# ARTERIAL INJURIES

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An analysis of 50 cases of major arterial injury was made in patients presenting for treatment at Baragwanath Hospital over the past 2½ years. Those patients who died before any form of therapy had been carried out were excluded from the series, as were those with injuries involving minor arteries such as the radial, ulnar, superficial temporal, posterior tibial and dorsalis pedis, which commonly occurred.

The location of the arterial injuries are summarized in Table I. The commonest vessels involved were the brachial, femoral, carotid, and subclavians; arterial injuries being dispersed throughout the arterial tree.

TABLE I. LOCATION OF ARTERIAL INJURIES

| | | |
|---|---|---|
| Aorta | Thoracic | 2 |
| | Abdominal | 1 |
| Carotid | Common | 7 |
| | Internal | 0 |
| Vertebral | | 2 |
| Subclavian | | 3 |
| Axillary | | 6 |
| Brachial | Above profunda | 3 |
| | Below profunda | 7 |
| Femoral | | 10 |
| Popliteal | | 5 |
| Pulmonary | | 1 |
| Anterior tibial | | 2 |
| Transverse cervical | | 1 |
| Total | | 50 |

Two cases of injury of the anterior tibial artery were included in the series because of complications — one developed gas gangrene and the other an aneurysm which resulted in severe anoxia of the extensor compartment. Both required extensive fasciotomy and excision of the extensor muscles of the leg.

Arterial injuries were classified according to the usual 4 types encountered, lacerations accounting for 70% of the lesions (Table II). Transections only occurred in 14%.

TABLE II. TYPES OF ARTERIAL INJURIES

| | | |
|---|---|---|
| 1. Transections | | 14% |
| 2. Lacerations (including intimal dissections) | | 70% |
| 3. Contusion (with thrombosis) | | 4% |
| 4. Spasm | Benign | 6% |
| | Malignant | 6% |

In most series the proportion of lacerations to transections is approximately equal and in De Bakey and Morris's[1] series of 136 cases the proportion was 41 : 52%.

In the present series the results could not be correlated with the type of arterial injury. If any, the results were slightly better with complete transections than with incomplete lacerations.

No cases of contusion occurred without associated thrombosis. Spasm was classified as benign or malignant according to the type of injury sustained, the response to treatment, and the final result. Kinmonth[2] distinguishes a benign local or myogenic spasm as distinct from a more extensive circumferential neurogenic spasm which involves collaterals due to severe crushing or an occluding injury, as may occur with a fracture or a tourniquet-occlusion.

Three patients with benign spasm presented with brachial artery occlusion and all responded to open operation and application of papaverine, 2·5% locally; whereas in 3 patients with extensive spasm in the popliteal region, resulting from crushing injury, bullet concussional effect, or fracture-dislocation of the knee, revascularization failed in the lower extremity, and ended in amputation. A dissection of one of the limbs subsequently revealed

thrombosis of the anterior and posterior tibial and peroneal arteries distal to the site of spasm, as well as thrombosis of the popliteal veins. It would appear that prolonged spasm may precipitate thrombosis in the distal static vessels.

Intimal dissection was recorded in only 1 case and was caused by acute angulation at the site of a closed midshaft fracture of a femur. It may also occur in association with concussional effects of a high-velocity missile or in a closed injury with bruising of an artery.

With rupture of a subintimal clot, arterial pressure causes a dissection of the subintimal space which may spread in the wall of the artery for a considerable distance.

### AGE

The age variation was between 9 and 43 years. One patient was 60 years old. The median age was 24 years. All but 4 were male subjects and the problem of atherosclerotic vessels did not occur in any of the patients.

### TIME OF PRESENTATION AFTER INJURY

No correlation could be found between the time of presentation at hospital after the injury and the end results. Good results were obtained in patients operated on 24 hours after injury, and the reverse also applied. Delay did not contraindicate surgery.

Hughes[3] stresses the patient's general condition, amount of shock, exposure, collateral supply present, soft-tissue injury, and the affected artery, and uses these criteria as a guide rather than the time factor. If there is any doubt regarding the viability of the limb it is better to repair the artery, which may salvage a part of the limb. In civilian practice arterial injuries present earlier and are treated sooner than during war time.[2] The patients in this series presented in two main groups:

1. *Within 24 hours*
   - (i) Within 6 hours, 31.
   - (ii) Between 6 - 12 hours, 4.
   - (iii) Between 12 - 24 hours, 1.

