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KNEE DISARTICULATION

An Experimental Study

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In a previous experimental study (Hansen-Leth & Reimann 1972) we found, in agreement with other investigators (Erikson 1965, Hulth & Olerud 1962), that hypervascularization develops in the stump during the first weeks after a crus amputation. The aim of the present study was to investigate the vascular changes occurring in connection with a knee disarticulation and to compare the result with earlier findings in connection with a crus amputation. As after an unsuccessful crus amputation the surgeon is often faced with the choice between knee disarticulation and reamputation on crus, for the purpose of comparison we have also investigated the state of vascularization after reamputation on crus.

MATERIAL

Altogether 26 female rabbits, aged approx. 3 months, were used for the investigation. In 10 of the rabbits disarticulation was performed at the right knee. At the operation the knee joint was opened with a curved incision with a large anterior flap so the patella was preserved, and gastrocnemii was resected at the insertion on the femoral condyles; the inferior patellar ligament was sutured to the cruciate ligaments when the popliteal artery was ligated at knee joint level, and then the skin was sutured.

As a supplement to the knee disarticulation, 6 of the rabbits had a minor osteotomy performed distally on the femur; in 2 cases in the form of partial removal of the femoral condyles; in 4 cases as partial osteotomy at the distal end of the femur; of these, 2 were performed in the frontal plane of the epiphysis and 2 in the metaphysis perpendicular to the longitudinal axis.

In the remaining 10 rabbits amputation was performed on crus twice with an interval of $\frac{1}{2}$ to 3 weeks; one rabbit had, however, been amputated three times (H 3). The amputations were performed with myoplasty, and all under Nembutal anesthesia. In 7 of the knee disarticulation cases healing was without reaction; in the remaining 3 cases a small dry fistula formation was found (X 7, X 11, and X 15). In the 6 combined operation cases (disarticulation/osteotomy) the stumps

healed without complications. In the series of 10 reamputated rabbits dry defect was discovered in the stump in 2 cases (M 6 and H 1).

The rabbits were killed at intervals of 1-4 weeks postoperatively. Prior to death tetracycline labelling with Reverin (30 mg/kg body weight) was made twice at an interval of 3 days.

In connection with the killing, arteriography was performed according to a modification of the Trueta-Harrison technique (Trueta & Harrison 1953). Under Nembutal anesthesia the peritoneum was opened and through a catheter in aorta abdominalis saline was perfused at 1 m pressure, as simultaneously the animal, heparinized beforehand, was bled through the vena cava. Perfusion was continued with 25 per cent micropaq for approximately 45 min followed by micropaq with 10 per cent formaline for about 15 min. Finally the skin was removed from the hind part of the body, which was fixed in 10 per cent formaline.

All the macroscopic specimens were radiographed, using X-rays from a Machlett A. E. G. tube (Carl Drenck). The pictures were taken at a distance of 40 cm, exposure time 12 min at 12 m. Amp. and 19 Kv. Industry film Gevaert Structurix D 7 was used. For evaluation of the pictures the classification described by Erikson (1965) was applied, taking into consideration the degree of vascular richness, the degree of dilation, and the presence of tortuous vessels. Here it should be mentioned that the arterial conditions in the rabbit differ in more ways from those in man, first and foremost in that no arteria profunda femoris exists; instead the arteria genu suprema as well as the arteria saphena are well-developed and branch off from the arteria femoralis as two independent branches, whereas in man the arteria saphena is a small branch of arteria genu suprema (Brookes 1971).

After radiography the amputation stumps were macroscopically studied. Then the distal part of the femur in disarticulation cases and the crus in reamputation cases, respectively, were sawn off the stumps. Corresponding parts from the sides not amputated were removed. All the bone specimens were then divided in half by sawing at the frontal plane. The posterior parts were used for bone angiography; they were decalcified and embedded in methyl metacrylate, then cut into slices of 2.5 mm thickness, photographed on a spectroscope plate at a distance of 40 cm, exposure time 12 min, 19 m. Amp. and 40 Kv, and evaluated in a stereo microscope SH XX-Jena, magnification $\times 10$. The anterior parts of the bone specimens were used for investigation of the growth factor on the basis of the tetracycline labelling. These specimens were undecalcified, fixed in methyl metacrylate, then cut out and ground down to a thickness of 50-60 μ . They were then studied in a fluorescence microscope where the interval between the two fluorescent lines on the metaphyseal side of the epiphyseal plate was measured. The interval, which corresponds with the growth in length of the bone between the two tetracycline labellings, may vary in the individual specimens owing to the curved sequence of the epiphyseal plate. Three measurements have been made on each specimen, and 2-3 specimens from each stump were measured.

