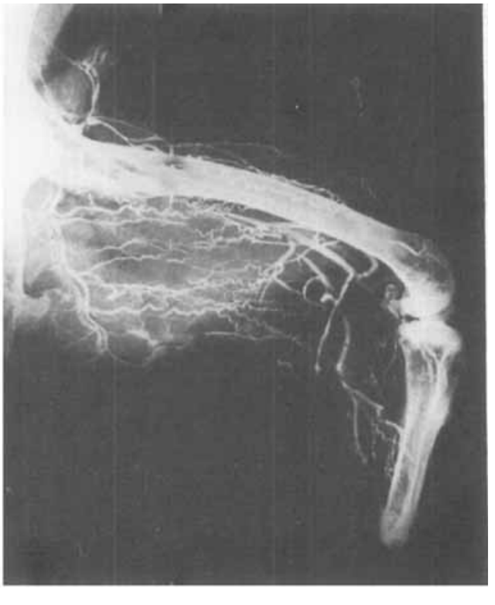

Figure 8. Crus amputation 3 days after femoral artery occlusion, photographed 10 weeks after amputation (rabbit N33).

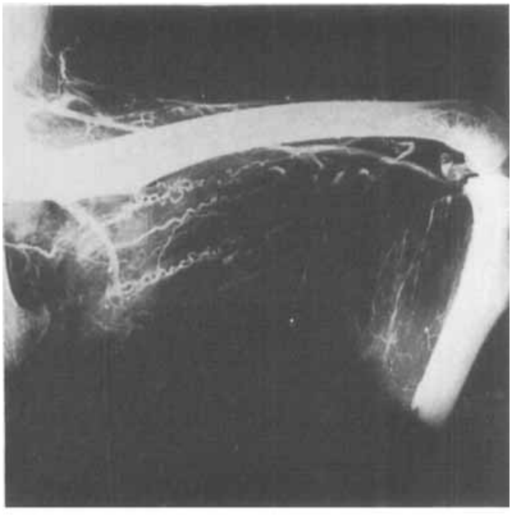

Figure 9. Crus amputation 18 weeks after femoral artery occlusion, photographed 2 days after amputation (rabbit N47).

