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HEALING OF AMPUTATION STUMPS, WITH SPECIAL REFERENCE TO VASCULARITY AND BONE

By

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INTRODUCTION

Hulth & Olerud (1962) have previously shown, by angiography, hypervascularization with tortuous arteries in amputation stumps in rabbits. They studied the animal by means of manual contrast injection, performing the exposure during contrast passage. The investigation could not be repeated at different intervals on any one animal, and the veins did not always fill particularly well.

Leriche (1950), *Erikson & Hulth* (1962) and *Erikson* (1965) report similar findings in man on the investigation of small groups of leg amputees. It was not possible with the method used, however, to study the course of vascular development, especially in the period immediately following the amputation. Not until after 3-4 weeks were the first arteriographies obtained in these amputees.

We have considered it of interest to study the process of recovery in the stump both immediately after and a short period after amputation, and have attempted to do this by experiments on rabbits.

MATERIAL AND METHODS

a) *Operative Procedure*

15 albino rabbits, weighing 2.5-3 kg, were amputated unilaterally below the knee under nembutal anaesthesia. The usual sterility was observed, and special attention was paid to careful haemostasis. The tibia was sawn with a circular saw at the level between first and second third. Available muscle was sutured over the bone stump, and the tendons and skin were then sutured with catgut. The animals were placed in cages the floor of which was covered with sawdust in order to prevent decubital sores in the amputation area.

b) *Angiographic Procedure*

Angiographies were performed according to an experimental method described by *Ekholm, Erikson & Skoglund* (1964): 25 per cent Th O₂ solution (thorotrast) in a dose of 10 ml/kg body weight was injected intravenously, whereby the greater part of both the arterial and the venous network remained visible for 1½ hours. In two rabbits the vascular system was filled before the amputation. The other rabbits divided into seven groups of two. The respective groups were studied after 1 day, 2 days, 3 days, 7 days, 21 days and 6 weeks, and one animal after 4 months. In 3 rabbits the investigation was repeated on up to 3 different occasions. 7 rabbits were investigated twice and 10 rabbits once.

Single exposure was used. The focus-film distance was 125 cms, and the animal lay on the film cassette. Exposure data 65 kV, 0.010 S, 250 mA. The film was developed in an automatic developing machine.

RESULTS

Angiographic Results

The angiographies were evaluated with respect to the width of the large arteries and veins. The tortuosity and richness of the peripheral vessels in the amputation stump were noted, and as far as possible graded.

The arrangement of the vascular pattern indicated in some cases the presence of a haematoma in the stump

Vascular Width

The arteries and veins were found to be narrower on angiography immediately after the amputation and during the first 24 hours than on pre-operative angiography, in all 9 rabbits were investigated at

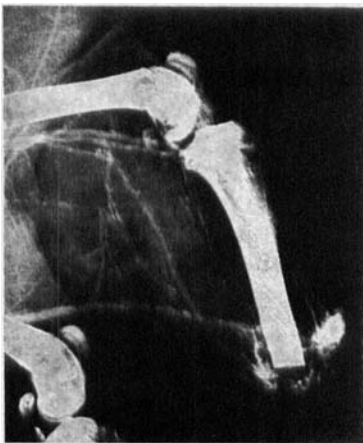


Figure 1. Amputation stump investigated immediately after amputation. The contrast medium, thorotrast, was injected 20 minutes before the amputation. Note the relatively narrow vessels and the haematoma at the distal end of the stump.