RESULTS

As it appears from Tables 1 and 2, the investigations show that in connection with knee disarticulation hypervascularization in the soft

Table 1. Arteriographical findings in soft tissue.

Case no.	Operation	Time (weeks)	Vascular richness thigh	Vascular width		Tortuous vessels
				a.femoralis	a.poplitaea	
X 2	Knee disarticulation	1	2	1	1	1
X 5	-	1	1	1	1	1
X 6	-	1	1	1	1	1
X 4	-	1½	1	1	1	1
X 1	-	2	1	1	1	1
X 16	-	2	1	1	1	1
X 7	-	2½	1	-1	-1	2
X 9	-	3	1	-1	-1	2
X 11	-	3	1	-1	-1	2
X 15	-	4	-1	-1	-1	2

Vascular richness: 1: Same as at the corresponding level of the intact leg.
 2: Moderately increased.
 3: Markedly increased.
 -1: Less than at the corresponding level of the intact leg.

Vascular width: 1: Same as at the corresponding level of the intact leg.
 2: Moderate dilation.
 3: Marked dilation.
 -1: Narrower than at corresponding level of the intact leg.

Tortuous vessels: 1: None 2: Moderate occurrence 3: Abundant occurrence.

Time: Interval from operation to death of animal.

tissues of the femur was not found except in a single case; after re-amputation on crus changes were observed distally on the stump, where a distinct hypervascularization was found in all cases.

As regards the degree of dilation in the arteria femoralis and arteria poplitea, a change was not observed until 2½ weeks after knee disarticulation and then in the form of a calibre reduction in comparison with that of the side not amputated. We attempted to save the arteria genus suprema, which is stated to play a significant part in the blood supply to the stump, at the amputation, but it was seen only in a few cases and on the whole it was not possible to investigate it. After reamputation on the crus moderate vascular dilation was observed during the first two weeks (Figures 1 and 2).

The presence of tortuous vessels, which is not a normal occurrence in the musculature, is often observed after amputation (Eriksen 1965,

Table 2. Arteriographical findings in soft tissue.

Case no.	Operation	Time (weeks)	Vascular richness				Vascular width			Tortuous vessels
			Thigh	Calf	Distal end of the stump	a. fem.	a. popl.	a. gen. supr.		
M 8	Reamputation crus	½	1	1	2	3	2	1	1	
H 1	—	1	1	1	3	2	2	2	1	
M 6	—	1	1	1	2	3	1	1	1	
H 2	—	1½	1	1	2	1	1	1	2	
H 7	—	1½	—1	1	2	2	2	1	2	
H 5	—	2	1	1	2	3	3	2	2	
M 11	—	2	1	1	2	1	1	—1	1	
H 3	—	2	1	2	3	1	1	1	2	
H 8	—	2	1	1	2	1	1	1	1	
H 4	—	3	1	1	3	1	1	2	3	

Explanation as Table 1.

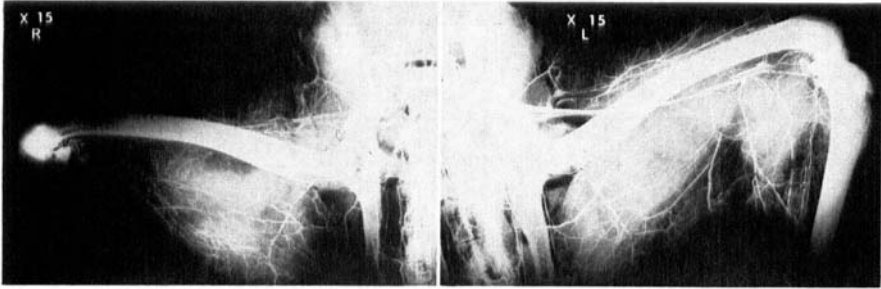


Figure 1. Radiograph from case X 15, angiography 4 weeks after knee disarticulation on the right side. On the amputated side the muscles of the calf are removed; marked constriction of a. femoralis and a. poplitea and slightly decreased vascularization in the muscles of the thigh are seen.

(The amputated side is seen to the left, the unamputated to the right.)

Hansen-Leth & Reimann 1972, Hulth & Olerud 1962). As shown in the tables, they occurred $2\frac{1}{2}$ weeks after disarticulation, after reamputation on crus already after $1\frac{1}{2}$ weeks.

In the 6 cases (Table 3) where in connection with the knee disarticulation a supplementary osteotomy was performed distally, no hypervascularization was observed in the soft tissues; tortuous vessels were found in 4 of these cases, starting after 2 weeks.

