DeBakey and Simeone (1946) found that 68.6 per cent of amputations among United States troops in the second world war were done as the result of arterial trauma. Amputation was required in 40.3 per cent of cases of arterial trauma. Arterial injuries associated with fractures showed a 50 per cent loss of limb with reparative measures, whereas there was a 70 per cent loss of limb when the vessel was ligated.

During the Korean War more advanced arterial techniques were used, particularly in reconstruction, with consequent improvement in the results—the amputation rate after arterial repair was reduced to 7 per cent (Morton, Southgate and Deweese 1966).

This paper reviews twelve patients with major arterial trauma—six closed injuries and six open—admitted to the Surgical Professorial Unit of the Richmond Hospital, Dublin, from 1964 to 1966.

CASE REPORTS
CLOSED INJURIES

Case 1—A boy of seventeen fell from a motor scooter, sustaining a fracture of the midshaft of the right femur and the upper tibial epiphysis. Tibial skeletal traction was applied. The leg and foot became cold, blue, swollen and pulseless. After four days the patient was transferred to this unit. Arteriography showed an obstructed popliteal artery (Fig. 1), the result of posterior displacement of the upper tibial fragment.

Operation—The artery was exposed at the tibial fracture site and was found to be intact but pulseless. Arteriotomy showed that the intima of the vessel was disrupted over a distance of 2.5 centimetres. The artery was reconstructed by excising the damaged part and inserting, end to end, a reversed autogenous vein graft from the long saphenous vein. Arteriography demonstrated that the vein graft was functioning satisfactorily (Fig. 2). Fasciotomies were performed in the leg to reduce oedema. The tibial fracture was stapled and the femoral fracture fixed by an intramedullary nail.

Progress—After operation all the anterior tibial muscles sloughed and there was little distal sensation or movement. There was, however, a good posterior tibial pulse. After removal of the necrotic muscle an acceptable limb was eventually obtained, enabling the patient to walk without a limp.

Comment—if this patient's arterial injury had been treated earlier an even better result might have been obtained without necrosis of muscle.

Case 2—A man of twenty-eight sustained a crush injury to the left thigh. The femur was fractured at the midshaft and was treated by skeletal traction. There was some anxiety about circulation of the foot, but this improved when traction was reduced. The thigh slowly increased in size and became more painful. There was also evidence of sciatic nerve injury. Two months later there was an obvious pulsating haematoma in the thigh. Arteriography showed the haematoma and a lacerated femoral artery at the femoral fracture site (Fig. 3).

Operation—The common and deep femoral vessels were clamped to control haemorrhage; the haematoma was evacuated and the lacerated lower femoral artery exposed. The lacerated part of the vessel, about two centimetres long, was excised. The vessel was then united by end-to-end anastomosis. The fracture of the femur was firm and was left undisturbed. The sciatic nerve injury slowly improved. Arteriography one year after operation showed a patent femoral artery (Fig. 4).

Comment—the site of the fracture in this case was the junction of the lowest and middle thirds of the femur. The artery was apparently injured where it was tethered to the shaft by the adductor magnus muscle. This appears to be a not uncommon area for injury to the femoral artery (Cases 2, 6 and 10). The femoral artery in Hunter's canal is also particularly prone to develop atherosclerosis. It is therefore the commonest site for both arterial injury and arterial disease.

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Case 1. Figure 1—Right femoral arteriograph showing an obstructed popliteal artery, due to displacement of the upper tibial epiphysis, the projecting tibial metaphysis traumatising the vessel. Figure 2—Arteriograph after operation showing the patent vein graft in situ and the fracture secured by a staple.

Case 2. Figure 3—Femoral arteriograph showing a leak from the artery and a large haematoma, the artery having been displaced from the fracture site by the haematoma. Figure 4—Arteriograph after operation showing the repaired femoral artery and the united fracture.
Case 3—A man of twenty sustained a crush injury to his knee in a tractor accident. Skeletal traction was applied for a badly comminuted fracture of the tibial condyles with displacement of the fragments, and a below-knee plaster was also applied. Six days later the circulation in the foot gave rise to anxiety and he was transferred to this unit eight days after injury. The limb was markedly swollen below the knee. The lower leg and foot were obviously devitalised and showed pregangrenous change. Arteriography demonstrated a complete occlusion of the popliteal artery (Fig. 5).