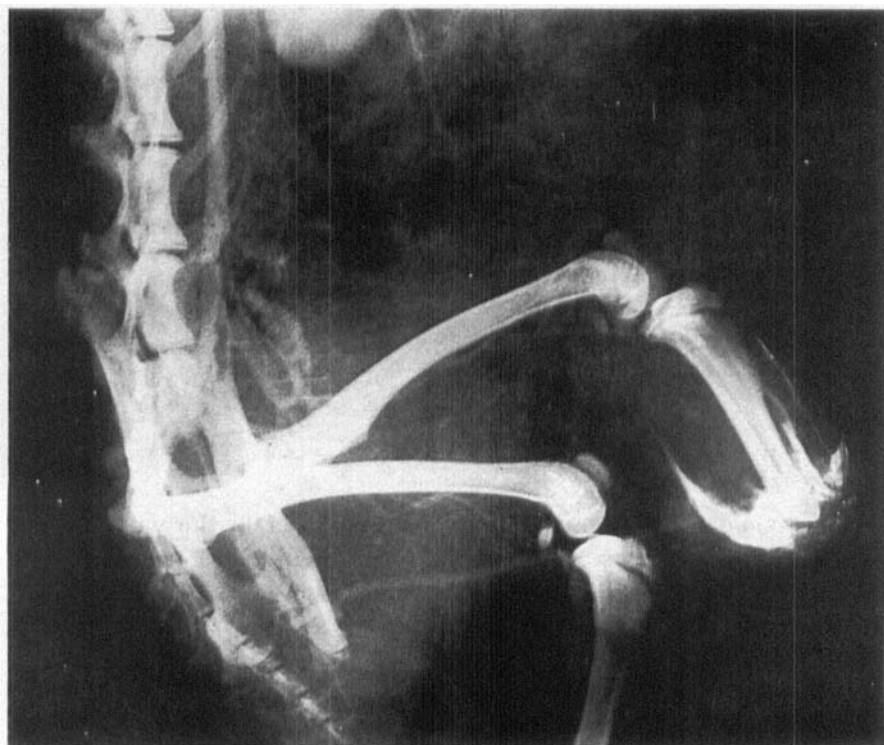


Figure 2. The same stump as in Figure 1 investigated 1 day after amputation. The spur-shaped haematoma is visible because of thorotrast injected before amputation. A second dose of thorotrast made the rather narrow vessels visible.

these times (Figures 1 and 2). Two of the rabbits were investigated twice. Three days post-operatively a widening of the arteries and veins in the amputated leg was observed in all 4 rabbits investigated at this time (Figure 3). This widening increased progressively and was in some cases even more pronounced after 4 weeks, remaining unchanged after 4 months in all 3 rabbits observed during this period.

Vascular Richness

Angiographies of animals investigated immediately after the amputation showed no increase in vascular richness. In all animals investigated 3 days or longer after the amputation, increased vascular richness was seen (Figures 4 and 5). This development, which thus took place parallel with the vascular width changes, was found to be more pronounced 3–4 weeks after amputation (see Figures 6 and 7).

Figure 3. A stump investigated 3 days after amputation. The haematoma is visible due to the injection of thorotrast 6 hours after amputation. The vessels at the distal end of the stump surround the haematoma.



Figure 4. A stump 7 days after amputation. The vessels are dilated and the vascularization is increased. Owing to thorotrast given for an investigation 4 days earlier, dense contrast-filled regions are visible. No haematoma was developing at the first investigation, because the bleeding had already ceased.

Tortuosity of the Vessels

There was a greater incidence of tortuous vessels in those stumps exhibiting a high degree of vascular richness. They were noted in the main trunks and also peripheral branches of both arteries and veins. This phenomenon was most pronounced in the peripheral vessels, which often showed spiral-shaped (corkscrew) formation. The tortuous vessels were observed most often in rabbits investigated 3-4 weeks after the amputation.

Haematoma

The development of haematomas was studied in animals whose vascular systems had been filled with thorotrast immediately before the amputation. A small haematoma arose rapidly in the soft tissues in the distal region of the stump, and could be seen owing to the fact