In Tables 4 and 5 the results are calculated, partly of the angiographic findings in the bones, and partly of the effect of the amputation on growth by means of tetracycline labelling.

The angiographic findings (Figures 3 and 4) were evaluated in a

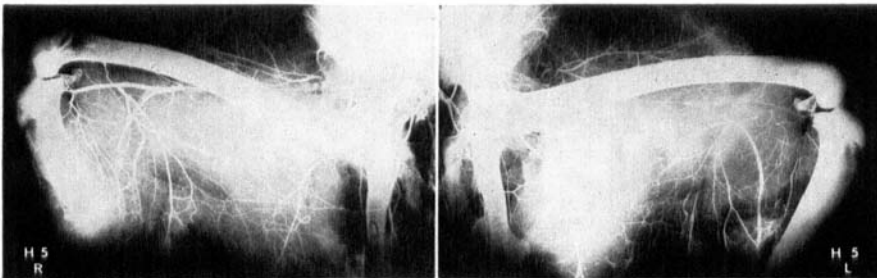


Figure 2. Radiograph from case H 5, angiography 2 weeks after reamputation on right side of crus. On the stump, which is covered with muscles, there is marked dilation of a. femoralis, a. poplitea and a. genus suprema. Hypervascularization in the muscles of the calf and presence of tortuous vessels in the stump are seen.

(The amputated side is seen to the left, the unamputated to the right.)

Table 3. Arteriographical findings in soft tissue.

Case no.	Operation	Time (weeks)	Vascular richness thigh	Vascular width		Tortuous vessels
				a. femoralis	a. popliteae	
X 14	Knee disart. +part. osteotomy in epiphyses	2½	1	1	2	3
X 19	—	2½	1	1	1	2
X 18	Knee disart. +fem. condyl resection	2½	1	1	-1	1
X 17	—	3	1	-1	1	2
X 20	Knee disart. +part. osteotomy in metaphyses	2	1	-1	-1	3
X 21	—	2	1	-1	-1	1

Explanation as Table 1.

Table 4. Angiographic findings and tetracycline labelling in bone.

Case no.	Operation	Time (weeks)	Angiographic findings in bone (vascular richness)	Growth at the epiphyseal plate
X 2	Knee disarticulation	1	-1	
X 5	—	1	-1	-33
X 6	—	1	-1	-50
X 4	—	1½	1	-25
X 1	—	2	1	
X 16	—	2	2	
X 7	—	2½	2	0
X 9	—	3	-1	-25
X 11	—	3	1	+50
X 15	—	4	3	+100

Time: Interval from operation to death of animal.

Vascular richness: 1: Same as at the intact leg.
2: Moderately increased.
3: Markedly increased.
-1: Decreased.

Growth difference: Expressed in percentage of the growth of the unoperated side.

Table 5. Angiographic findings and tetracycline labelling in bone.

Case no.	Operation	Time (weeks)	Angiographic findings in the bone (vascular richness)	Growth at the epiphyseal plate
M 8	Reamputation crus	½		+55
H 1	—	1	3	
M 6	—	1	2	+120
H 2	—	1½	2	+50
H 7	—	1½	3	+100
H 5	—	2	3	+100
M 11	—	2	2	+106
H 3	—	2	2	+100
H 8	—	2	3	+200
H 4	—	3	2	+100

Explanation as Table 4.

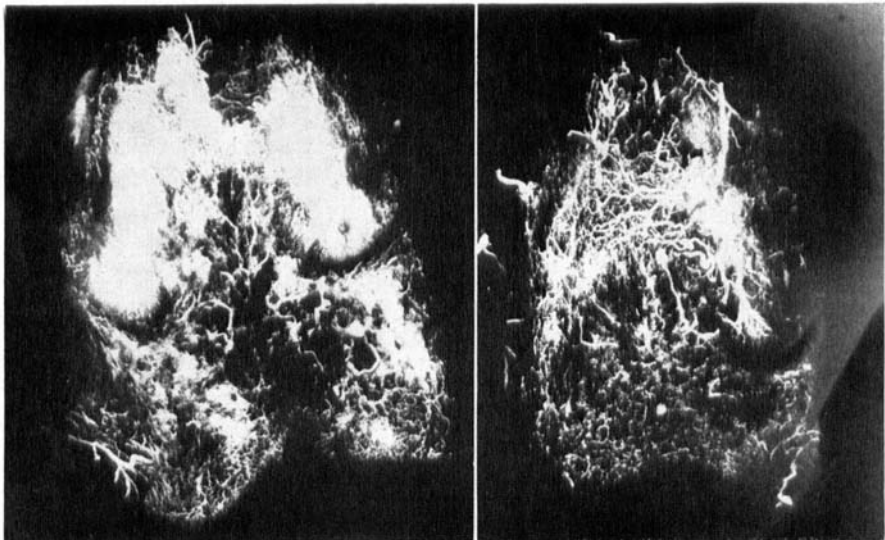


Figure 3. Illustrates bone angiography from case X 4, 1½ weeks after knee disarticulation on right side. As regards the vascularization, no difference between the amputated and unamputated side is found, neither in the epiphysis (bottom) nor in the metaphysis (top).