Operation—The popliteal fossa was explored and a large quantity of free blood clot evacuated. Seven centimetres of the popliteal artery were missing, presumably lacerated by the displaced upper tibial fragments. Attempted reconstruction failed because of damage to the distal tibial vessels. The limb subsequently became gangrenous and was amputated above the knee.

Comment—Again a delay in definitive treatment contributed towards the loss of the limb, although the original trauma damaging the calf vessels was the probable cause of the poor result of operation.

Case 4—a man of nineteen sustained a crushing injury to the left arm and forearm. The forearm began to swell almost immediately after the accident but no fracture was shown in radiographs. The swelling of the limb increased and the fingers became swollen, anaesthetic and paralysed. In spite of the circulatory upset there was a good peripheral skin circulation in the fingers and the radial pulse was palpable.

Operation and progress—Two days later, fasciotomies were performed in the forearm to relieve the swelling. The brachial artery was also exposed and found to be intact and pulsating. The accompanying veins appeared normal. A piece of muscle was taken for biopsy and subsequently showed floccular degeneration. The swelling of the limb slowly subsided leaving defects at the site of the fasciotomies. These skin defects were covered by skin grafts. The patient was eventually left with a “clawed” hand and a considerable loss of sensation (Fig. 6).

Comment—The cause of the condition was probably swelling of the muscles from crushing, oedema in the tight muscle compartments obliterating the vessels. Necrosis of muscles and nerves subsequently occurred with eventual fibrosis and Volkmann’s ischaemic contracture. Earlier and effective fasciotomy would almost certainly have saved this patient’s forearm muscles.

Case 5—A man of nineteen sustained a crushing injury to the right shoulder. Radiographs demonstrated a fracture of the neck of the right scapula with some displacement. Four days after the injury there was marked swelling of the arm and forearm, and the hand was cold, with no sensation or movement. The tip of the little finger was gangrenous. The subclavian artery was the only pulse palpable in the limb. Arteriography performed by puncture of the right subclavian artery showed complete obstruction of five centimetres of the second part of the axillary artery, with distal refill (Fig. 7).

Operation and progress—Exploration of the axillary artery revealed that five centimetres of the second part were missing opposite the fractured neck of scapula. Continuity was restored by a reversed...
saphenous vein graft (Fig. 8). Fasciotomies were performed in the swollen limb. A good radial pulse was palpable at the end of operation. After operation all the skin lesions healed and the radial pulse remained palpable; but the muscles of the forearm had obviously undergone necrosis and he was left with a virtually useless limb, with little sensation below the wrist and very little movement in the hand (Fig. 9).

Comment—The muscles and nerves were obviously necrotic when the patient was transferred to this unit. Reconstruction saved skin and bone only. Earlier exploration might well have saved the muscles.

Case 6—A boy of sixteen sustained a crushing injury to the left thigh in a traffic accident. Radiographs demonstrated a displaced fracture of the lowest third of the femur. He complained of numbness of the left foot but it was not until twelve hours after the accident that the foot was noticed to be bluish, mottled, cold and pulseless. The leg and foot were anaesthetic and paralysed. The ankle was rigid, suggesting necrosis of the leg muscles. Arteriography showed complete obstruction of the femoral artery at the fracture site (Fig. 10).

Operation and progress—Exploration showed the artery to be apparently intact but pulseless at the site of the fracture. Arteriotomy demonstrated that the intima was disrupted for 2.5 centimetres. The damaged artery was excised and replaced by an end-to-end reversed long saphenous vein graft. The fracture was treated by intramedullary nailing. Fasciotomies were performed to reduce oedema. A good popliteal pulse was restored but no foot pulses could be felt. The foot warmed up to ankle level at first and then the dorsalis pedis pulse became palpable. There were, however, gangrenous patches at the tips of the toes. Paralysis of the ankle and foot and loss of sensation from the knee downwards remained unchanged. Eventually the anterior compartment muscles of the leg and muscles of the foot sloughed and were evacuated.
The fracture united satisfactorily and arteriography showed satisfactory filling of the graft (Fig. 11), but the boy was left with a permanently damaged leg and foot. Later it was possible to amputate the foot at the ankle.