   Total 36 cases.
2. *After 24 hours*

   Variation between 2 days and 4 years. Median 1 month. All these patients presented with aneurysms or fistulae. Total 14 cases.

### ASSOCIATED INJURIES

These are important in arterial injuries and occurred in the present series on 29 occasions (58%). They included the following: (1) Bone or joint injury 6, (2) extensive soft-tissue injury 3, (3) nerve injury 8, (4) major vein injury 8, and, (5) unassociated injuries 4.

1. *Bone Injury*

In 4 cases of arterial injury fracture of the femur occurred — the arteries sustaining transection, spasm, subintimal dissection, and mechanical obstruction due to bone fragment, respectively.

One dislocated knee caused extensive contusion with thrombosis, and 1 supracondylar fracture of the humerus resulted in benign spasm.

2. *Extensive Soft-tissue Injury*

This was an important factor in the thigh only, where it occurred on 3 separate occasions in open injuries. This resulted in extensive muscular collateral involvement. Collaterals are better developed in a muscular region such as the thigh than in a non-muscular part like the knee, although there are more named collaterals in the knee.[4]

Extensive soft-tissue injury associated with arterial injury, therefore, has a bad prognosis.[5] Of the above 3 cases of extensive soft-tissue injury, 1 required an above-knee amputation and the remaining 2 were left with permanently ischaemic limbs.

3. *Nerve Injuries*

An associated nerve injury should be assessed in detail at the original examination with a view to differentiating it from ischaemic neuropathy. An associated nerve injury will present initially, not be progressive, and will conform with typical motor and sensory topography.

Ischaemic neuropathy is progressive; it is characterized by a typical glove or stocking distribution, selective sensory loss and delayed pain sensation which is the last to disappear. Epicritic sensation is involved early. Wrist drop and weakness of the long extensor to the big toe is a notable feature of ischaemic neuropathy. Intrinsic muscles of the foot and hand are also involved.[4]

In this series nerve lesions occurred in the upper limb and root of the neck only, with partial involvement of the brachial plexus (2), Horner's syndrome (2), median nerve (3), and musculocutaneous nerve (3). No nerve injuries occurred in the lower limbs where the arteries and nerves are at some distance from each other.

In one patient with a wrist drop and intrinsic muscle palsy following brachial artery occlusion, the radial nerve was explored and found to be normal in appearance — a case of ischaemic neuropathy.

All the nerves were repaired with the arteries at the original procedure.

4. *Vein Injuries*

All veins other than the superior vena cava and inferior vena cava above the renal veins may be ligated, but the tendency is for repair rather than ligation. Treatment will depend on the site, collateral supply, type, and accessibility of the injury and general condition of the patient. Deep-seated venous injuries such as occur in the root of the neck and abdomen may be more difficult to treat than arterial injuries. Often repair by lateral suture may be easier than ligation. An unsuccessful repair may result in thrombosis which may become propagated.

In the present series 8 major venous injuries occurred: 3 internal jugular veins — all ligated, 1 axillary vein — ligated, 1 brachial vena comes — ligated, 2 femoral veins — 1 ligated and 1 repaired. No complications, attributed to these injuries, occurred.

The 8th case was a contused popliteal vein with intimal clot which occurred as a result of missile concussion; the clot was soft and friable and small emboli had probably occurred.

5. *Unassociated Injuries*

These lower the patient's general resistance and may

mask the arterial injury. This occurred in the following circumstances:

(a) Head injury — semicoma; closed abdominal injury, as a result of being run over by a car. A crushed contused popliteal artery resulted in an above-knee amputation.

(*b*) Haemothorax — on 3 occasions; patients being treated conservatively for haemothorax, in 2 cases the condition was caused by a lacerated subclavian artery and in 1 by a lacerated aorta.