(The amputated side is seen to the left, the unamputated to the right.)

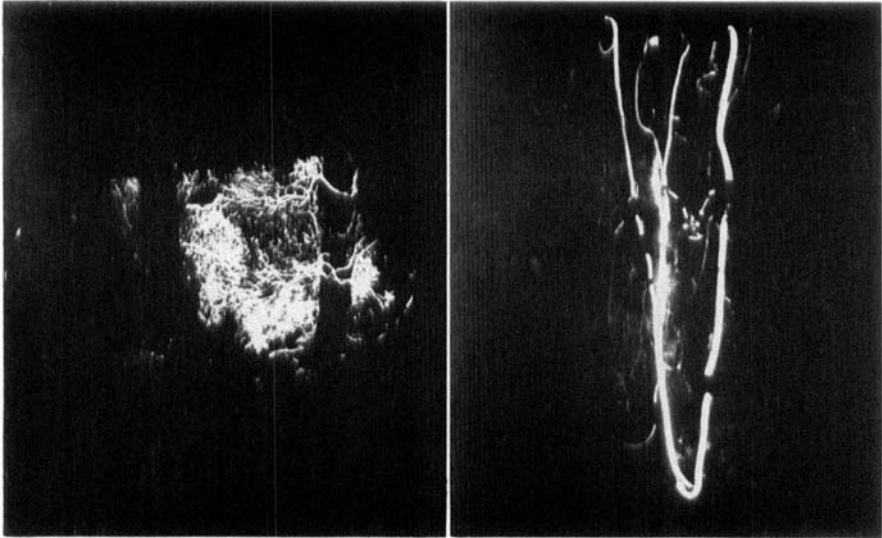


Figure 4. Illustrates bone angiography from case H 8, 2 weeks after reamputation on right side of crus. The amputated side at left shows marked hypervascularization in the stump compared with the unamputated side at right. The bone from the normal side is from the same level as that of the amputated. The lower end of the stump is seen distally.

stereo microscope. As illustrated in Table 4, hypervascularization after knee disarticulation was only observed in 3 cases, and by comparison with the normal side it was localized to the epiphysis. After reamputation distinct hypervascularization was always observed in the stump (Table 5). As regards the effect of amputation on growth of bones, Table 4 shows that in cases of knee disarticulation no actual growth changes occur; after a slight deceleration of growth during the first week, a moderate acceleration of growth occurs 3–4 weeks after amputation. Contrary hereto, a clear acceleration of growth always takes place in the reamputation cases (Table 5).

In the series of 6 cases (Table 6) with osteotomy performed supplementary to disarticulation, hypervascularization in the bone was found in 5 cases (the interventions were performed 2–3 weeks prior to death), and in these also a considerable increase of growth was found.

Table 6. *Angiographic findings and tetracycline labelling in bone.*

Case no.	Operation	Time (weeks)	Angiographic findings in bone (vascular richness)	Growth at the epiphyseal plate
X 14	Knee disart. +part. osteotomy in epiphyses	2½	2	+200
X 19	—	2½	—1	+233
X 17	Knee disart. +fem. condyl resection	3	2	
X 18	—	2½	2	+150
X 20	Knee disart. +part. osteotomy in metaphys.	2	3	+130
X 21	—	2	2	+100

Explanation as Table 4.

DISCUSSION AND CONCLUSION

By clinical and experimental studies it has previously been proved that in connection with amputation on the crus vascular changes occur in the form of transient hypervascularization in the soft tissues of the stump and moderate dilation of the large vessel (Erikson 1965, Hansen-Leth & Reimann 1972, Hulth & Olerud 1962). By disarticulation at the knee on rabbits we did not find these changes; no hypervascularization occurred in the musculature and no volume change in the larger vessels during the first weeks after amputation; but after 2½ weeks a constriction of arteria femoralis and arteria poplitea was observed, possibly indicating that these vessels adjust themselves to the decreased volume of tissue they must supply with blood.