Comment—This is another example of a poor result due to the delay in restoring an effective circulation.

OPEN INJURIES

Case 7—A man sustained a small puncture wound on the front of the right wrist one month before admission to hospital. The wound had been caused in a road accident by a fragment of glass smashed from a driving mirror. The puncture was sutured but a pulsating swelling slowly developed in the next month. The swelling which was about two centimetres in diameter was over the radial artery and was diagnosed as a false aneurysm (Fig. 12). The findings were confirmed at operation. The aneurysm was easily excised and the two ends of the artery were ligated and divided. Reconstruction was unnecessary and the patient made an uneventful recovery.

Case 8—A man of thirty-two accidentally discharged a shotgun, severely injuring his left elbow. Soon after the accident he was admitted to hospital with a large disruption of skin and muscle over the front of the elbow. The hand and fingers were blue and mottled, and the radial pulse was not palpable. The hand and fingers were paralysed and devoid of sensation.

Operation and progress—The wound was explored and the median, ulnar and radial nerves were found to be disrupted over a distance of about seven centimetres. There was extensive damage to muscle and the upper end of the shaft of the radius. The brachial artery, the ulnar and radial arteries were destroyed over a distance of about three inches. Reconstruction was impossible. The brachial artery was tied in the upper end of the wound and the radial and ulnar...
arteries tied about half way down the forearm. The forearm and hand became gangrenous over the next day or two. Above-elbow amputation was carried out, after which he made a good recovery.

Case 9—A boy of twelve cut the back of his right knee with an axe and suffered severe haemorrhage. He was transfused with blood and the wound was explored.

Operation and progress—The popliteal nerves were found to be cut and the popliteal artery was divided. The artery was sutured end to end under tension. After operation the boy became anuric and underwent renal dialysis on two occasions before renal function returned. Meanwhile the leg and foot were noticed to be cold, mottled and pulseless. Four days after injury the wound was re-explored. The artery was not pulsating. In view of the tension on the anastomosis it was decided to excise it. The distal end of the vessel was flushed out with heparinised saline and there was a good “backbleed.” A section of reversed long saphenous vein about 3-7 centimetres long was used to restore continuity. Peripheral pulsation was present after operation and fasciotomies were performed on the anterior and posterior tibial compartments. The leg warmed up to ankle level but the foot pulses failed to return. Nine days after operation the foot was still ischaemic and the popliteal wound became infected in spite of antibiotic therapy. A brisk haemorrhage occurred the following day. Provisional amputation was performed through the knee joint. Some weeks later when the infection had cleared up a formal above-knee amputation was performed.

Comment—Reconstruction in this case failed because of the long delay (three days) before effective arterial continuity was restored. The distal arterial tree was probably partially occluded by thrombosis and the muscles and skin non-viable. This was the only patient in this series in whom we encountered anuria, presumably due to prolonged hypovolaemia caused by extensive haemorrhage and delayed transfusion. All the other patients were adequately transfused within a short time after injury.

Case 10—A man of eighteen had a stab injury in the left popliteal fossa. The wound was sutured but a swelling appeared which slowly increased in size. One month later he had an oval pulsating swelling, about twenty centimetres by fourteen centimetres, in the adductor canal and popliteal space.

Although there was no obvious interference with blood flow to the leg and foot, no pedal pulses were palpable. Motor function and sensation below knee appeared to be absent and a concomitant injury of the sciatic nerve was diagnosed. A femoral arteriograph confirmed the diagnosis of a false aneurysm (Fig. 13).

Operation and progress—The vessel was exposed after clamping the common femoral and profunda femoris arteries. The haematoma was evacuated and a 1-5 centimetres laceration in the femoral artery in Hunter’s canal was exposed. The adjacent vessels appeared to be normal. The edges of the laceration

![Fig. 13](image1.png)

**Fig. 13**

Case 10. Figure 13—Femoral arteriograph showing the false aneurysm, the result of a stab wound. Figure 14—Arteriograph after operation showing the repaired vessel which was closed by a patch of vein.
were freshened and an autogenous vein patch sutured into position to close the defect. There was a good restoration of posterior tibial and dorsalis pedis arterial pulses. The sciatic nerve lesion is now recovering and arteriographs after operation demonstrate a satisfactory repair (Fig. 14).