## DIAGNOSIS ON ADMISSION

A study was made of the provisional diagnosis by casualty officers and house surgeons on arrival of the patients at the wards. In only 32 patients was a diagnosis of arterial injury or a condition indicating arterial injury made. A provisional diagnosis of 'stab neck', 'haemothorax', 'lacerated thigh', 'multiple injuries with shock', or any urgent direct admission was allowed. In the remaining 18 cases arterial injury was misdiagnosed for 3 main reasons:

1. *Aneurysm, called an abscess,* occurred in 6 cases: 4 brachial aneurysms, 1 axillary aneurysm, and 1 vertebral aneurysm diagnosed as tuberculous adenitis.

Two patients were booked for surgery for incision of an abscess. One was incised and one was needled.

This mistake is not difficult to make. An aneurysm need not pulsate or have a bruit. Blood in the extravascular compartment causes general and local effects of inflammation and may closely resemble an abscess. Occasionally an infected pulsating haematoma occurs.

2. *Overlooked because of associated injuries:* 1 patient in semicoma had closed abdominal injuries (popliteal artery occlusion was only detected 48 hours after laparotomy) and nerve injuries occurred in 3 patients in whom brachial artery occlusion was not diagnosed — the patients having been admitted with radial, median nerve, or partial brachial plexus injuries.

3. *In fractures and dislocations:* 5 patients with a fractured femur and 1 with a dislocated knee were admitted without associated arterial injury being diagnosed, although in all cases the pulse was not present below the fracture. Two patients were transferred from other hospitals and all were radiographed before admission. No provisional splints had been removed in those patients transferred from other centres. House surgeons in the wards also overlooked arterial injuries.

## TREATMENT

### *Blood Replacement*

The amount of blood replaced varied between nil and 14 pints. The average was 3·1 pints and the median was 4 pints. The requirements were greater in acute injuries than in aneurysms and fistulae, and were greater in arterial lacerations and transections. More replacement was required where bleeding was difficult to control, as in the neck, axilla, and thorax.

More than 3 pints of blood were seldom required in injuries of the arm and thigh where fracture or extensive soft-tissue injury did not occur.

In arterial surgery, the aim of replacement should be to maintain an adequate blood pressure throughout the procedure particularly after reconstruction of the vessel, where a drop in blood pressure and circulatory stagnation may result in clotting at the site of repair. Inadequate fluid replacement may manifest itself by a fall in blood pressure during the induction stage of anaesthesia. Overloading of the circulation may occasionally occur with the use of hypothermia and in the repair of arteriovenous fistulae.

### *Exposure*

Before treatment of the affected artery, the exposure should allow tape control of the artery both proximally and distally. This should be done in all cases. Peep-hole surgery may result in tragedy and occurs particularly in the root of the neck. There should be no hesitation in removing wide segments of clavicle and costal cartilages, and splitting the manubrium longitudinally with lateral extension, to secure adequate exposure.[16]

The upper carotid and vertebral systems may be exposed by an oblique or transverse incision in the neck.

Arterial injuries around and including the heart may be adequately exposed by an anterior transverse intercostal incision cutting across the sternum with a Gigli saw. Both internal mammary arteries will have to be secured. The space selected will depend upon the site of entry. The standard approaches to the thoracic contents may also be used.

Incisions crossing flexion creases at the inguinal region, popliteal, and antecubital fossae should be interrupted by an S-shaped or transverse incision parallel to the flexion crease, in order to prevent scar contracture. This is more important in the Bantu who develop keloids and hypertrophic scars quite frequently.

### *Treatment of the Affected Artery*

Before 1950, the treatment of arterial injuries was ligation.[4] The largest recorded series is that of De Bakey and Simeone[6] who analysed 2,471 injuries of the Second World War. The amputation rate was 50%. In 81 patients who were treated by lateral repair, or end-to-end anastomosis, the overall amputation rate was 35%.

The results of ligation of major arteries are shown in Table III. With the advent of antibiotics and abundant blood transfusions, surgical techniques developed by procedures such as repairing coarctations of the aorta and

TABLE III. RESULTS OF LIGATION OF MAJOR ARTERIES IN 2,471 CASES. (DE BAKEY AND SIMEONE[6])

| | *2,471 Cases* | |
|---|---|---|
| Subclavian | 28% | amputated |
| Axillary | 43% | amputated |
| Brachial — Above profunda | 55% | amputated |
| Brachial — Below profunda | 25% | amputated |
| External iliac | 46% | amputated |
| Common femoral | 81% | amputated |
| Superficial femoral | 54% | amputated |
| Popliteal | 72% | amputated |
| Carotids | 30% | (hemiplegia—death) |

Fallot's tetralogy, and methods of storing arterial homografts. Arterial injuries were now approached with a view to repair.