By reamputation on the crus a considerable hypervascularization was noted in the distal part of the stump already after one week, and it was more pronounced than that observed after an amputation on the crus (Hansen-Leth & Reimann 1972). After reamputation a moderate dilation of the large vessels was also found.

As regards the presence of tortuous vessels, the origin of which is not yet quite elucidated (Hansen-Leth & Reimann 1972), they have been found in a number of cases after amputation on the crus (Erikson 1965, Hansen-Leth & Reimann 1972, Hulth & Olerud 1962), just as they may be observed in connection with artery occlusion (Allen et al. 1946). In the present study tortuous vessels always occurred after a period of about 2½ weeks after disarticulation at the knee and a little earlier after reamputation on the crus. Erikson (1965) proved that the tortuous vessels develop especially in relation to stump pains and necrosis in the stump. Tortuous vessels were found in the three cases of dry fistula formation after disarticulation, whereas not in the two reamputation cases with defect in the stump.

In connection with amputation on the crus (Hansen-Leth & Reimann 1972) as well as with reamputation on the crus, pronounced hypervascularization in the bone was already observed a few days after surgery; this was not observed in knee disarticulation cases unless an osteotomy was performed at the same time.

Correlation was found between the incidence of hypervascularization and growth stimulation; thus the microangiographic investigations of the epiphysis disclosed hypervascularization in such cases where growth stimulation was observed. This is in agreement with the demonstration by Trueta & Morgan (1960), that growth stimulation depends first and foremost on the vascularization of the epiphysis.

Not only in connection with osteotomy, but also in connection with changes in the vascular system may an effect on the growth of bone be seen. Growth acceleration is thus noted in connection with arterial-venous shunt formation, increase of the arterial flow, or venous stasis. Also immobilization of the extremity without any other intervention may cause changes in the vascular conditions and have an effect on the growth of bone. Thus Hulth & Olerud (1962) found that by immobilization an increased blood flow is observed, as is a dilation of the larger vessel and the formation of tortuous vessel. Sundén (1967) reported a growth acceleration in the proximal tibial epiphysis following immobilization obtained by cutting of the Achilles tendon. The hypervascularization in the bone and the growth acceleration which we found 3-4 weeks after knee disarticulation, may be a consequence of the lack of use of the extremity operated on.

Contrary to earlier findings in connection with crus amputations, the investigations showed that in connection with knee disarticulation no vascular changes occur in the soft tissues. The vascular changes

are conditioned, among other things, by the development of collaterals branching off from the large branches of arteria femoralis; their preservation is attempted in connection with knee disarticulation as well as with crus amputation.

The difference between the two operations, apart from the cutting of bone, is that in connection with an amputation the preserved musculature is cut and sutured.

In case of reamputation on the crus a marked increase in vascularization was noted distally in the soft tissue on the stump and more pronounced than in connection with amputation on crus.

An osteotomy, as that made in the six cases where knee disarticulation was combined with osteotomy at the distal end of the femur, had no effect on the vascularization in the soft tissues.

From a clinical point of view these circumstances may be of interest, as the absence of hypervascularization in the soft tissues after the knee disarticulation may possibly be a contributory cause to the known healing problems often bound at this level (Rogers 1940, Mazet & Hennessy 1966).

SUMMARY

In connection with knee disarticulation performed on growing rabbits, the vascular state in soft tissues and bone and the effects of the operation on the growth of bone were investigated. The results were compared with an earlier investigation of the vascularization after amputation on the crus and a supplementary investigation of the vascularization conditions in connection with reamputation on the crus. Moreover, investigations have been made of changes occurring when the knee disarticulation is combined with a minor osteotomy at the distal femur end.

After knee disarticulation, contrary to earlier findings in crus amputations, no hypervascularization occurred in the soft tissues and no dilation of the larger vessels was found, but rather a calibre decrease was noted after 2½ weeks. By reamputation on the crus a distinct hypervascularization was found distally in the soft tissues of the stump and more pronounced than after amputation on the crus. When knee disarticulation was combined with a minor osteotomy, no changes occurred in the soft tissues. Tortuous vessels were found after disarticulation as well as after reamputation approx. 2 weeks post-surgery.

Angiographic studies of bone have disclosed that no hypervasculari-

zation occurs after knee disarticulation unless this operation is combined with an osteotomy, and that pronounced hypervascularization in the bone always occurs in reamputation cases, just as it was proved in a previous investigation of crus amputation. Correlation was found between the occurrence of hypervascularization in bone and growth stimulation.

It is concluded that the disclosed absence of hypervascularization after knee disarticulation may influence the healing tendency at this level.

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