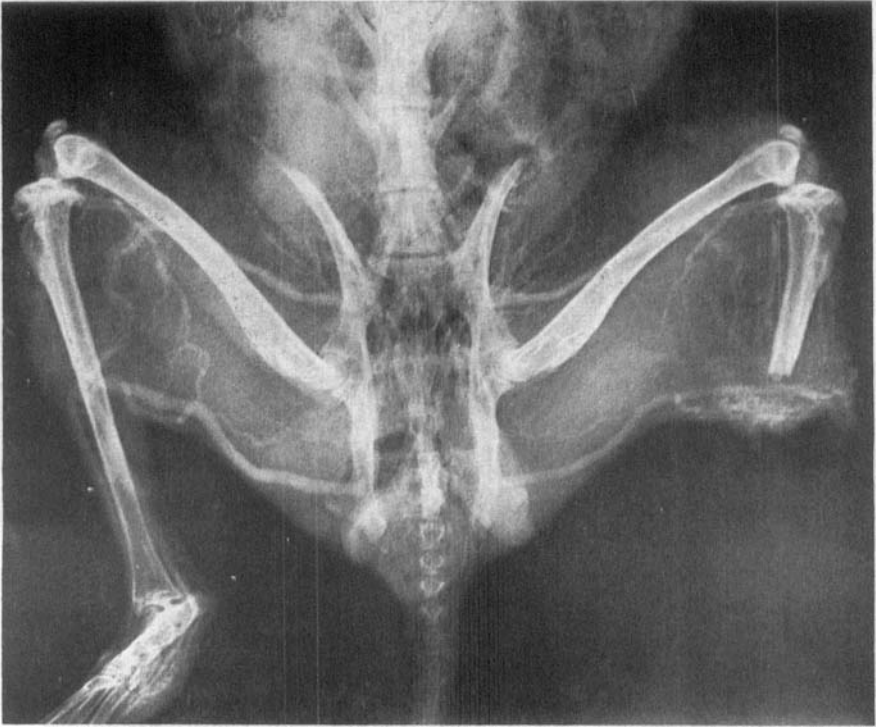


Figure 5. Two weeks after amputation the stump shows increased vascularization with an abundance of small tortuous vessels.

that the blood was mixed with contrast medium (Figures 1 and 2). The haematoma continued to develop, and after 3 days was relatively extensive (Figure 3). In some of the animals which had been injected with contrast medium shortly after the amputation, some of the vessels were seen to have separated, which as far as could be judged had been caused by the haematoma.

Bone Changes

A reformation of the distal bone end took place. The first sign of this was an increasingly dense zone immediately around the distal bone end. After 3 weeks a spur had developed at this site in all of the animals (Figures 6, 7 and 8). The shape and site of the spur formation corresponded to a certain degree to the position of the stump haematoma which was present at an earlier stage.

Figure 6. A stump investigated 3 weeks after amputation. A spur has developed and is surrounded by a large number of vessels.



Figure 7. A stump investigated 4 weeks after amputation. Note the marked spur formation.

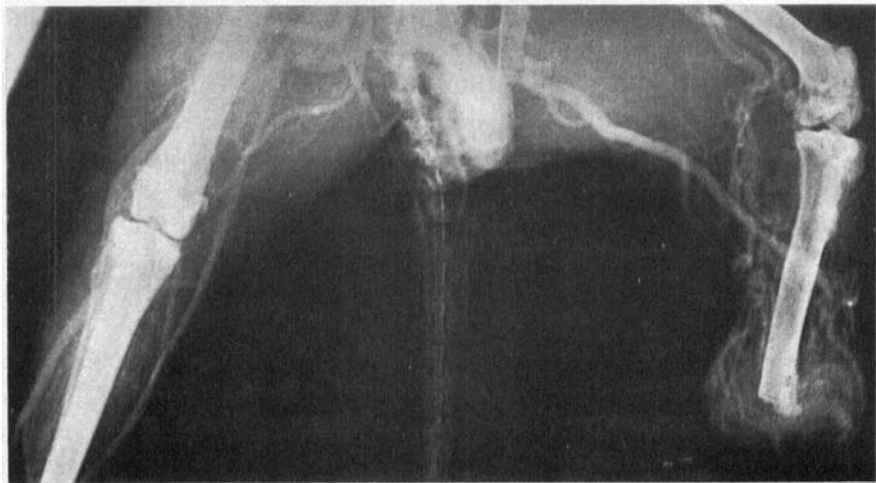


Figure 8. A stump investigated 4 months after amputation. A spur has developed and the vascularization in the stump is markedly increased.