In the Korean War and subsequently, these principles were put into practice on a large scale.

In Table IV a summary is given of the results of repairs of major arteries.

TABLE IV. RESULTS OF REPAIRS OF MAJOR ARTERIES (KOREAN WAR AND CIVILIAN INJURIES)

Hughes[2] 73 repairs, 8 amputations (1 upper limb)
Jahnke and Howard[5] 56 repairs, 6 amputations
Morris and De Bakey[1] (civilian injuries)
93 repairs, 7 amputations, 3 deaths
32 ligations, 5 amputations, 2 deaths
Seeley, Hughes, Cook and Elkin.[15] Aneurysms.
33 repairs, no amputations, 2·8% insufficiency
28 ligations, no amputations, 24% insufficiency

Acute arterial injuries after repair had an average overall amputation rate of about 10%.

Ligations had an amputation rate of about 20%.

The best results were obtained in fistulae and aneurysms where in large series amputations were a rarity.

The problem that any surgeon is faced with is: what arteries may be ligated, and what arteries have to be repaired. All arteries should be repaired, the only contra-indication being very poor condition of the patient.

Cranley has divided arteries into 3 groups[2] (Table V).

TABLE V. ARTERIES DIVIDED INTO THREE GROUPS AS REGARDS LIGATION (CRANLEY)

1. Tied with impunity
   External carotid
   Radial or ulnar
   One of arteries below popliteal trifurcation
2. Tied under certain circumstances
   Common carotid, Vertebral, Subclavian, Axillary, Brachial
   (*a*) Collaterals intact
   (*b*) Minimal soft tissue damage
   (*c*) Blood pressure maintained throughout
3. Repaired under all circumstances
   Aorta
   Innominate
   External iliac
   Femorals, popliteal

In the present series results should have been better than those obtained in battle injuries because of smaller calibre missiles, less frequent soft-tissue and bony injury, and earlier presentation.

Debridement of a lacerated artery, well clear of the affected part, is as important here as it is in the treatment of lacerated skin or muscle. Holman[7] advises resection of at least 1 cm. on either side of the laceration and has demonstrated degeneration including necrosis for some distance from the site of injury.

Mobilization of small collaterals in the vicinity is permissible to oppose the resected segments without tension, or only slight tension. Subintimal dissection should be transected well clear of its extremities. Anastomosis should be performed with atraumatic oiled silk 50, with at least one-third of the circumference being interrupted to allow for expansion or growth of the artery in young patients. Loose continuous sutures may be used. Adventitia should be stripped to allow suture of the media without interference with the anastomosis or inversion of the adventitia into the lumen. Potts or bulldog clamps should be avoided because of possible intimal damage they may produce. Proximal and distal control can be obtained by applying a firm catheter round the artery and securing it with artery forceps. Tapes may be used for the same purpose.

Spasm may be overcome by sympathetic block, local application of papaverine, 2·5%, or the injection of normal saline into the proximal segment under pressure to distend the spastic artery.[8] Deep fascia should be left unsutured at the end of the procedure, and where the affected limb is under tension fasciotomy should be performed. If in doubt this should be done. Heparin is generally not required systemically, but may be used locally in undiluted form to flush out the artery. It may be neutralized at the end of the operation by protamine sulphate 10 ml./5,000 u.heparin.

Autogenous vein grafts are adequate for any defect up to 4-5 inches. The vein should be reversed to offset the effects of valves that may be present. They are required in 10-15% of cases only.

Contusion with thrombosis should be resected because of the tendency for further thrombosis after thrombo-endarterectomy.[9]

Associated fractures should be stabilized by internal fixation by Küntscher-nailing or plating procedures. Limbs should not be encased in plaster of Paris; a slab will generally maintain adequate fixation. If plaster encasements are used they should be split down to the skin immediately after operation.

The results of arterial repair are shown in Table VI. Vein grafts were used in 8% of the present series and in 20% of repairs.

