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SURGERY OF ACUTE ARTERIAL INJURIES
IN CONNECTION WITH FRACTURES
AND DISLOCATIONS

ERKKI V. S. KOSKINEN

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I INTRODUCTION

Acute traumatic arterial injury in connection with fracture is one of the most serious conditions as regards traumas of the extremities. As compared to other states causing insufficiency of circulation in the extremities, such as aneurysm, arteriovenous fistulae or arteriosclerosis, which are chronic of character and in which there are collateral paths, injuries of the blood vessels, produced by trauma, constitute an immediate menace to the extremity: they may result in loss of the extremity or in severe functional disturbance.

In comparison with the progress that has taken place in the field of traumatic, and specially reconstructive surgery, arterial lesions in association with fractures have not met with the understanding and attention actually deserved by this severe complication. As a consequence, many cases of this kind with fracture and arrest or disturbance of blood flow owing to arterial lesion have led to loss of the extremity or to disability on account of claudication, muscular atrophy, pareses and coldness. Not much interest has been attached to surgery of these injuries. The modern reconstructive surgery in this particular field has, however, created possibilities implying a decisive change of prognosis.

According to the material of *de Bakey* and *Simeone* (1) from World War II, simple ligation of the common iliac artery results in an incidence of 53 per cent amputation of the leg, ligation of the common femoral artery in 81 and of the superficial femoral artery in 54, and ligation of the popliteal artery results in 72 per cent. gangrene and loss of the extremity. On the other hand in series of arterial injuries from the time of the Korean war, with treatment consisting of primary repair and reconstruction, loss of extremity ensued approximately in 15 per cent (5, 6), and in cases with major vascular lesion amputation became necessary later in 8.8 per cent only (7). These figures already serve to show that amputation of a considerable number of extremities could be avoided by applying reconstructive arterial surgery instead of ligation. In addition, later functional disturbances in the extremity, muscular atrophy, ischaemic contractures and paraesthesias occur in fewer instances (5).

Accidents occurring in civilian life provide more favourable conditions for repair of the injured extremity and it is appropriate to assume that the less destructive nature of most civilian injuries and, particularly, the shorter time within which definitive treatment can be instituted may even further improve the results.

Published reports on arterial injuries occurring in connection with fractures are rather few. Earlier reports deal mainly with gangrene, and amputation was the sole measure of treatment. Recently some successfully treated cases have been described in which the extremity could be saved (2, 10, 13, 14, 15, 17).

With respect to therapy we are confronted with a new problem because two therapeutic principles are concerned, namely, those of vascular surgery and of bone surgery. This report concerns an effort to apply these principles to cases of traumatic arterial injuries associated with fractures and dislocations which would not be considered amenable to surgery by older standards. It is intended to attract greater attention to arterial injury in association with fractures and dislocations by pointing out the importance of this complication. An attempt to a more active therapeutic approach in view of restoration of blood flow in the injured extremity is essential. Thus it would be possible to create more favourable conditions for union of the fracture to take place.

II MATERIAL WITH CASE REPORTS

The most essential aspects of the cases included in the present material, relating to the type of the arterial injury and fracture, to its preoperative symptoms and surgical treatment and to the results, can be seen in Table 1.

The material consists of 18 patients treated from 1960 to the beginning of 1962 in the Clinic for Orthopaedics and Traumatology, University of Helsinki, all but two of them (cases No. 6 and 7) having been treated by the present writer. In all instances the immediate arterial injury was an association of fracture or dislocation. The injury of the cases has been generally of severe degree and in most cases the injury has created a critical condition as regards saving of the extremity. None of the transient or slight peripheral ischaemic states have been taken into account. During the time in question altogether 410 closed and open fractures of equivalent location have been treated in this hospital, which received a great number of severe traumatologic cases. This implies that severe arterial injury has accompanied skeletal trauma in 4.4 per cent. of the cases. In addition to arterial injury and skeletal trauma, most patients were seriously traumatized, in a state of shock and they had cerebral, thoracic and abdominal traumata indicating surgical treatment. Sixteen of the patients had not previously experienced any circulatory disturbances. The history of two cases (No. 1 and 13) contains slight symptoms of arteriosclerosis obliterans, these patients, however, being able to do their daily work. All patients were male, most of them young in age. The ages varied between 14 and 69 years.

Case Reports

The first four cases, all of them due to traffic accidents, displayed trauma of the femoral artery, accompanying fracture of the femur. In cases No. 1 and 4 there was traumatic thrombosis in connection with the femur fracture;

A brief report of this work has been presented at the meetings of the Finnish Surgeons' Association on May 5 1962, and of the Finnish Orthopaedic Association on November 25, 1961.

TABLE 1. PRINCIPAL DATA ON THE MATERIAL OF THE PRESENT WORK.

<i>Case; Age, years</i>	<i>Type of arterial injury</i>	<i>Bone fracture or dislocation</i>	<i>Associated injuries</i>	<i>Preoperative vascular signs and arteriographic findings</i>	<i>Surgical treatment</i>	<i>Results</i>
Injured artery: Femoral artery						
No. 1 69	Thrombosis	Compound femur fracture	Cerebral contusion. Rupture of the kidney.	Pedal pulses not palpable. Sensory and motor disturbances below the knee. Total occlusion of the femoral artery. Local gangrene developed.	Thromboendarterectomy. Intramedullary nailing. Cutaneous transplantation.	Strong dorsal pedal and posterior tibial artery pulses. Motor and sensory function restored. Gangrene healed. Free passage in femoral and distal arteries. Fracture consolidated.
No. 2 16	Obliteration	Comminuted femur fracture	Cerebral contusion	Ischaemic paralysis of the leg with ulcerations, coolness and claudication. Dorsal pedal artery pulseless, posterior tibial artery almost pulseless. Obstruction of femoral artery.	Repair with autogenous vein graft	Strong peripheral pulsations, warm extremity, ulcerations healed. Unrestricted gait. Femoral artery fills completely including the distal arteries. Fracture consolidated.
No. 3 26	Traumatic spasm	Compound femur fracture	Cerebral contusion. Intracranial haemorrhage.	Extremity cold distally of the knee, pulseless. Femoral artery angulated, spastic at the point of fracture, fills poorly.	Liberation and adventitia stripping. Retrograde flushing. Internal fixation.	Dorsal pedal and posterior tibial arteries distinctly palpable. Extremity warm. Patient expired later as a result of cerebral haemorrhage.
No. 4 14	Thrombosis	Comminuted femur fracture	Cerebral contusion. Traumatic haemo-pneumothorax.	Peripheral pulsations not palpable. Early deep gangrene of foot and lower leg. Occlusion of femoral artery at the point of fracture.	Thoracostomy. Skeletal traction. Amputation.	Recovery. Stump healed.
Injured artery: Popliteal artery						
No. 5 62	Rupture	Dislocation of knee joint	Dislocation of femur. Acetabulum fracture. Fracture of the leg.	Extremity cold distally of the knee, pulseless. Ischaemic paralysis. Popliteal artery only fills with contrast medium up to the boundary of the femoral artery.	Repair with Teflon prosthesis. Retrograde flushing. Amputation.	Teflon prosthesis worked initially. Progressive ischaemia resulted in gangrene. Stump healed.

No. 6 30	Thrombosis	Dislocation of knee joint	None	Ischaemic paralysis and early peripheral gangrene. Occlusion of popliteal artery.	Thrombectomy. Flushing. Amputation.	Irreversible ischaemic state and gangrene. Stump healed.
No. 7 31	Rupture	Dislocation of knee joint	None	Far progressed gangrene of foot and lower leg. Arteriography showed the popliteal artery to be severed at the knee joint gap	Amputation	Stump healed
Injured artery: Anterior and/or posterior tibial arteries						
No. 8 19	Thrombosis	Comminuted fracture of the leg	Cerebral contusion. Fracture of pelvis. Fracture of tibial condyle.	Foot cold and anaesthetic, disturbed motility. Pedal pulses not palpable. Arteriography showed occlusion of anterior tibial artery and spastic posterior tibial artery.	Thrombectomy. Retrograde flushing. Internal fixation. Iliac bone grafting.	Strong pedal pulses. Sensibility and motility intact. Arteriography shows all arteries of the extremity filling without defect. Bony consolidation of the fracture.
No. 9 18	Thrombosis	Compound fracture of the leg	Cerebral contusion. Rupture of the liver. Fracture of humerus.	Peripheral ischaemic paralysis. Pedal pulses not palpable. Arteriographically occlusion of anterior tibial artery at the point of fracture.	Thrombectomy. Retrograde flushing. Laparotomy. Suture of liver rupture.	Peripheral pulses strong, foot warm. Sensibility and motility normal. Arteriography shows all arteries of the extremity filling without defect. Fracture consolidated.
No. 10 19	Traumatic spasm	Compound fracture of the leg	None	Foot cold and anaesthetic, restricted motility. Peripheral contusion. Posterior tibial artery pulseless, dorsal pedal artery almost pulseless.	Liberation and adventitia stripping. Internal fixation with fibula transposition.	Foot warm, sensibility restored, as well as motility. Slight residual contusion of toes. Strong pulsations. Fracture consolidated.
No. 11 23	Traumatic spasm	Compound fracture of the leg	Fracture of the leg	Pedal pulses not palpable. Arteriographically all arteries of the leg angulated, spastic at the point of fracture, not filling in the region of the foot.	Fasciotomy. Cutaneous transplantation.	Foot vital and warm, gangrene on the medial side healed. Fracture consolidated.
No. 12 16	Thrombosis	Compound fracture of the leg	Cerebral contusion. Intracranial haemorrhage. Compound fracture of femur.	Pedal pulses not palpable. Extremity cold, pale distally of middle of lower leg. Arteriographically the arteries fill only to the point of fracture.	Thrombectomy. Craniotomy. Evacuation of subdural haematoma.	Peripheral pulsations palpable, extremity warm. Patient expired as a result of cerebral lesion.