Case 11—A boy of sixteen slipped while jumping on to a railway platform from a moving carriage. He arm was crushed and almost severed above the elbow. The elbow and forearm remained attached to the arm by a small bridge of skin and the ulnar and median nerves.

Operation and progress—The limb vessels were flushed out with heparinised saline. The arterial continuity was then restored by end-to-end anastomosis within three hours of the accident. A suitable vein was joined by end-to-end anastomosis, and the humerus was fixed by an intramedullary nail. The muscles were loosely sutured and the limb supported by a plaster-of-Paris back slab. Fasciotomies were performed to reduce swelling. The radial pulse returned and a viable hand and forearm were obtained. Everything went well for five days when the wound became infected. Secondary haemorrhage occurred from the vascular anastomosis and the limb had to be amputated.

Comment—In this case limb salvage was well worth trying, but infection marred the result. Serious infection in the neighbourhood of vascular anastomoses nearly always leads to secondary haemorrhage.

Case 12—A man of forty-seven was involved in a collision, his right leg being trapped under the dashboard. He sustained a crush injury to the right calf which fractured the neck of the fibula. He received lacerations on the leg and a long laceration in the popliteal fossa.

Operation and progress—The wounds were sutured and afterwards diminished sensation of the foot and foot-drop occurred. Circulation was apparently normal although the pulses were not present. The limb began to swell, and three days later the foot was noticed to be pale and cold, anaesthetic and paralysed. A calf fasciotomy was performed which relieved the swelling of the leg. The muscle was noted to be pale. There was no real improvement in the circulation of the foot. It became mottled and ischaemic. No pulses were palpable in the foot and a femoral arteriograph demonstrated occlusion of the anterior tibial artery in the region of the fracture (Fig. 15). Presumably, therefore, the anterior tibial artery and common peroneal nerve were damaged by the injury. The circulatory defect was aggravated by the crush injury to the calf muscles. This resulted in oedema and compression of the collateral vessels compromising the residual and collateral blood supply to the leg. Fasciotomy was performed too late to relieve the oedema and this led to gangrene of the foot. The leg was amputated through the knee and the patient made a good recovery. Injury to vessels and nerves is an unusual complication of fracture of the neck of the fibula.

RESULTS

Six limbs were saved and in one other patient (Case 6) a Syme's amputation left the patient with a useful limb. If a successful reconstruction had not been performed, a mid-thigh amputation would have been necessary.

Amputation was performed in six patients. It is worthy of comment that more limbs were saved after closed injuries than after open injuries (5:2).

DISCUSSION

The time interval between injury, interruption of blood supply and irreversible changes occurring in the limb varies with the vessel damaged, the state of the collateral circulation and the amount of interstitial oedema. Damage to a brachial artery may not jeopardise the circulation to the arm, but with gross soft-tissue swelling and compression of collateral vessels which may occur as in a supracondylar fracture, severe ischaemic changes may result.

Femoral arterial injury often leads to total limb ischaemia and, if untreated, gangrene. How long can a limb be deprived of its blood supply? This varies with the site of interruption,
the state of the collateral vessels and the amount of tissue swelling; six to eight hours is a good working figure. If the blood supply is not restored within this period the nerves are the first to die, followed by muscle, then skin and then bone. If blood supply can be restored within this time, possibly as much as twelve hours, full restoration of function can be obtained. If, however, there is delay then nerves and muscles will die leaving a limb with only skin and bone alive. At the best, damaged muscles undergo fibrosis (Volkman’s ischaemic contracture) and at the worst, they die. With further damage, the skin dies and gangrene follows, when amputation becomes inevitable.

In open injuries to main arteries there is usually a major wound; consequently there is usually less delay in seeking expert treatment, on average about fifty hours. False aneurysm may occur after a puncture wound or laceration of a major vessel. This type of injury does not usually lead to dramatic interference with blood supply because it develops slowly. In most instances the blood supply is even greater than normal, so that surgical repair can be undertaken under the best conditions, often some time after the original injury (Cases 2, 7 and 10).