TABLE VI. RESULTS OF ARTERIAL REPAIR

A. Lateral suture or end-to-end anastomosis

| | *No.* | *Functional* | *Failed but viable* | *Amputated* | *Died* |
|---|---|---|---|---|---|
| Upper limb | 7 | 6 | 0 | 1 | 0 |
| Lower limb | 7 | 3 | 3 | 1 | 0 |
| Aorta | 2 | 1 | — | — | 1 |

B. Vein grafts

| | | | | | |
|---|---|---|---|---|---|
| Carotid | 1 | — | — | — | 1 |
| Axillary | 1 | — | 1 | — | — |
| Femoral | 2 | 1 | — | 1 | 0 |
| Total | 20 | 11 | 4 | 3 | 2 |

Absolute failures occurred in 5 cases (25%) and relative failures (viable extremities, failed repairs) in 4 cases (20%), the total number of occluded repairs being 9 (45%).

In arterial ligations the amputation rate was 14% with 33% remaining with ischaemic extremities, total complication rate being about 47% (Table VII). Ischaemic sequelae were much less where arterial repair was undertaken.

TABLE VII. RESULTS OF ARTERIAL LIGATION

| | *No.* | *Normal* | *Deaths* | *Amputated (or hemiplegia)* | *Ischaemic* |
|---|---|---|---|---|---|
| Carotico-vertebral system | 7 | 5 | 1 | 1 | — |
| Upper limb | 11 | 7 | — | — | 4 |
| Lower limb | 4 | 1 | — | 2 | 1 |
| Total | 22 | 13 | 1 | 3 | 5 |

The location and treatment of aneurysms and fistulae

are shown in Table VIII. The best results were obtained where the arterial injury had presented as an aneurysm or fistula, or where an acute injury was treated after an interim period after developing an aneurysm.

TABLE VIII. A. LOCATION AND TREATMENT OF ANEURYSMS AND FISTULAE

| *Site* | *No.* | *Ligation* | *Repair* | *Results* |
|---|---|---|---|---|
| Carotid .. .. | 2 | 1 | 1 | Good |
| Vertebral .. .. | 1 | 1 | — | Good |
| Upper limb .. | 7 | 4 | 3 | Good |
| Lower limb .. | 6 | 3 | 3 | Good |
| Aorta .. .. | 1 | — | 1 | Good |
| Total .. .. | 17 | 9 | 8 | |

B. ACUTE INJURIES TREATED CONSERVATIVELY

| | *No.* | *Ligated* | *Repaired* |
|---|---|---|---|
| Carotid .. .. | 2 | 1 | 1 |
| Brachial .. .. | 2 | 1 | 1 |
| Femoral .. .. | 3 | 3 | 0 |
| Aorta .. .. | 1 | 0 | 1 |
| Total .. | 8 | 5 | 3 |

Eight patients with acute injuries were treated conservatively because of small haematomas, pulses present distal to the affected artery, and small skin openings which did not allow of much external blood loss and in which soft-tissue injury was minimal.

The present consensus of opinion is that all acute arterial injuries should be explored initially,[20] but Hughes[8] is of the opinion that carotid artery injuries are best treated conservatively and allowed to develop a collateral circulation where the local condition allows.

In the present series those treated conservatively were operated on after an average of 35 days, the variation being 5 days to 5 months. All did well. Only 3 were repaired.

### CAROTID ARTERIAL INJURIES

These present unique problems in that no matter what local procedure is adopted, whether ligation or repair, occlusion of the carotid circulation for as little as 3 minutes may result in irreversible cerebral softening causing death or hemiplegia.[11]

Harris and Udvarhelyi[12] and Brackett[13] in two separate series of a total of 131 cases of cerebral aneurysm, in which the carotid artery was ligated, had the following results: Death 10%, permanent hemiplegia 25%, and epilepsy or psychotic changes 15%. The incidence of these complications may be reduced to a bare minimum (approximately 5%) if several factors are considered:

1. *Cross-circulation test.* A contralateral carotid angiogram with ipsilateral compression (at operation if necessary) is performed to show if an adequate cross circulation (mainly *via* the anterior communicating artery) exists. If cross circulation is not present, ligation is fraught with danger.