Table 1, Continued

<i>Case; Age, years</i>	<i>Type of arterial injury</i>	<i>Bone fracture or dislocation</i>	<i>Associated injuries</i>	<i>Preoperative vascular signs and arteriographic findings</i>	<i>Surgical treatment</i>	<i>Results</i>
No. 13 63	Thrombosis	Compound fracture of the leg	None	Early peripheral gangrene. Pedal pulses not palpable. Arteriographically arteriosclerotic changes in femoral artery and complete arrest of blood flow at the point of the leg fracture.	Amputation	Stump healed
No. 14 21	Traumatic spasm	Compound fracture of the leg	Fracture of the leg	Imminent peripheral gangrene. Pedal arteries pulseless. Arteriographically arrest of anterior tibial artery, posterior tibial artery spastic.	Liberation and adventitia stripping. Flushing. Intramedullary nailing.	Peripheral pulses strong. Sensibility and motility normal. Fracture consolidated.
No. 15 24	Traumatic spasm	Compound fracture of the leg	None	Peripheral ischaemic condition. Arteriographically angulation of tibial arteries. Anterior tibial artery not filling, posterior tibial artery spastic below the fracture level.	Lumbar sympathectomy. Internal fixation and iliac bone graft.	Pedal pulses palpable, foot warm. Fracture consolidated.
No. 16 35	Traumatic spasm	Dislocation of ankle	None	Dorsal pedal artery pulseless, tibial posterior artery almost pulseless. Foot cold, pale.	Decompression. Open reduction.	Strong pulsations. Foot warm, good function.
Injured artery: Brachial artery						
No. 17 26	Rupture	Fracture-dislocation of the elbow joint	None	Peripheral ischaemic paralysis. Radial and ulnar arteries pulseless.	Resection and arteriorrhaphy. Excision of capitulum radii.	Radial artery pulse strong. Arteriographically good function in brachial, ulnar and radial arteries.
No. 18 33	Thrombosis	Compound fracture of humerus	None	Extremity cold, pulseless. Early finger gangrene. Incomplete filling of brachial artery at the point of fracture.	Liberation. Adventitia stripping. Flushing. Bone transplantation.	Extremity warm. Pulsation of radial artery palpable. Finger stumps healed. Consolidation of the fracture.

in the first case it was treated by thrombectomy and thromboendarterectomy, and medullary nailing of the fracture was performed at the same time. In case No. 4 restoration of circulation was contraindicated on account of other injuries and the extremity was lost. In case No. 2 the obstruction ensuing after rupture of the femoral artery was corrected by autogenous vein graft, and in case No. 3 circulatory disturbance produced by traumatic spasm of the artery was treated by liberation and adventitia stripping.

Case No. 1. F.G., farmer, aged 69. As a result of a traffic accident, there was on the right side a compound, dislocated fracture of the femur and injury of femoral



Fig. 1 *Case No. 1.* Traumatic thrombosis of the femoral artery in association with compound femur fracture, causing peripheral ischaemic paresis and gangrene.

Fig. 2 *Case No. 1.* Postoperative arteriogram three months after thrombectomy and thromboendarterectomy of the femoral artery. Internal fixation of the fracture by medullary nailing was done in connection with arterial surgery.



Fig. 3 Case No. 1. Gangrene as a result of traumatic thrombosis of the femoral artery in association with femur fracture.

Fig. 4 Case No. 1. Ten months after arterial surgery and medullary nailing, the ischaemic state has been corrected; arterial pulsations in the extremity are strong. The fracture is consolidated, scars are visible.

artery, cerebral contusion, and rupture of the kidney. Foot and lower leg were cold and there was no demonstrable sensory or motor function below the knee. Popliteal and pedal pulses could not be palpated, and arteriography revealed an obstruction in the femoral artery at the point of fracture. Fig. 1. The patient's condition was critical owing to associated traumata and not until two weeks after the accident, when there were deep gangrenes (Fig. 3) in calcaneus and lower leg, was thrombectomy of femoral artery performed, as well as intramedullary nailing of the femur. — At the point of fracture, the femoral artery was hard and pulseless, in conformity with the arteriographic findings. The arteriotomy wound was filled by a fresh thrombus, which continued proximally and distally as a thickening of the intima. Upon removal of the thrombus, 15 cm in length, and upon thromboendarterectomy, blood flow was completely free. The leg was warm after the operation and pedal pulses could be



Fig. 5 Case No. 2. Obstruction of the femoral artery after rupture and ligation in connection with femur fracture. Severe ischaemic state, ulcerations, coldness and claudication ensued upon the injury. — At operation, three months later, the femoral artery was strongly adherent to the bone, angulated, pulseless and occluded.

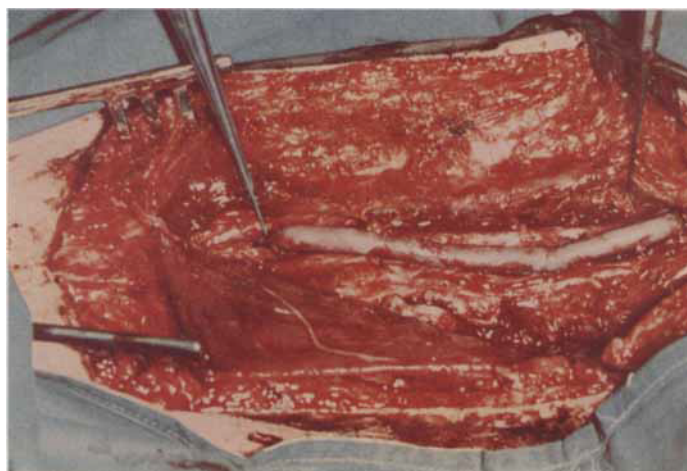


Fig. 6 Case No. 2. Restoration of blood flow was achieved by autogenous vein transplantation.

strongly felt. One week later excision of necrosis and cutaneous transplantation was made. Arteriography three months later (Fig. 2) showed that the femoral and distal arteries filled rapidly, and well. Ten months after the operation (Fig. 4) there were no signs of circulatory insufficiency in the extremity; the fracture had consolidated and the patient had returned to his normal mode of life.

Case No. 2. S. J., painter, aged 16. As a result of traffic accident, the patient had a fracture of the left femur, and cerebral contusion. The leg was cold, the foot insensible and could not be moved. In connection with nailing of the femur, in the local hospital, it was mandatory to ligate the femoral artery owing to rupture and profuse haemorrhage. On account of insufficiency of arterial circulation, the patient was transferred to our clinic after three months, when ischaemic paralysis of the leg, peripheral ulcerations and strong muscular atrophy and claudication were ob-



Fig. 7 *Case No. 2.* Arteriogram three months after the autogenous vein grafting, in obstruction of the femoral artery, showing good function of the artery.