Delay in treatment occurs most often in closed arterial injuries, on average about eighty hours, especially those complicating fractures (Cases 1 to 6). All the closed injuries in this series were sent for vascular repair some time after the original injury. The delay (average 80 hours) was invariably due to a missed diagnosis of acute ischaemia of the limb. In all cases of limb trauma, damage to vessels and nerves should be looked for in addition to a fracture. Radiographs will take care of fracture diagnosis but not an arterial or nerve injury. One must always examine to exclude a complicating soft-tissue injury.

The important clinical features of acute arterial interruption complicating a limb injury are: severe pain in the limb; paralysis or rigidity of muscles; the hand or foot becoming cold, pale or a mottled blue colour. Swelling of the extremity complicates the picture and makes detection of the peripheral pulses difficult. Absence of a previously felt peripheral pulse is highly significant. If in doubt an arteriograph will give a definite answer.

Acute swelling of a limb after a crush injury may precipitate acute circulatory embarrassment. Swelling often reaches its zenith within twenty-four hours of injury and is not usually apparent to begin with. Consequently if the limb is tightly bandaged or put in plaster, then the blood supply will be obliterated. When swelling is severe, immediate fasciotomy should be done in order to decompres the musculo-fascial compartments. In the lower limb this means a longitudinal incision over the calf and anterior tibial compartments, dividing skin and deep fascia.

Sometimes the toes or fingers may show no signs of circulatory inadequacy and indeed all peripheral pulses may be present (Case 4), yet the limb may be extremely swollen and in danger. Even when the skin circulation in the foot or hand is normal, ischaemic necrosis of muscle may occur, with consequent Volkman’s ischaemic contracture. This type of lesion was first described in the anterior tibial compartment and termed the “antterior tibial syndrome” (Voght 1943). Blandy and Fuller (1957) described this condition following strenuous physical activity alone: the muscles of the anterior compartment of the leg become acutely swollen, but the pulses in the foot remain normal. An early sign of this complication is weakness of the involved muscles, extensor hallucis longus in the case of compression in the anterior tibial compartment. In addition the nerves are often damaged by ischaemia resulting in wide sensory loss—usually in the distribution of the anterior tibial nerve. Unless relieved by early fasciotomy of the anterior tibial compartment the muscles die and are replaced by fibrous tissue. It is believed (Harman 1948) that trauma to muscles, whether by excessive exercise or crushing, leads to swelling and increased pressure within the confined space of the muscle sheath. Impairment of circulation in the muscle occurs due to high interstitial pressure with compression of the vessels and then necrosis. The nerves in this tight compartment are presumably affected by the same pressure and, being even more sensitive to anoxia, undergo necrosis.
Traumatic amputation of a limb and reattachment poses a special problem. Several such successful operations have been recorded in the literature (Huang, Li and Kong 1965). In this series one case is recorded: although it was successful initially, the result was spoiled by severe contamination of the wound and subsequent infection. This resulted in secondary haemorrhage and amputation of the limb (Case 11).

When circumstances are favourable the severed part should be cooled in or packed in ice and sent to hospital with the patient. Operation must be begun, at the most, within six hours after injury. The limb should be perfused with cold heparinised isotonic saline or low molecular weight dextran with penicillin added. If necessary autogenous blood mixed with heparin and dextran can be used to perfuse the severed part. The bone should be rigidly fixed and shortened if necessary. At least two veins (British Medical Journal 1966, Takayuki Inoue et al. 1967) are anastomosed and then the artery or arteries are reconstituted directly, or by the use of an autogenous vein graft. Fasciotomy should be performed above and below the site of injury; nerves, tendons and muscles may be sutured.

Prevention of infection, which often leads to secondary haemorrhage from the arterial anastomosis, is essential.

Treatment of false aneurysm resulting from trauma appears to be the most successful of the injuries described. Penetration of an artery by a sharp implement or bone fragment results in blood leaking into the tissues. This leakage becomes encapsulated and forms a pulsating tender swelling. Pain is often a marked feature but disturbance of the peripheral circulation is usually negligible. Normal blood flow continues and the haematoma can be evacuated and continuity of the vessel restored if the size of the vessel permits it (Cases 2, 7 and 10).