2. *Drop in cerebral blood pressure* of as little as 10 mm. mercury may precipitate cerebral anoxia. This may occur with blood loss or during anaesthesia. Neurosurgeons often ligate the carotid artery under local anaesthesia for this reason (it also allows the early detection of hemiplegic signs, which may be reversed if the patency of the artery is immediately restored).[17] Important aids in the treatment of acute injuries as well as fistulae and aneurysms are hypothermia and an arterial bypass which should be of wide enough bore to allow good cerebral circulation.

### VERTEBRAL ARTERIAL INJURIES

These may be of considerable importance because of their supply to the subtentorial structures.[17] Adequate collateral circulation is normally present provided both vertebrals and carotids are patent. In 5 - 10% of patients one vertebral artery is underdeveloped or absent. Ligation of the only normal vertebral artery in these circumstances may prove extremely hazardous. This anomaly may be detected only by angiography or direct exploration.[14]

Aneurysms may be treated by Hunterian ligation in the vertebral triangle or by trapping between ligatures or clips. Exposure of the vertebral artery in the neck may be obtained by nibbling the costo-transverse process.

In the present series 7 common carotid injuries occurred; 5 were operated on in the acute phase and 2 formed aneurysms or fistulae. Of the 5 operated on initially, 1 negative exploration resulted in hemiplegia which showed occlusion of the middle cerebral artery (a result of possible embolus from contused artery), and 2 were ligated without complications. One patient had a ligation and died of cerebral softening 12 hours later, and another with a saphenous vein graft died of the same cause 12 hours later, although the graft was patent at the end of the operation. The cerebral circulation had been occluded during the process of repair.

The 2 patients who developed aneurysm and fistula respectively were investigated by cross-circulation tests which were normal, and operated on under hypothermia. In the patient with a fistula the artery was repaired and the jugular vein ligated, and in the other patient the aneurysm was obliterated. Both patients made uneventful recoveries.

Two vertebral artery injuries were successfully treated by ligation in the vertebral triangle. No cross-circulation tests were done.

### INCIDENCE OF SEPSIS

This is generally stated to be not very important. All the patients in this series received routine antibiotics (pencillin and streptomycin) and antitetanus serum.

In all cases where sepsis was a factor, thrombosis of the affected artery occurred. This may have developed without infection. Amputation was performed because of gas gangrene, not because of thrombosis (Table IX).

TABLE IX. INCIDENCE OF SEPSIS*

| *Type of infection* | *No.* | *Amputation* | *Thrombosis* |
|---|---|---|---|
| A. Gas gangrene .. | 3 | 3 | 3 |
| B. Gross .. .. | 1 | 1 | 1 |
| C. Mild .. .. | 2 | — | 2 |

* Total number of cases 6, i.e. 12%.

### RÔLE OF ANGIOGRAPHY

The indications for angiography are summarized in Table X. Angiography plays little part in the acute injury before exploration in the detection of the site of the lesion. Direct angiography may be easily performed during operation.

TABLE X. INDICATIONS FOR ANGIOGRAPHY

1. Acute injuries
   After any form of repair to establish presence of occlusion (by clot) more distally (during operation). Performed twice.
2. Aneurysms and fistulae
   (*a*) Establish specific artery
   (*b*) Collateral supply
   (*c*) Diagnosis and venous filling
   Performed 16 times.
3. Long-term after-repair or graft
   Performed 8 times.
4. Cross-circulation test
   Performed twice.

Total no. 28.

It is not indicated to establish the presence of an adequate circulation in the first 24 hours after operation where pulses are absent. This may be surmised on clinical and oscillometric study alone.

Angiography should be performed as a long-term follow-up in arterial repairs to study the technique of anastomosis, length, and tortuosity of the graft and the occurrence of thrombosis.

## SUMMARY

An analysis of 50 cases of major arterial injuries was made of patients presenting for treatment at Baragwanath Hospital over a 2½-year period.

Of these patients 3 died, 8 had amputations (one upper limb), 2 were left with permanent hemiplegias, 3 developed gas gangrene, and 5 were left with vascular insufficiency of the affected limb.

The complication rate for all the cases was approximately 40%. The type of treatment did not materially alter the result. The series is too small to come to any definite conclusions.

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