Fig. 8 *Case No. 2.* Nine months after the arterial surgery. There are no symptoms of arterial insufficiency, peripheral pulsations in the extremity are strong and the fracture is consolidated.

served. Arteriography showed a constriction in the artery below the middle of the femur at the point of fracture, and deficient filling in the peripheral arteries. — Operation revealed that in the region indicated by the arteriography the femoral artery was strongly adherent to the underlying femur at the very point of fracture, which had not consolidated. The artery was narrow, hard, pulseless on a length of 10 cm (Fig. 5). Proximally and distally of this section it had soft consistency and its pulsation could be felt. Arteriotomy revealed thick deposits in the intima; after their removal there was only minimal blood flow. Autogenous vein graft was performed, using the vena saphena, end-to-side (Fig. 6). The graft worked well and the leg was warm after the operation; strong pedal pulses were palpable. Contrast arteriography three months later (Fig. 7) showed good and rapid filling in the entire femoral artery, continuing into the distal arteries. The necrotic wounds

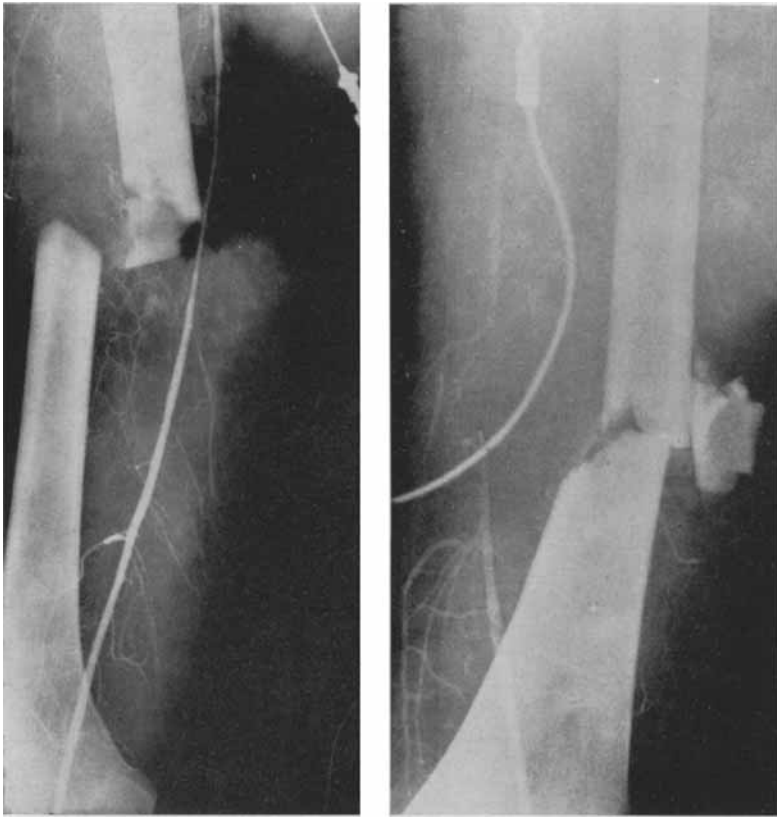


Fig. 9 Case No. 3. Traumatic vasospasm of the femoral artery in association with open, dislocated femur fracture. The circulation of the extremity is seriously deranged as a result of the arterial injury.

Fig. 10 Case No. 4. Arteriogram revealing a defect in the femoral artery at the point of fracture in association with femur fracture.

on the lower leg and in the metatarsal region healed and closed rapidly. On follow-up examination after nine months the fracture was clinically consolidated and the patient had no symptoms of arterial insufficiency in his leg. Dorsal flexure of the foot was slightly reduced, but the patient was able to move freely and to work (Fig. 8).

Case No. 3. L. R., welder, aged 26. As a result of traffic accident, the patient had a severe compound fracture of the right femur, and a cerebral lesion. Two hours later, when the patient was brought into the hospital, he was under shock. The right thigh was markedly swollen, deformed, with a gaping wound on the inner side. The leg was cold, pulseless, and could not be moved by the patient. X-rays revealed dislocated fracture of the femur, which displayed a shortening. On ateriography (Fig. 9) the femoral artery was found to bend medially at the point of fracture and to be narrowly filling and spastic over about 15 cm. On exploration carried out after the general condition had improved, the femoral artery was very narrow and no pulsation could be observed. After performed liberation, adventitia stripping and treatment with warm saline the artery became wider and pulsation was obtained. There was no thrombosis. At the same time internal fixation of the fracture was carried out. After the operation the leg was warm and the peripheral pulsations were clearly palpable. However, the patient expired later as a result of cerebral haemorrhage.

Case No. 4. J. Y., machinist trainee's son, aged 14. As a result of traffic accident, the patient had a fracture of the right femur and traumatic thrombosis of the femoral

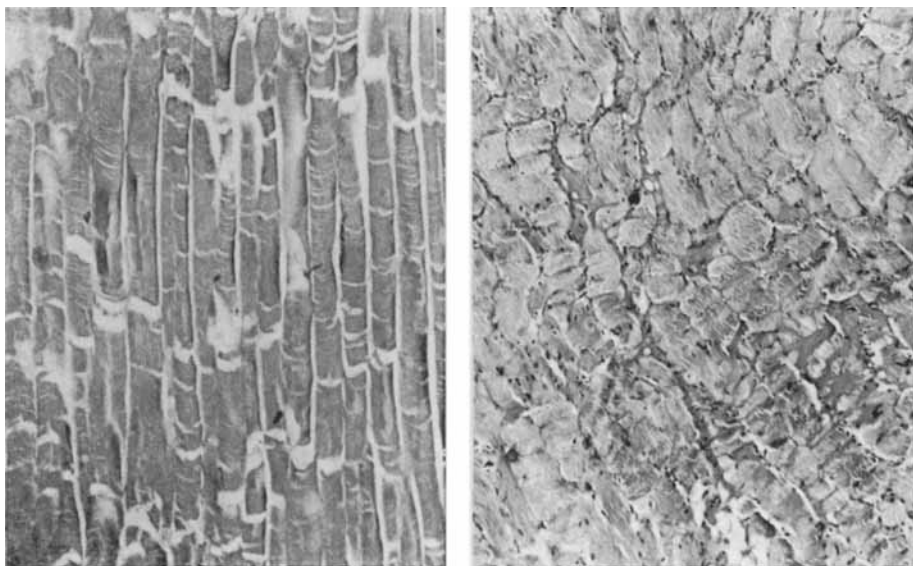


Fig. 11 *Case No. 4.* Typical muscular necrosis as a result of the ischaemic state. Muscle fibres can be recognized in the photomicrograph but there are no nuclei (Left). — On the right, the micrograph of a biopsy from the boundary between healthy and necrotic tissue $\times 120$.

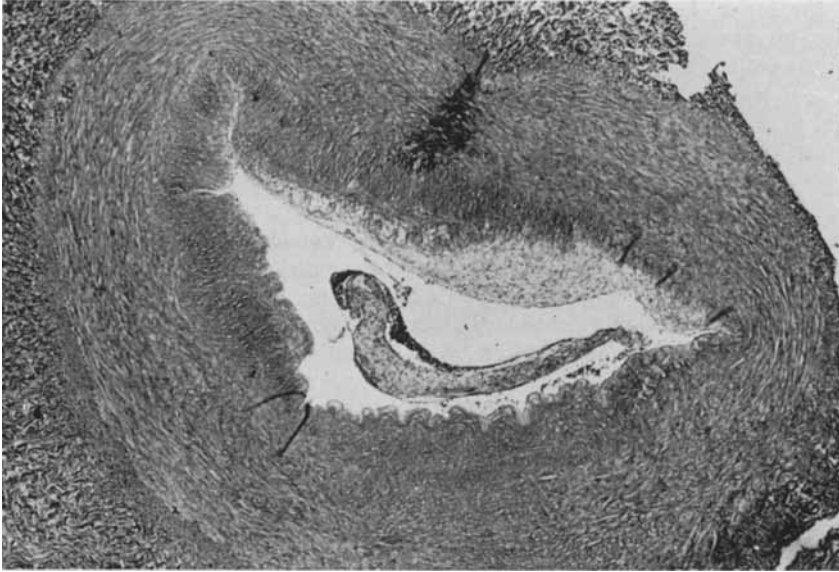


Fig. 12 Case No. 4. Photomicrograph of the femoral artery, revealing proximally to the thrombosis strongly thickened intima and new formation of connective tissue. This is a result of trauma to the arterial wall. $\times 60$.

artery. Moreover, cerebral injury and thorax compression, displacement of mediastinum, causing breathing difficulties and indicating thoracostomy. Operation of the artery was counterindicated by these injuries. A line of demarcation developed in the region of the ankle, and deep necrosis in the lower leg. Arteriography (Fig. 10) revealed a contrast medium defect at the point of fracture in the femoral region. Popliteal and posterior tibial arteries filled well, but the anterior tibial artery was not filled in its distal part. Syme's amputation was performed after three weeks, but on account of poor healing of the stump amputation of the lower third of the thigh had to be done after two months. Examination of the leg showed that the greater part of all its muscles were in necrosis (Fig. 11) even above the knee as far as the quadriceps muscles. This finding was surprising as compared with the arteriography, but it is explained by acute femoral artery obstruction (Fig. 12) with subsequent irreversible ischaemia, aggravated by a severe state of shock.

The next three cases are injuries of the popliteal artery. In case No. 5, anterior dislocation of the knee joint resulted in severance of the artery; in case No. 7 the same result was produced by compression of the knee and lateral dislocation. The thrombosis in case No. 6 was a sequel of a major hyperextension injury. Reconstruction with a Teflon prosthesis was done in the first-mentioned case and thrombectomy in case No. 6. However,



Fig. 13 *Case No. 5.* Serious dislocation of the knee joint, causing transection of the popliteal artery.

Fig. 14 *Case No. 5.* Arteriograph showing arrest of the contrast medium in the popliteal artery above the knee joint.

definitive treatment could only be instituted at a later stage and the prognosis was bad.