CONCLUSIONS

After experience we now use this classification of peripheral vascular injuries: 1) open arterial injury; 2) closed arterial injury; 3) false aneurysm; 4) massive traumatic oedema; and 5) traumatic amputation.

Open arterial injury—Injury to the main artery is usually obvious because of severe haemorrhage, distal ischaemia, paralysis, anaesthesia and absent pulses. Exploration of the wound will reveal the extent of arterial injury. The vessel is usually divided either partly or completely. If partly divided it is often possible to close the defect by a patch of saphenous vein. If not it is usually necessary to excise the damaged part of the vessel. If there is no tension, and this is unusual, then end-to-end anastomosis, fashioned obliquely, can be done. If there is tension, then continuity can best be restored by a reversed vein graft. This is usually inserted end to end with an oblique or “fish-tailed” anastomosis to avoid stenosis.

Closed arterial injury—These usually follow crush injuries and are most commonly associated with fractures at the knee, of the shaft of the femur, the elbow and shoulder. When diagnosis of arterial compression or laceration has been made, immediate exploration is essential. Bleeding into the tissues causes considerable swelling, and blood loss must be restored by immediate transfusion.

Exploration is the same as in open injuries. The artery wall may appear intact, though not pulsating. This was formerly thought to be due to spasm of the vessel, yet a non-pulsating vessel should always be opened by longitudinal incision, after haemostatic control above and below the site of injury. Usually one finds the intima disrupted and detached, forming a flap valve which impedes flow and usually leads to secondary thrombosis. It is often necessary to resect the injured vessel wall and either restore continuity by end-to-end anastomosis or by a reversed autogenous vein graft. Laceration of the vessel is dealt with by patching, vein replacement or end-to-end anastomosis. It is always wise to do fasciotomies beyond the site of arterial injury to reduce oedema. Any fractures should be fixed before reconstruction of the injured artery.
False aneurysm—This least disturbs the circulation, yet unless repaired, external rupture will usually occur. Diagnosis can be confirmed by arteriographs (Cases 2, 7 and 10) and excision can be done with reconstruction as already mentioned.

Massive traumatic oedema—Acute oedema of a limb following crushing or other forms of trauma is an emergency whether the distal circulation or pulses are present or not. All constricting bandages and appliances must be removed and, if there is no improvement in the blood supply or anaesthesia of the hand or foot, fasciotomies should be performed over the point of greatest swelling. If there is no improvement and there is still doubt about the circulation an arteriograph should be performed to eliminate arterial interruption. The sooner fasciotomies are done the less the risk of muscle ischaemic necrosis and the possibility of Volkman's ischaemic contracture (Cases 4 and 5).

Traumatic amputation—The quicker the limb is reconnected the better. The more distal the amputation the better is the chance of success. Contamination and subsequent infection remains one of the greatest difficulties in treatment. The amputated part should be cooled in ice and perfused with ice-cold heparinised saline or low molecular weight dextran with heparin added. Perfusion with autogenous blood may also help to preserve the part before reattachment. The bones should be fixed by internal fixation; arteries and several veins should be reconnected. If contamination is slight, tendons and nerves may also be sutured. Fasciotomies should be performed above and below the site of injury, and loose closure of the skin and immobilisation complete the procedure.

SUMMARY

1. Experience with twelve cases of arterial trauma are presented.
2. Six limbs were amputated and six limbs saved.
3. Delay in effective treatment was the major cause of failure to save the limb.
4. Five types of limb injury involving vessels are described.

Addendum—The author has had experience of three further arterial injuries since submission of this paper for publication.

Case 13—Pulsating haematoma of the left brachial artery following metallic fragment penetration. Successfully repaired one month after injury.

Case 14—Complete division of the popliteal artery and vein in a seven-year-old boy following glass penetration. Successfully repaired by end-to-end anastomosis within four hours of injury.

Case 15—Closed injury of the distal popliteal artery in a forty-year-old patient following a comminuted upper tibial fracture. Initial repair by resection and vein graft elsewhere failed. Four days later successful restoration of circulation by reversed vein graft.

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