DISCUSSION

The trauma which the amputation involves appears to lead to an immediate but transient decrease in the diameter of the arteries and probably also the veins. This may possibly be explained by an arterial spasm and vein spasm provoked reflectorically. *Kinmonth, Rob & Simeone* (1962) state that spasm may be either segmental or general, involving large proportions of a major artery after trauma. The incidence of arterial spasm among casualties is not known, however. Furthermore, swelling occurs in the stump due to tissue oedema and haematoma, and this may also possibly contribute to decreased vascular diameters in the first period of the post-operative phase.

The haematoma may develop rapidly after the amputation and become relatively extensive. The bleeding arises mainly from the medullary canal, but also of course from other damaged tissue.

Within 2-3 days a new phase arises in the circulatory conditions in the stump, when dilation of the arteries and veins takes place. This is an expression of increased blood flow in the traumatized region.

This vascular process continues to develop and appears to reach its maximum in 3-4 weeks. By this time during the healing stage of the stump there is pronounced hypervascularization, with a high degree of further vascular changes, namely tortuosity of arteries and veins.

Hulth & Olerud (1962), on studying the recovery process in the amputation stump, observed the development of both periosteal and endosteal callus. Abundant vascularization was demonstrated with microangiographic methods.

In the present study this callus formation was confirmed. It was expressed as a spur-like formation, which became visible after 3-4 weeks. Around this spur there was pronounced hypervascularization, which has been described previously.

The spur occurs at the site of the haematoma, which thus seems to participate in its development. It is possible that a part of the haematoma is transformed to an osteoid tissue, which in turn develops into the osseous spur.

On repeated thorotrast injections, an accumulation of thorotrast was sometimes seen in the stumps, mostly within the boundaries of the haematoma. This may indicate that thorotrast can be taken up by phagocytosing cells in the haematoma. This phenomenon was not studied closely in this investigation, however.

SUMMARY

15 rabbits were investigated angiographically immediately before and after leg amputation.

The investigation showed vascular and bone changes which occurred either immediately after or a short time after the amputation.

Immediately after the amputation the arterial diameter appears to decrease. After 2-3 days, however, the vascularization begins to increase, and when this is at its most pronounced stage an abundance of tortuous vessels is seen. These develop further and at the same time a spur formation arises on the bone stump. A possible cause of this spur is the post-operative haematoma, which during its different phases of development may also conceivably influence the vascular development.

RESUME

15 lapins ont été examinés angiographiquement immédiatement avant et après une amputation de la patte.

Les examens ont montré des modifications vasculaires et osseuses qui apparaissent immédiatement ou très peu de temps après l'amputation. Immédiatement après l'amputation, le diamètre artériel semble diminuer. Après 2-3 jours, cependant, la vascularisation commence à augmenter et quand elle est au stade le plus prononcé, on voit une abondance de vaisseaux tortueux. Ceux-ci se développent encore et il se forme simultanément un éperon sur le moignon. La cause possible de la formation de cet éperon est l'hématome post-opératoire qui, dans ses différentes phases de développement a peut-être une influence sur le développement vasculaire.

ZUSAMMENFASSUNG

15 Kaninchen wurde unmittelbar vor und nach einer Beinamputation angiographisch untersucht.

Die Untersuchung zeigt Gefäß- und Knochenveränderungen, die unmittelbar oder eine kurze Zeit nach der Amputation auftraten.

Unmittelbar nach der Amputation scheint der arterielle Durchmesser abzunehmen. Nach 2-3 Tagen jedoch beginnt die Gefäßversorgung zuzunehmen, und wenn dieser Zustand am ausgesprochensten ist, sieht man einen Überfluss von gewundenen Gefäßen. Diese entwickeln sich weiterhin und zu gleicher Zeit entsteht eine Sporenbildung am

Knochenstumpf. Eine mögliche Ursache dieses Sporens ist das postoperative Hämatom, das während der verschiedenen Phasen seiner Entwicklung möglicherweise auch die Gefässentwicklung beeinflusst.

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