Case No. 5. T.B., farm worker, aged 62. The patient fell from a tractor and sustained anterior dislocation of the right knee joint (Fig. 13), and rupture of the popliteal artery. Moreover, luxation of femur, acetabulum fracture, and fracture of the left lower leg. Arteriography revealed filling with contrast medium up to the boundary between the popliteal and femoral arteries (Fig. 14). Exploration showed the popliteal artery to be severed altogether. Although more than two days had passed since the accident, an attempt at reconstruction was made with a Teflon prosthesis by the end-to-end technique. The distal thrombus was removed by retrograde flushing and good pulsation was achieved through the prosthesis, which worked (Fig. 15). On the next day the dorsal pedal pulse could be felt, but there was still insufficiency of circulation. At repeated exploration the points of anastomosis were free, but progressive peripheral ischaemia ensued all the same and supracondylar amputation was performed on the tenth day.



Fig. 15 *Case No. 5.* Teflon prosthesis of the popliteal artery at operation.

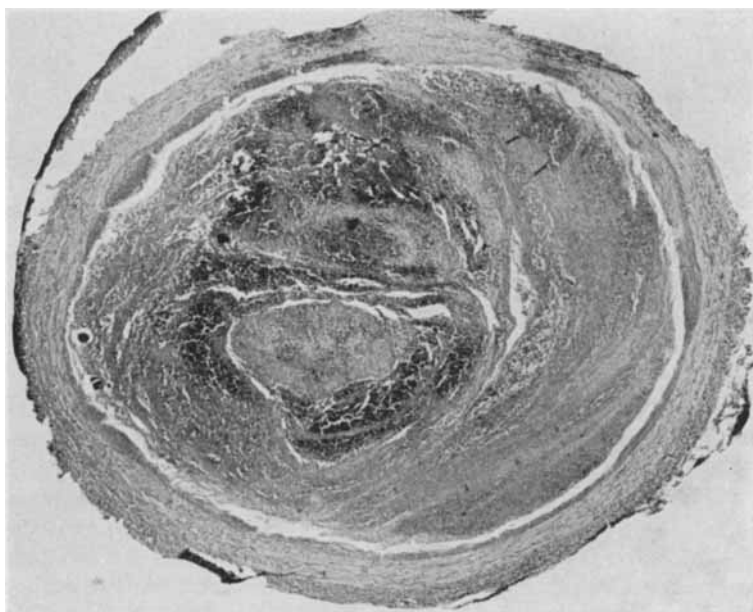


Fig. 16 *Case No. 6.* Photomicrograph showing thrombosis of the popliteal artery resulting from serious dislocation of the knee joint. $\times 60$.

Case No. 6. V.M., telephone lineman, aged 30. While he was up a pole, the pole fell and the patient's left knee was forced into hyperextension. In the local hospital dislocation of the knee joint was established. Injury of the popliteal artery was suspected and the patient was sent to our hospital. Now, on the tenth day after the

injury, arteriography revealed an obstruction in the popliteal artery 5 cm proximally of the joint gap. On exploration, the artery was hard, pulseless. The intima was thickened; a thrombus 8 cm in length was removed and the distal branches were flushed. As could be expected, no improvement of circulation ensued; gangrene developed and the lower part of the thigh was amputated (Fig. 16).

Case No. 7. M. K., lorry driver, aged 31. The patient's left leg was caught between the lorry and trailer, resulting in open dislocation of the knee, profuse haemorrhage and shock, of which the patient recovered in the local hospital. Arteriography showed the popliteal artery to be severed at the knee joint gap; in the lower leg no filling was to be seen excepting the occurrence of fine collaterals down to about its middle. The foot became necrotic and amputation of the lower third of the thigh was done one week after the accident. Exploration of the amputated leg showed that the popliteal artery had been totally severed just proximally of its branching point.

In nine cases (No. 8 to 16) there was a traumatic injury of the anterior tibial and/or posterior tibial artery accompanying fracture of the lower leg. All but one were caused by traffic accidents. In cases No. 8 and 9 there was a thrombus of the anterior tibial artery, and in case No. 12 thrombosis of the anterior and posterior tibial arteries. In all of the cases circulation could be restored and the leg saved by thrombectomy and retrograde flush manoeuvre. In cases No. 10 and 14 the circulatory disturbance produced by compression of anterior and posterior tibial arteries and by traumatic spasm was treated by liberation of the arteries and adventitia stripping. A case (No. 15) with traumatic spasm of the distal tibial arteries was successfully treated by high lumbar sympathectomy. In case No. 11 the ischaemic condition of the extremity was relieved by fasciotomy. In case No. 13 there was a thrombus of the anterior and posterior tibial arteries, and the leg was lost. In this case the traumatic arterial injury occurred in a leg with previous arteriosclerotic changes of the femoral artery. In one case (No. 16) injury of the anterior tibial artery was caused by severe dislocation of the ankle.

Case No. 8. S.S., type-setter, aged 19. In a traffic accident, the patient was hurled 10 m by a car. Comminuted, dislocated fracture of the right lower leg, fracture of the condyle of tibia, fracture of the pelvis and cerebral contusion were established. The foot was cold and anaesthetic. Pedal pulses could not be palpated. Arteriography revealed that the anterior tibial artery did not fill distally of the fracture, and the posterior tibial artery was spastic. At exploration the artery was pulseless. Arteriotomy was performed, removing a fresh thrombus, and retrograde flushing was done. At the same time internal fixation of the fracture and iliac bone graft were carried out. — The artery pulsated well after the operation. Contrast arteriography 22 months later showed that femoral, popliteal and anterior and posterior tibial arteries filled well without gaps in the entire region (Fig. 17). The fracture had consolidated and the leg functioned well.



Fig. 17 Case No. 8. Example of a case with high traumatic thrombosis of anterior tibial artery and spasm of posterior tibial artery in association with fracture of the lower leg, and consequent imminent peripheral gangrene. Thrombectomy and retrograde flush-out manoeuvre were performed, with simultaneous internal fixation of the fracture and iliac bone graft. — The arteriogram has been made 22 months after the operation. Anterior and posterior tibial arteries are strongly palpable, bony consolidation of the fracture has taken place and function of the leg is good.

Case No. 9. A.R., handyman, aged 18. As a result of a traffic accident, the patient sustained a compound fracture in the upper part of the right lower leg, fracture of the upper arm, rupture of the liver and cerebral contusion. Clinically, imminent distal gangrene of the extremity could be observed and arteriography revealed the anterior tibial artery to be broken at the level of the fracture. Posterior tibial and fibular artery were thin and filled poorly. Upon appropriate treatment for shock, arteriotomy and thrombectomy of the anterior tibial artery was performed and good blood flow was obtained. The fracture was repositioned and placed in a well-padded plaster cast. After this manipulation pedal pulses were strong by palpation, and the

extremity was warm. Furthermore, laparotomy was performed and the rupture of the liver sutured. — Arteriography three months later showed completely free blood passages in the lower extremity. The fracture had consolidated and the function of the leg was good.

Case No. 10. S.R., tractor driver, aged 19. The trouser leg of the patient's coverall caught on the transmission shaft of the tractor, resulting in compound fracture of the right lower leg and arterial lesion. On admission for treatment the foot was cold and partly anaesthetic; there was only minimal motility of ankle and toes. Posterior tibial artery was pulseless and dorsal pedal pulse weak. Exploration revealed the bone fragments to be dislocated so that the anterior and posterior tibial arteries were compressed and angulated. Hardly observable pulsation existed. The arteries were liberated and adventitia stripping was performed, whereupon strong pulsation was obtained. The fragments were repositioned and internal fixation was carried out with a fibula graft. — Six months later the peripheral pulsations were strong. The fracture had consolidated and the function of the leg was good.

Case No. 11. P. K., electrical fitter, aged 23. Sustained fracture of both tibiae in a traffic accident. On the left side, with compound fracture, imminent gangrene of the leg was at once observable. Foot and toes were anaesthetic and pale; no movements were possible. Arteriography revealed at the site of the fracture, in the middle third, angulation and dislocation of both tibial arteries, and a break distally. The vascular condition did not improve on reduction. Fasciotomy was performed and the compressing haematoma was removed. Quite rapidly hereafter the ischaemic condition was relieved; sensation and motility were restored.

Case No. 12. M. S. draftsman, aged 16. Sustained in a traffic accident compound fractures of the right femur and lower leg. The extremity was cold; dorsal pedal and posterior tibial arteries were pulseless. Cerebral symptoms indicated intracranial haemorrhage. The state of shock was treated, after which a subdural haematoma was removed from the right hemisphere and the anterior and posterior tibial arteries of the right leg were exposed. They were pulseless and spastic. The haematomata compressing the arteries were evacuated and a thrombus removed by retrograde flush from both arteries, after which pulsation returned and could be palpated after the operation. As a result of the cerebral lesion, however, the patient died after two days. — In the preoperative arteriography the femoral artery filled well past the point of the femur fracture; anterior and posterior tibial arteries were only filled to the level of the leg fracture and there was no arterial filling beyond this.