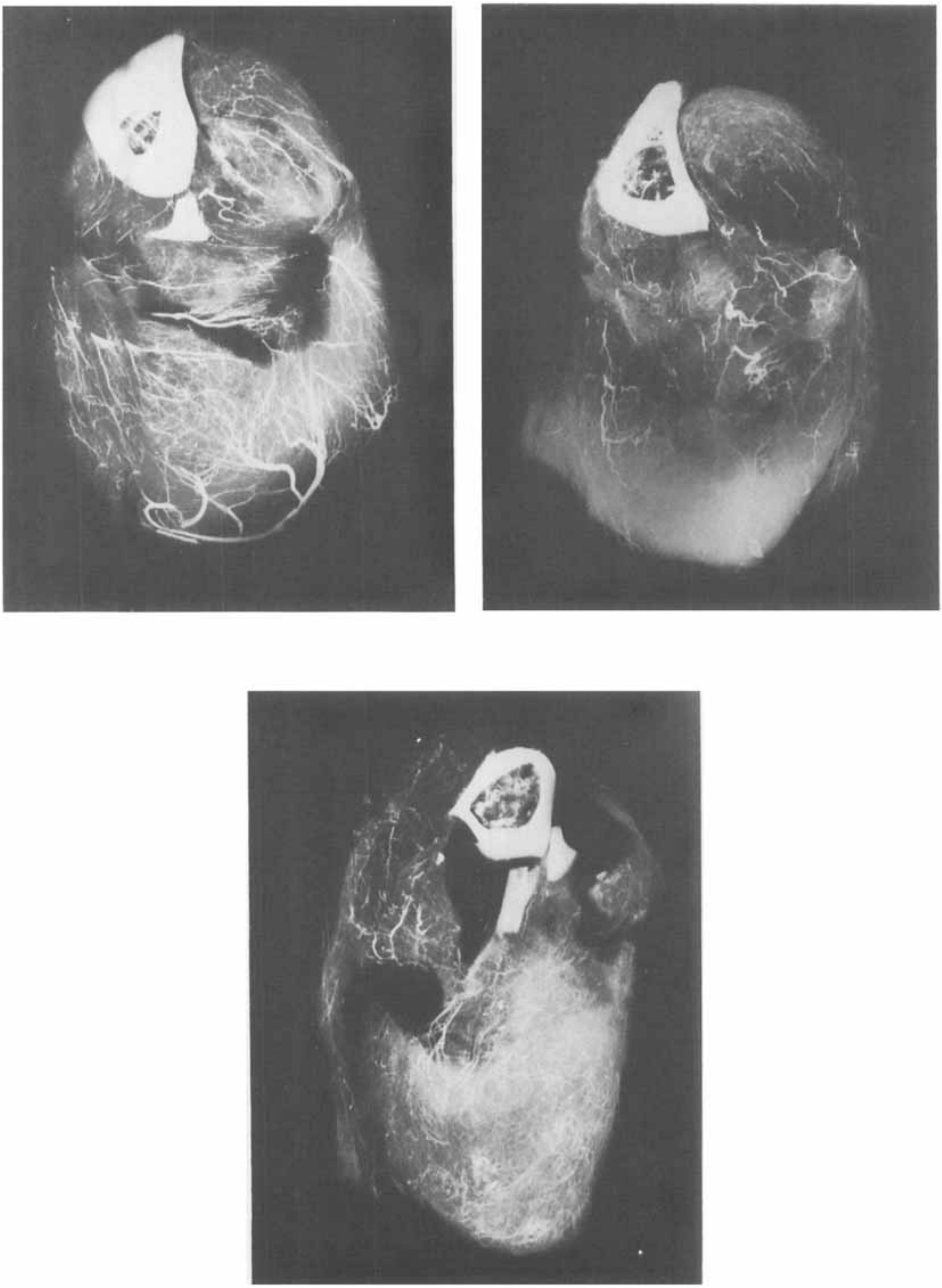

Figure 10. Cross section of triceps surae; a) in an unoperated leg, b) 4 weeks after proximal crus amputation without myoplasty, c) 3 weeks after distal crus amputation with myoplasty.

vessels (Hulth & Olerud 1962, Erikson & Olerud 1966, Hansen-Leth & Reimann 1972). This hypervascularization may in part be a component of a reparative process and may in part be a consequence of immobilization of the amputated extremity (Hulth & Olerud 1961). Muscular trauma in the amputation stump is greatest in amputation without myoplasty. The muscles are excised in the region of amputation and are retracted. This involves arterial occlusion and arterial dilatation and a rise in blood pressure in the remaining intact arteries, which induces the development of new circulatory paths. Erikson (1965) found that spirally-twisted arteries occurred in one-half of the amputation stumps in amputations without myoplasty, and he proposed that both a metabolic disturbance as well as an alteration in the nervous stimulation were involved in the formation of the vessels.

It was found in the present investigation that spirally-twisted vessels are present in the amputation stump 1–2 weeks after amputation, irrespective of the amputation technique or amputation level. However, while the hypervascularization of the stump in proximal crus amputations with myoplasty was implemented by arteries of normal appearance, it was brought about by newly-formed, spiral arteries in the stumps of proximal crus amputations without myoplasty, in distal crus amputations and in femur amputations with myoplasty (Figure 10). The length and small diameter of these vessels considerably increased the flow resistance and, hence, reduced the muscular blood flow. Determinations of muscular blood flow in amputation stumps (Hansen-Leth 1976, 1977) disclosed that blood flow in distal crus amputations and in proximal crus amputations without myoplasty was less than in proximal crus amputations with myoplasty. In femur amputations in the rabbit, Itohara (1972) found that myoplasty induced hypervascularization in the stump, in contrast to decreased vascularization in amputations without myoplasty. Hansen-Leth & Reimann (1972) observed in amputations in not fully-grown rabbits that spiral vessels were more numerous in the absence of myoplasty.

After amputation there is an immobilization of the amputated leg as well as a muscular inactivity in the amputation stump. After immobilization of the hind legs of rabbits in plaster casts Ferguson & Akahoshi (1960) and Hulth & Olerud (1961) observed a hypervascularization and a dilation of the larger arteries, whereas increased formation of small vessels was seen after muscular inactivity resulting from tenotomy (Ferguson & Akahoshi 1960). In the present work it was found that the hypervascularization after amputation with myoplasty corresponded to the vascular changes occurring after immobilization, whereas amputation without myoplasty evoked vascular changes corresponding to those described after tenotomy.

The results of the present investigation therefore suggest that the amputation trauma, as well as the immobilization and muscle inactivity, bring about the vascular changes in the amputation stump. There is less amputation trauma and muscular inactivity in amputations with myoplasty, and hypervascularization in these cases takes place through normal arteries.

Crus amputation with myoplasty on an extremity supplied with collaterals similarly causes hypervascularization of the amputation stump, but its magnitude is dependent on the time interval between arterial occlusion and amputation. Collaterals are preformed vessels and can quickly become functionally active after arterial occlusion (Krahl et al. 1954), but if the amputation is performed immediately after arterial occlusion vasospasm is aroused by the amputation (Erikson & Olerud 1966, Hansen-Leth & Karle 1978b), and this counteracts the collateral development. If the collaterals are open and functional the amputation will rapidly produce a hypervascularization of the amputation stump. In the case of amputations carried out after a longer time interval between arterial occlusion and amputation, however, no initial hypervascularization of the stump takes place, despite dilation of the supplying collaterals.

Schoop & Jahn (1961) differentiate between primary collaterals, which are anatomically unmodified vessels that rapidly become functionally active, and secondary collaterals, which are arteries that undergo anatomical development due to their new function in the course of weeks or months. These secondary collaterals have the appearance of dilated and twisted vessels, constituting a considerable resistance, and thereby reducing the muscular blood flow.

The results of this investigation are in agreement with the findings of Schoop & Jahn (1961) . The vascularization in the crus declines 8 weeks after ligation of the femoral artery, even in the presence of intact collaterals, and crus amputation after this time evokes a lower hypervascularization, despite the occurrence of dilated and twisted collaterals. Similarly, determinations of muscular blood flow in the amputation stump after the development of collaterals (Hansen-Leth 1978) demonstrated an increased blood flow in the stump that was dependent on the time interval between arterial occlusion and amputation.

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