Case No. 13. A.B., worker, aged 63. In a motorcycle accident, the patient sustained a compound fracture of the left lower leg. There had previously been symptoms of claudication in his left lower extremity. Ten days later the leg was cold without peripheral pulsation. Arteriography revealed obstruction of femoral artery and complete arrest of blood flow at the fracture level. Gangrene of the leg developed gradually despite sympathicus blocks and heparin; this was a result of fracture of the initially poorly vascularized extremity (Fig. 18). Femur amputation was performed 16 days after the accident. The amputated leg was examined and there was arterial and venous thrombosis proximal of the fracture. The condition *in situ* correlated with the arteriogram made prior to operation and with the arteriogram from the amputation specimen (Figs. 19 and 20).

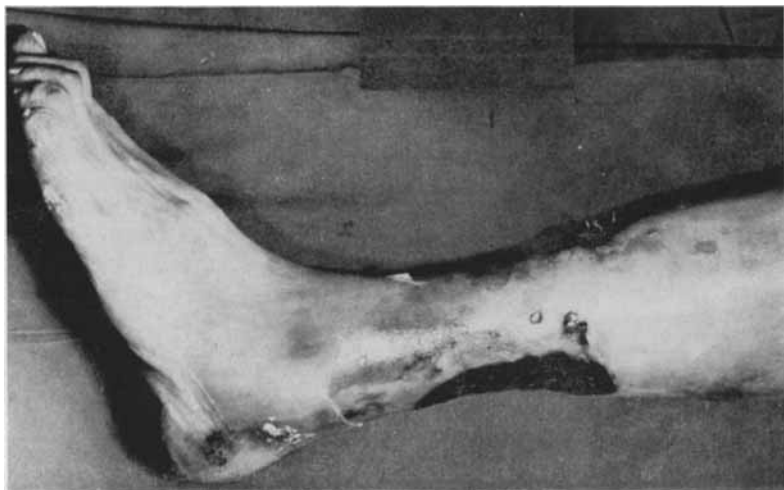


Fig. 18 Case No. 13. Compound fracture of tibia and fibula followed by arterial lesion and early gangrene. The history contained symptoms of arteriosclerosis obliterans. The extremity was lost and amputation was performed ten days after the trauma.



Fig. 19 Case No. 13. Arteriogram of the amputation specimen, showing arrest of circulation at the level of the fracture in anterior and posterior tibial arteries and in the fibular artery.

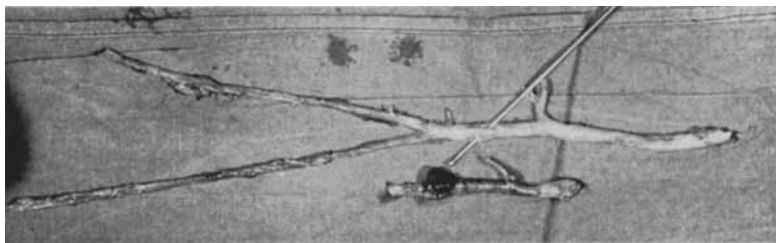


Fig. 20 Case No. 13. Preparation, revealing in the popliteal artery occlusion by an organized thrombus, and signs of contusion in anterior and posterior tibial arteries. The lumen of both arteries is filled by a fresh traumatic thrombus. An associate venous thrombosis had developed.

Case No. 14. A.E., gardener, aged 21. In a traffic accident, sustained bilateral fracture of the leg. On the right side, with open fracture, imminent gangrene was observable. Peripheral pulsations could not be palpated. In arteriography: arrest of the anterior tibial artery at the level of the fracture; posterior tibial artery was spastic and thin. Both tibial arteries were immediately exposed; they were dislocated by fragments, pulseless and narrow. After liberation, adventitia stripping and heparin-saline flushing, the arteries dilated and pulsation reappeared. The fracture was repositioned and intramedullary nailing was performed. The fracture consolidated and good vascular function ensued.

Case No. 15. A.O., mechanic, aged 24. In a traffic accident, sustained fracture of the right leg. Ischaemic condition developed rapidly, the peripheral arteries were almost pulseless, foot and leg were cold, partly anaesthetic. Arteriography showed the arteries of the leg to be angulated at the level of fracture; distally from this point only posterior tibial artery poorly filled. Early, strong osteoporosis in bones of leg and talus. Since the vascular lesion was fairly distal, high lumbar sympathectomy was performed, which considerably relieved the ischaemic condition. One week later, internal fixation of the fracture and iliac bone graft were performed. The fracture consolidated rapidly and good function of the leg was obtained.

Case No. 16. K.T., worker, aged 35. A fall from a high building resulted in serious dislocation of ankle and talus. This caused compression and stretching of the anterior tibial artery and circulatory disturbance in the foot. At operation, the dislocation obstructing circulation was corrected, whereupon the condition of the foot improved. After six months the function of the foot was good and there were no signs of circulatory disturbance.

Two cases of the present material (No. 17 and 18) concern injury of the brachial artery caused by posterior fracture-dislocation of the elbow joint in one case (No. 17) and by compound fracture of the upper arm in the other (No. 18).

Case No. 17. E.V., tradesman, aged 26. A fall from great height resulted in posterior fracture-dislocation of the elbow joint. The peripheral part was cold, numb, pulseless; extensive haematoma at the elbow joint. On immediately performed exposure, the brachial artery was found to be completely severed, the ends thrombosed. Resection and arteriorrhaphy were performed, after which the radial artery pulse was strong. The fractured capitulum radii was removed and the dislocation corrected. Later arteriography showed brachial, ulnar and radial arteries filling well, without arrest; the joint had a good range of motion (Figs. 21—24).

Case No. 18. J. K., mechanic, aged 33. Sustained in a traffic accident a compound fracture of the right upper arm with traumatic spasm of the brachial artery, and thrombosis. In spite of intensive vasodilatory treatment the fingers became necrotic owing to blocks of the stellate ganglion. The entire extremity was cold, with reduced sensibility. The arteriogram revealed incomplete filling of the brachial artery distally of the fracture level. On exploration, two months later, the artery was found to be surrounded by thick scar tissue and there was pulsation only halfway down the upper

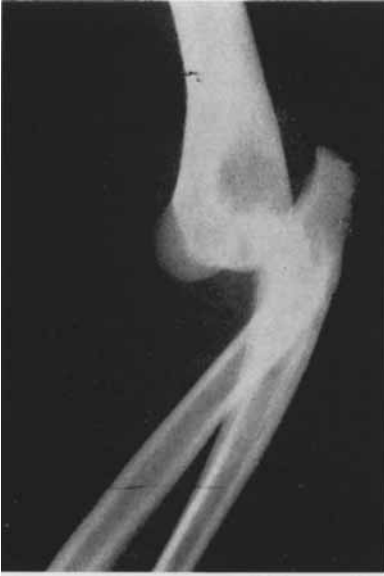


Fig. 21 Case No. 17. Posterior fracture-dislocation of the elbow joint, which caused total rupture of brachial artery.

Fig. 22 Case No. 17. Arteriogram after resection of thrombosed ends of ruptured brachial artery and arteriorrhaphy. Fractured capitulum radii has been excised and dislocation corrected.

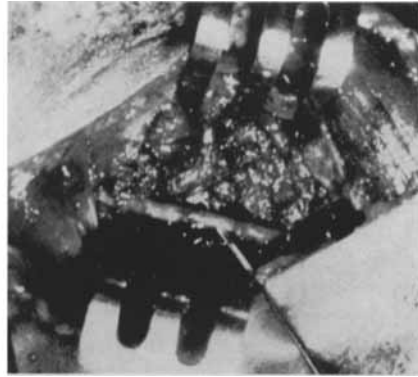
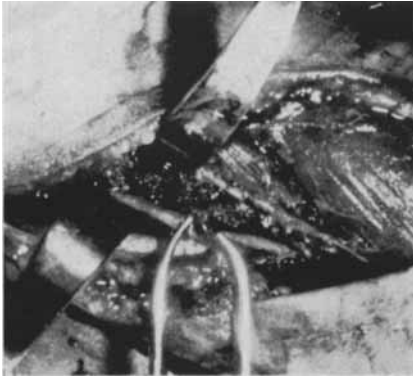


Fig. 23 Case No. 17. Rupture of brachial artery in connection with fracture-dislocation of the elbow joint.

Fig. 24 Case No. 17. Restoration of blood flow achieved by excision of thrombosed ends of the artery and arteriorrhaphy.

arm, to the point of fracture. The artery was exceedingly hard-walled, narrow and spastic. After adventitia stripping and flushing, pulsation reappeared in the entire artery. The changes in the vessel were of the kind encountered in an old thrombosis with recanalization. Control arteriography showed that the artery filled. Four months later the extremity was warm, but only fibrous consolidation of the fracture had ensued. A bone transplantation was required, which resulted in osseous consolidation.

III ARTERIAL TRAUMA

While most direct vascular lesions are associated with penetrating wounds and lacerations, the principal types of acute arterial injury associated with skeletal trauma are 1) arterial contusion and subsequent traumatic vasospasm, 2) thrombosis and 3) arterial rupture.

The aetiology, mechanism and surgical aspects of each type will be reviewed in the following paragraphs and related to the cases of the present material.

Arterial Contusion and Traumatic Vasospasm

Traumatic vasospasm is a consequence of crush-type injury caused by the fracture. A fragment or fracture haematoma may mechanically compress the blood vessel, or the spasm may be the result of stretching of the artery. When the blood vessel is explored, signs of contusion in the adventitia can be seen. It is reduced in size, and adhesences to the surrounding tissues may have formed. In acute arterial spasm examination in the intimal region reveals no changes.

In case No. 3 typical, contusion-induced traumatic vasospasm of femoral artery had ensued after a serious compound fracture of the right femur. At clinical examination two hours later the extremity was cold distally of the knee; popliteal and pedal pulses were not palpable. Arteriography showed the femoral artery to be angulated medially at the point of fracture, narrow, and slowly filling (Fig. 9). On exploration, the muscle tissues at the point of fracture were found to be lacerated, the artery displaced from its usual location and surrounded by an extensive haematoma. On closer examination, the adventitia showed signs of contusion; there were no lacerations, but the artery was considerably constricted and pulseless at the point of fracture. After liberation, adventitia stripping and treatment with warm saline the artery was dilated and pulsation reappeared. Also the peripheral pulsation could be palpated after the operation and the extremity was warm.

The present material contains six cases of disturbed circulation of an extremity caused by arterial contusion and traumatic vasospasm, namely, one traumatic arterial injury of the femoral artery (case No. 3), four of the anterior and posterior tibial arteries (cases No. 10, 11, 14 and 15) and one of the anterior tibial artery (case No. 16).

Thrombosis

Thrombosis is a common sequel of arterial contusion. The artery may be obstructed owing to mechanical pressure, subfascial haematoma or bone fragments. Traumatized wall of the artery and lesion of the intima or media are predisposing to thrombosis. Subintimal haematoma narrows the lumen, with thickening of the intima and formation of thrombus as a result, as histological investigations show (Figs. 12 and 16). The irritating effect of the thrombus may produce secondary arterial spasm and further embarrassment of circulation. In one bilateral injury of the lower extremities with disturbance of circulation, the condition was complicated by strong renal spasm, demonstrated in the urogram (8). Obviously reflexory vasoconstriction was concerned here, which according to *Leriche* (9) occurs in the manner that the impulses from the region of the damaged artery travel to the paravertebral plexus and stimulate the sympathetic system. A phenomenon similar in kind occurs in the crush syndrome.

The commonest type of arterial injury associated with skeletal trauma was thrombosis. In eight out of 18 cases there were arterial thromboses in the region corresponding to the fracture. Of these, two were thromboses of femoral artery (cases No. 1 and 4), one of popliteal artery (case No. 6), two of anterior and posterior tibial arteries (cases No. 12 and 13), two of anterior tibial artery (cases No. 8 and 9), and one of brachial artery (case No. 18). In five, the thrombosis had extended to the distal arteries.

A characteristic case is No. 1, in which a 69-years-old man with previous slight claudication sustained a comminuted fracture of the femur and lesion of the femoral artery. There were clinically distinct signs of arterial occlusion and in the arteriogram an obstruction in the femoral artery showed at the level of the fracture (Fig. 1). On account of associated injuries producing a perilous condition, exploration of the blood vessels had to be postponed. Local gangrene developed in the extremity, which was pulseless and ischaemic but did not become completely gangrenous (Fig. 3). After two weeks thrombectomy and thromboendarterectomy were performed on the femoral artery and intramedullary nailing was done at the same time (Fig. 2).

It is obvious that the retarded circulation caused by the thrombus at the point of lesion and the time needed to improve the patient's general condition before restoration of circulation contributed to the spread of the thrombosis. In this instance collateral circulation sufficed to maintain blood flow in the extremity although acute occlusion of the main artery was concerned.

Thrombosis is not rare either as a consequence of fracture of the lower leg. It is well-known that the upper part of the tibia is a dangerous area for fracture to occur with respect to arterial injury, owing to the proximity of the popliteal artery and of the bifurcation to the bones. *Watson-Jones* (16) mentions that of seven high oblique leg fractures with displacement five were complicated by gangrene of foot and leg. In an earlier work the author (8) has reported cases of fracture of the lower leg with gangrene resulting from arterial injury. Of the eight fractures of the lower leg in the present material, thrombosis caused severe acute disturbance of circulation in four. In all but one of them restoration of the blood flow could be achieved and the extremity was saved.

Case No. 8 is a typical case of fracture of the lower leg and associated arterial lesion, in which imminent gangrene could be avoided by removing a thrombus from the anterior tibial artery and by retrograde flush. At the same time internal fixation of the fracture was carried out. At follow-up examination two years later the dorsal pedal and posterior tibial pulses could be strongly felt, the fracture showed bony consolidation and the leg displayed good function. Arteriography revealed that all three arteries of the lower leg filled well with contrast medium (Fig. 17).

Arterial rupture

Transsection or perforation of the artery is not as common in association with fracture as it is in open lesions of the blood vessels, *e.g.* in stab or shot wounds. Traumatic arterial rupture in connection with diaphyseal fracture is less common than thrombosis, but it may be a consequence of serious injury and dislocated fracture or fracture-dislocation. A sharp fragment may produce rupture of a vessel, and this may secondarily cause pulsating haematoma, traumatic aneurysm or arteriovenous fistulation.

Profuse haemorrhage may force arterial ligation to be employed as an emergency measure, as can be seen in case No. 2. In this illustrative case, a serious traffic accident resulted in rupture of the femoral artery, which

had to be ligated in connection with the medullary nailing of the femur, owing to haemorrhage. Primarily, ischaemic paralysis was observable, succeeded by severe peripheral disturbance of circulation, coldness, ulcerations and claudication symptoms. Moreover, healing of the fracture was delayed and only a fibrotic callus was demonstrable at the time of the arterial reconstruction by means of autogenous vein graft, three months later. The artery was strongly adherent at the point of fracture, angulated, pulseless and very narrow (Figs. 5 and 6). This case is an example of the vulnerability of the femoral artery in fracture of the distal part of the femur, owing to their close anatomical relation. In fractures in this region, and particularly if there is dislocation, the possibility of arterial lesion should always be kept in mind and prepared for. Total rupture of the brachial artery in connection with fracture-dislocation of the elbow joint is demonstrated by Case No. 17. (Figs. 21—24). Restoration of blood flow and good function of the joint were achieved by immediately performed arterial surgery and bone surgery.

In connection with injuries, dislocations and fractures of the knee region arterial ruptures surpass thrombosis in frequency, owing to the peculiar anatomical conditions in the popliteal region. The popliteal artery passes distally between the heads of the gastrocnemius muscle and then beneath the tendinous arch of the soleus muscle, by which it is anchored firmly against the underlying bone. At this point, at the bifurcation, the artery branches into the anterior and posterior tibial arteries, the first of which passes immediately through the interosseous membrane. Any distortion of the skeletal anatomy causes stretching of the popliteal artery. This occurs particularly when the tibia is dislocated forward with respect to the femur, or in serious hyperextension injuries. When the knee joint or a fracture is dislocated, the communicating arteries poorly protected by soft tissues are also likely to be damaged. Distal circulation remains very unsatisfactory and the prognosis with respect to viability of the extremity is poor. In the material recently reported by Hoover (4), in which altogether 12 cases of popliteal arterial injury have been collected from the years 1912—1960, six of them presenting rupture, gangrene and amputation ensued in eleven cases. In the one remaining case the surviving limb was subsequently cool and anaesthetic.

In the three cases of popliteal arterial injury of the present material, complete transection of the artery was concerned in two and thrombosis in one. In all cases the trauma was severe in degree and definitive treatment could not be instituted until at a later stage so that the prognosis was bad. One of the complete transections of the artery was corrected by a Teflon

prosthesis and retrograde flush was applied. However, distal thrombosis was so far progressed that circulation could no longer be restored although the graft worked. In the other two cases the ischaemic state had already developed to the stage of gangrene in the peripheral parts and they terminated in amputation.

IV SKELETAL TRAUMA

In the present material all fractures with associated vascular lesion, with the exception of one fracture of the humerus and one fracture-dislocation of the elbow joint, were fractures or dislocations of the lower extremities. In the entire series of 18 cases the different sites of fracture or dislocation were represented by the following numbers of cases: femur — 4, knee joint — 3, tibia or/and fibula — 8, ankle — 1, humerus — 1, and elbow joint — 1.

Ten patients had a compound fracture, while there was no wound in the skin connected with the fracture in the other eight. Generally considered, the injury was serious in degree in all cases, which is indicated except by the relatively high number of compound fractures above all by the fact that most patients had associated injuries and were in shock on admission. Most bone injuries were comminuted fractures and all presented dislocation on admission. The fragments were in most cases greatly displaced, the lesion in the soft parts was remarkable and there was shortening of the extremity. All femur fractures had their site in the distal part of the thigh, while the location of the fracture in the lower leg varied so that it was in the upper third in two cases, in the middle third in two cases and on the boundary between the middle and lower thirds in another two cases. In contrast to earlier investigations, in which the upper part (16) and the lower part (8) of the lower leg were found to be dangerous locations of fracture as regards arterial lesion, no distinct predisposition in this respect was evident in the present cases. In all dislocations of the knee joint there was rupture of the subcutaneous soft tissues surrounding the knee joint, and the degree of dislocation was considerable. It appears obvious that the extent of dislocation and the consequent damage of soft tissues, which otherwise have a protective effect, play an important part in the occurrence of arterial injury.

Owing to anatomical relations in certain regions even a less pronounced dislocation may produce arterial lesion *e.g.* in the distal part of the femur, where the femoral artery lies close to the bone in Hunter's canal. The popliteal area and the supracondylar and elbow region of the upper arm are well-known to be zones of fracture or dislocation involving great danger to arteries. The humerus fracture in the present material was located distally of the middle part of the bone.

V TREATMENT

Combined arterial injury and bone trauma in an extremity implies combined treatment, aiming simultaneously at restoration of blood flow and bony consolidation of the fracture, in this order. Of course, therapeutic measures dictated by immediate peril to the patient's life must take precedence over such treatment no matter what the consequences may be for the extremity.

For restoration of the blood flow methods are employed which enable circulation to be reestablished by surgical means, and on the other hand measures conducive to maximum establishment of collateral circulation in order to secure blood supply to the extremity. All conservative measures of treatment have the last-mentioned object and they include the use of anticoagulants, vasodilatory agents and sympathicus blocks. The extremity may retain its life depending on the location, kind and degree of severity of the arterial lesion, but when the main artery is eliminated from circulation, at least relative ischaemia will remain, which causes its typical symptoms of claudication, sensibility to cold and various motor and sensory disturbances. A segmental arterial obstruction of this kind, which can be achieved as final result, is equivalent to the state in which the patients come under treatment in chronic obliterative arteriosclerosis.

When there is a fracture in the same extremity in addition to arterial injury, maximum practicable restoration of arterial circulation is mandatory. The extremity experiences an acute emergency after its circulation has ceased. Normal healing of the fracture implies conditions of circulation aiding the formation of callus and bony consolidation. An extremity with both disturbed arterial circulation and non-union is functionally extremely poor.

The surgical approach should in the first place be toward restoration of blood flow. If laceration is concerned, the result may be achieved by lateral arterial suture. If the artery is completely transected, its ends have to be excised and arteriorrhaphy has to be performed. If the excised segment is of such length that this cannot be done even by mobilizing the artery, the best thing to do is an autogenous vein graft, using the vena saphena or an artificial prosthesis. If thrombosis is concerned, thrombectomy will

be done. In the cases of arterial spasm, in which the artery is collapsed, pulseless and slack, adventitia stripping and local procaine or papaverine injection may produce pulsation. Sympathectomy has a favourable effect in view of the improvement of collateral circulation and may relieve arterial spasm. When the artery is compressed by haematoma it is evacuated and fasciotomy made. In doubtful cases it is advisable to perform arteriotomy in order to reveal a potential distal embolus. The key to success is reestablishment of good flow through the manipulated artery, which is ascertained by distal retrograde flush-out manoeuvre, using a dilute heparin-saline solution. A free flow of saline from the proximal arteriotomy indicates that the vessel is open.

The time lag between the injury and repair of artery is decisive with regard to a successful operation. Degeneration and necrosis of the muscle tissue starts 6—8 hours after arrest of circulation. Arterial repair carried out within this time has the best functional prognosis. Existing collateral paths may prolong this critical period. The necrosis may remain local so that it turns into cicatricial fibrosis and some muscular function remains. Experience has shown that operation is beneficial even when performed at a later time: if the necrosis was not extensive, the extremity will become warmer, the atrophic changes become less and the function is improved. It has been possible to demonstrate also experimentally (12) that there is hope of functional recovery upon nearly total ischaemia as late as after 24 hours. If there is gangrene, however, then amputation is the sole appropriate treatment.

In the treatment of a fracture complicated by arterial injury internal fixation of the fragments has to be considered superior to other methods owing to the primary stability it creates. Especially in fracture of the femur medullary nailing has advantages over other procedures because it prevents redislocation and contributes to secure undisturbed healing of the manipulated vessel. Furthermore, the condition of the extremity can be watched, as it is freely exposed without external supports. If internal fixation cannot be done immediately on account of the time consumed in attending to the arterial injury or for some other reason, the surgery on the bone may be postponed. The essential thing is repositioning of the dislocation and taking care that the fragments cannot compress the artery. Clinical observations show that consolidation of the fracture is distinctly correlated with the arterial circulation of the extremity. If the circulation is deficient, bony consolidation of the fracture is delayed and the result may be fibrous consolidation between the fragments or pseudoarthrosis. It is often indicated to perform early bone transplantation in order to avoid this condition.

VI DISCUSSION

As a consequence of recent years' exigencies in traffic, transportation and industry the incidence of severe accidents has increased. As it can be assumed that the number of vascular injuries will increase together with that of multiple traumata, avoidance of the loss of extremities and of functional disturbances that are severe even in the best cases seems to require that a more aggressive approach should be adopted towards the restoration of blood flow in the extremity.

With regard to function and viability the development after traumatic interruption of a major artery is decisive (11). The body first responds with a spasm of the vessels in the affected part; which might be considered a protective mechanism against the injury. It is partially a reflex constriction, mediated through the sympathetic nervous system, and partly a traumatic arteriospasm intrinsic in the artery. During this phase of vasoconstriction the circulation of the extremity is most strikingly diminished. The condition of vasodilatation after several hours represents an effort of the organism to increase the blood flow to the part. The point of occlusion in the main artery is bypassed by means of flow through the maximally dilated collateral channels. During the highly unstable period of circulatory readjustment, thrombosis is taking place in the occluded artery, and it may remain local or spread farther, mostly distally. It may occlude the entire arterial tree to the part. The third phase, the development of collateral circulation, begins following stabilization of thrombosis and vasodilatation. The process takes place fairly rapidly over a period of 4—6 months and then more slowly over a period of years. Usually this collateral circulation never develops the capacity for flow possessed by the original vessel. Residual arterial insufficiency may be apparent as easy fatigue, intermittent claudication, cold intolerance and/or greater susceptibility to the circulatory complications of old age and arteriosclerosis. Where the circulation is sufficiently impaired it results in ischaemic tissue and gangrene. If the initial ischaemia is not too severe and distal thrombosis has not been extensive, the extremity may survive the acute occlusion with functional impairment. Besides, the site of the lesion has its own significance. It is known that the prognosis is poorest in occlusions of the popliteal and common femoral arteries.

Also, as the present work shows, acute arterial lesion distally from the popliteal bifurcation is dangerous and may develop gangrene, especially if both tibial arteries are injured.

The levels of skin demarcation and muscle demarcation may be quite different, a fact that carries significance in assessing the viability of the extremity. The nutrient arteries to muscles are frequently end-arteries (3). Thus the occlusion may result in death of a muscle or muscle group at much farther distal points than might be expected. The present case No. 4 is typical, in which the flexor muscles of the leg and quadriceps muscle of a 14-years-old boy were necrotic by macroscopic and histological examination as a result of comminuted fracture of the femur and thrombosis of the femoral artery although good collateral circulation existed. In cases where ischaemia is not severe enough to cause massive death, the state produces local muscular necrosis. One form is equivalent to the tibialis anterior syndrome, leading to contracting fibrous replacement of the muscle. If also the nerve is damaged as a consequence of ischaemia, a combined injury of muscle and nerve is concerned. This occurs characteristically as Volkmann's contracture in the upper extremity but is not rare in the lower extremity either as a sequel of ischaemic states, and can be demonstrated by muscle biopsy (Fig. 11).

The classical symptoms of arterial insufficiency, pallor or cyanosis of the skin, disappearance of pulse and sensory and motor disturbances are well-known. Recognition of a traumatic arterial injury may be more difficult and it may escape observation because the case will mostly be one of a patient under shock and with heavy blood loss, whose extremities are cold already owing to the state of shock and in whom it may be difficult to demonstrate differences in pulse. Also multiple non-skeletal traumata, cerebral, thorax and abdominal injuries may complicate the state to the extent that the symptoms of circulatory insufficiency may fail to receive due attention. But the arterial injury is recognizable by careful clinical examination.

The essential point is that the surgeon taking care of the victim of an accident is minded of arterial lesion, as only then diagnosis will be made at once and there is no wastage of valuable time, which may decisively affect the chances of saving the extremity. It should be kept in mind that muscular ischaemia produced by vascular lesion may be at the bottom of peripheral paresis of the extremity and simulate paralysis caused by the nerve trunk. One must not, if there is suspicion of arterial injury, wait for it to be possibly repaired of itself but one should verify the diagnosis by arteriography. Too many extremities have been lost by reliance placed on a therapy of waiting. It may furthermore be stressed in this connection that every fracture of an

extremity should be considered to have an associated vascular injury until proved otherwise. One must have the same awareness of the possibility of arterial lesion as one exercises in respect of possible nerve injury, tendon injury or fracture.

VII SUMMARY AND CONCLUSIONS

The present work deals with arterial injuries in connection with fractures and dislocations and their surgical approach with the object of restoring the blood flow so that the impending loss of the extremity or subsequent derangement of its function might be avoided.

The investigation comprises only cases verified by arteriography in which the injury has produced a critical condition with a view to the viability of the extremity. Of altogether 18 cases, four concern injuries of femoral artery, three of popliteal artery, nine of anterior and/or posterior tibial arteries, and two concern injury of brachial artery.

The types of acute arterial injury associated with skeletal trauma were: 1) arterial contusion and subsequent traumatic vasospasm, 2) thrombosis, and 3) arterial rupture. The aetiology, mechanism and surgical aspects of each type are discussed in the light of the present cases.

The treatment combines two simultaneously applied therapeutic principles, namely, those of vascular surgery and bone surgery. The preferential object of treatment is repair of the arterial injury by direct surgery in order to restore the circulation. Treatment of the fracture by medullary nailing has advantages over other methods. In thirteen cases restoration of blood flow by surgical approach was possible and the extremity was saved, while in five cases progressive ischaemia had developed so far that the extremity was lost.

The experience shows that in a considerable number of serious fractures with associated arterial injury, which would not be considered amenable to surgery by older standards, there is a good chance to save the extremity by this approach. Even operation at a later stage is useful unless the ischaemia and necroses are extensive. The coldness of the extremity and the atrophic changes become less and the function of the extremity improves.

The following more detailed conclusions and general principles emerge from the foregoing presentation:

— *In trauma of an extremity with fracture or dislocation and associated arterial injury, early recognition and appropriate treatment of the latter decide*

the ultimate fate of the extremity. The surgeon should be minded of arterial injury, and until the opposite can be established every fracture of an extremity should be assumed to have associated vascular injury.

— *Except in cases resulting in serious gangrene, the deficiency of active motility, sensory disturbances and contractures of the peripheral parts ensuing on numerous fractures are ischaemic of their aetiology and caused by arterial injury.*

— *By an active arterial surgery it is possible in numerous instances to avoid gangrene and loss or grave functional derangement of the extremity. By accomplishing restoration of circulation in the extremity the indispensable conditions are created for healing of the bone fracture to occur.*

— *Combined arterial injury and bone trauma in an extremity implies combined treatment, aiming simultaneously at restoration of blood flow and bony consolidation of the fracture, in this order. Of course, all necessary therapeutic measures should be taken to save the patient's life without hazarding anything, even if this be at the risk of loss of the extremity. In multiple injuries observance of the proper order of preference in therapy is the fundamental prerequisite of success.*

— *Treatment of the fracture by medullary nailing has advantages over other methods in that it guards against redislocation and thus contributes to ensuring undisturbed healing of the surgically manipulated artery. Another advantage is the possibility of watching the condition of the extremity, unobstructed by external supports.*

VIII ZUSAMMENFASSUNG UND SCHLUSSFOLGERUNGEN

Die vorliegende Arbeit befasst sich mit Arterienverletzungen im Zusammenhang mit Frakturen und Luxationen und mit ihrer chirurgischen Behandlung im Sinne der Wiederherstellung des Blutlaufs, um den vor auszusehenden Verlust der betroffenen Extremität bzw. schwergradig gestörte Funktion derselben vermeiden zu können.

Die Untersuchung umfasst ausschliesslich arteriographisch erhaltete Fälle, in denen die Verletzung einen kritischen Zustand im Hinblick auf die Erhaltung der Extremität herbeigeführt hat. Von den insgesamt 18 Fällen beziehen sich vier auf Verletzungen der A. femoralis, drei auf solche der A. poplitea, neun auf solche der A. tibialis anterior und/oder posterior und zwei auf eine Verletzung der A. brachialis.

Folgende Typen der Arterienverletzung in Verbindung mit Knochen-trauma kamen vor: 1) Arterienkontusion und anschliessender Vasospasmus, 2) Thrombose sowie 3) Riss der Arterie. Die Ätiologie, der Mechanismus und die chirurgischen Aspekte eines jeden dieser Typen werden im Lichte der hier berichteten Fälle besprochen.

In der Behandlung vereinigen sich zwei simultan zum Einsatz kommende therapeutische Prinzipien, die der Gefässchirurgie und der Knochenchirurgie. Das therapeutische Ziel mit Vorrang ist Instandsetzung der verletzten Arterie durch unmittelbaren chirurgischen Eingriff zum Zweck der Wiederherstellung des Kreislaufs. Behandlung der Fraktur mittels Marknagelung besitzt Vorteile den anderen Verfahren gegenüber. Sie gewährleistet einen Schutz gegen Redislozierung und trägt ihreits zum Sichern einer ungestörten Heilung der Arterie bei. In 13 Fällen wurde Wiederherstellung des Blutlaufs durch chirurgischen Eingriff erzielt und die Extremität gerettet, während in fünf Fällen die progressive Ischämie so weit fortgeschritten war, dass die Extremität eingebüsst wurde.

Die Erfahrungen erweisen, dass in einer grossen Zahl von ernsthaften Frakturen mit assoziierter Arterienverletzung, die nach älteren Auffassungen nicht als chirurgisch bezwingbar angesehen würden, gute Möglichkeiten bestehen, die Extremität durch diese Behandlungsweise zu retten. Selbst verzögerte Operation ist von Nutzen, insofern nicht die Ischämie und die

Nekrosen grosse Ausdehnung aufweisen; die Kälte der Extremität und die atrophischen Veränderungen werden geringer und bessere Funktion der Extremität stellt sich ein.

Die folgenden mehr ins Einzelne gehenden Folgerungen und allgemeinen Richtlinien ergeben sich aus der vorangehenden Darstellung:

— Bei Extremitätentrauma mit Fraktur oder Luxation und assoziierter Arterienverletzung ist zeitiges Erkennen und sachgemässe Behandlung der letzteren entscheidend hinsichtlich des bevorstehenden Schicksals der Extremität. Der Arzt soll sich der Arterienverletzung bedacht sein; bis Gegenteiliges nachgewiesen ist, ist jede Fraktur als von einer Arterienverletzung begleitet anzunehmen.

— Ausser in Fällen, die zu schwerartigem Gangrän führen, sind mangelhafte aktive Beweglichkeit, sensorische Störungen und Kontrakturen der peripheren Teile ischämischer Ätiologie und von einer Arterienverletzung verursacht.

— Durch aktives therapeutisches Vorgehen mit der Wiederherstellung des Blutkreislaufs in der Extremität mit Knochentrauma und Arterienverletzung als Ziel können in zahlreichen Fällen Gangrän und Gliedmassenverlust bzw. schwere funktionale Beeinträchtigung vermieden werden. Durch Wiedereingangbringen der Extremitätenzirkulation schafft man die unerlässlichen Vorbedingungen für die Heilung der Knochenfraktur.

— Kombinierte Arterienverletzung und Knochenfraktur in einer Extremität setzt eine kombinierte Therapie voraus, die zugleich auf Wiederherstellung des Blutlaufs und auf knöcherne Konsolidation der Fraktur hinzielt, und zwar in dieser Reihenfolge. Es versteht sich, dass alle zur Lebensrettung des Patienten notwendigen therapeutischen Massnahmen an erster Stelle vorzunehmen sind ohne irgend etwas aufs Spiel zu setzen, sogar auf Gefahr eines eventuellen Gliedmassenverlusts. Bei multiplen Traumata ist Beachtung einer richtigen Vorrangordnung in der Therapie Grundbedingung für den Erfolg.

— Behandlung der Fraktur mittels Marknagelung ist anderen Methoden gegenüber im Vorteil, indem sie einer Redislozierung vorbeugt und dadurch zur ungestörten Heilung der chirurgisch manipulierten Arterie beiträgt. Ein weiterer Vorzug ist die Möglichkeit zum Verfolgen des Zustands der Extremität ohne Behinderung durch äusserliche Fixierstützen.

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Address: 12 A, Temppelikatu, Helsinki, Finland.