Civilian Arterial Injuries

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During 1968–1973, 122 patients with 126 arterial injuries were treated. In 94 instances (90 patients), these injuries involved extremities. Systolic blood pressure was below 90 mm Hg upon admission in 55.6% of all patients and 37.7% of those with injuries to arteries of the extremities. The decision for operative exploration and repair of arteries of extremities was based largely on clinical grounds (shock, loss of pulse). Preoperative arteriography was needed infrequently, while operative angiography was nearly routine. Although several cases of late revascularization or traumatic thrombosis of renal artery have been reported, hypertension complicates the postoperative period, and early, aggressive approach is essential. Mortality was 10.6%, from aortic injuries. There were no deaths among patients with arterial injuries distal to inguinal ligament or thoracic outlet. The amputation rate from reconstruction failure was 1.1%, none occurring in the last 3 years of the series. The high patency rate and lack of evidence of pulmonary embolization suggest that associated venous injuries be repaired routinely. Arterial injuries represent ideal lesions (normal arterial wall with excellent run-in and run-off). Prompt treatment of shock and early, proper management of patients' mechanical disruptions will salvage many lives and most limbs.

THIS REPORT is based on the study of 122 patients with 126 arterial injuries who were treated in this institution between January 1, 1968, and December 31, 1973. Twenty-eight patients were treated during 1968 and 1969 on the General Surgery Service. Since 1970, the Vascular Surgery Section has been primarily responsible for initial evaluation and definitive treatment of 94 subsequent cases. The ages of the patients ranged from three to 62 years, with most patients in the third decade. Twenty-two patients (18%) were female.

Distribution and Types

One hundred nine patients suffered 113 injuries to major arteries, and 13 patients had injuries to minor arteries (radial, ulnar, tibial) (Fig. 1). Ninety-four of the injuries (74.6%) affected arteries of the extremities.

In 105 instances (83.3%), the arterial injury was caused by penetration (Table 1). Sixty-three (60%) of these injuries were due to gunshot wounds, and 42 (40%) to stab wounds. Perforation, transection, or lateral laceration were the mechanisms and findings in patients with penetrating injuries.

Twenty-one injuries (16.7%) were caused by blunt trauma. Five of 12 popliteal artery injuries were nonpenetrating, due to automobile accidents or to falls from high places. In the blunt trauma group, intimal disruption, retraction, and thrombois were usual findings (Fig. 2), although transection of artery was seen also.

Acute arterial fistulae occurred in two patients (1.6%) (deep femoral and superior mesenteric arteries), both being second arterial injuries not recognized at the time of repair of major nearby vessels. False aneurysms occurred in three patients (2.4%) (brachial, 2, and external iliac artery, 1). Arterial injury was not suspected in the former two, and operation was not performed early after injury. Iliac artery trauma was missed at the time of abdominal exploration in the third patient.

Clinical Findings

Sixty-eight patients (55.6%) were admitted with hypovolemic shock. All but one patient with aortic injury (89%) were in severe shock. Shock due to major arterial injury in the abdomen or thorax persisted because continued hemorrhage exceeded the rate of replacement with Ringer's lactate solution and unmatched O negative blood infusion. Hemorrhagic shock in patients with injury distal to the inguinal ligament or thoracic outlet responded to rapid infusion of Ringer's lactate solu-

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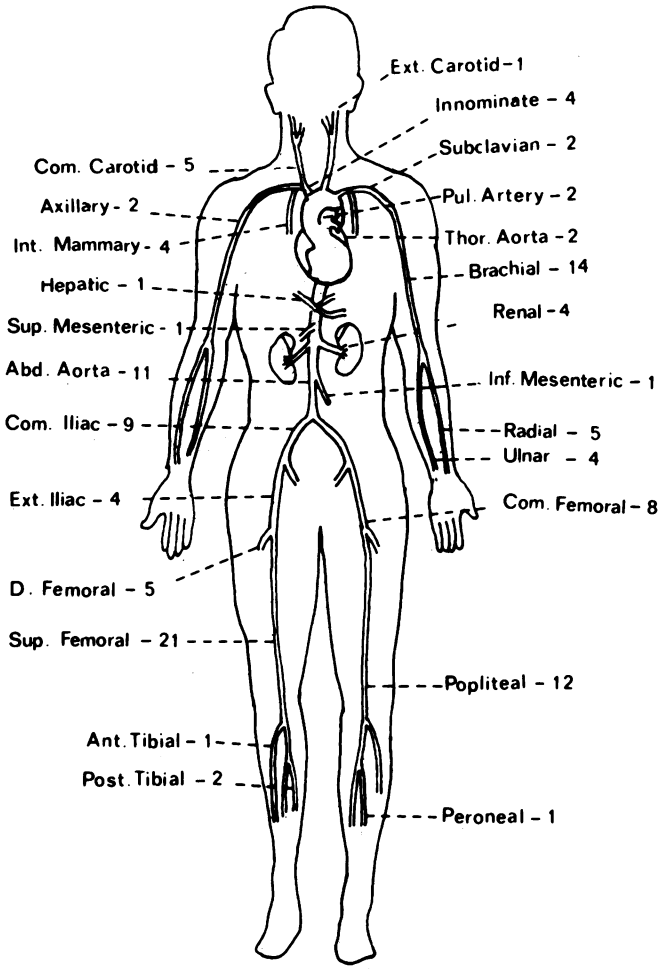

FIG. 1. Distribution of 126 arterial injuries in 122 patients.

tion while blood was being typed and cross-matched. Thirty-four patients (37.7%) with injuries to arteries of the extremities arrived in shock.

Sixty-two of 90 patients with arterial injuries to extremities had persistent absence of pulses distal to the site of injury (Table 2). The majority of them had clinical evidence of ischemia of varying degree (paresthesias and numbness) and cold, pale, cyanotic feet. Ischemic signs were marked in 9 of 12 cases of trauma to the popliteal artery. In 20 patients, the pulses distal to injury were palpable. Expanding hematoma (10) active pulsatile bleeding (5), and bruit (1) indicated arterial injury in 16 cases. Four had injury to profunda femoris artery. In 8 patients with persistent shock, the distal pulses could not be evaluated.

Five patients had injury to the common carotid artery. Three remained in shock until operative exploration controlled causes of persistent hemorrhage. Their neurological status could not be evaluated preoperatively. The other two manifested no clinical evidence of neurological abnormality. An additional patient with injury

TABLE 1. *Type of Injuries (126 Injuries)*

Mechanism	Number	%
Penetrating	105	83.3
Gunshot	63	60
Stab and puncture	42	40
Blunt	21	16.7

at the origin of the left external carotid artery had contralateral hemiparesis. Persistent shock, continuous rapid bloody drainage from chest tubes, and x-ray evidence of expanding mass in the superior mediastinum indicated major vascular disruption in the intrathoracic vessels.

Abdominal major arterial injuries due to stab wounds were accompanied by shock or signs of peritoneal irritation. Clinically, involvement of various intra- and retroperitoneal arteries could not be differentiated, with the exception of renal artery trauma, which was accompanied by hematuria. Associated visceral injuries were suspected in all cases of penetrating injury to the abdomen or thorax and were identified and treated or the absence of injury verified at the time of exploration. All gunshot wounds of the abdomen are routinely explored at this institution.

Fractures in association with arterial trauma in the extremities were obvious clinically. Ischemia precluded satisfactory neurological evaluation in patients with arterial injury to the extremities. Operative exploration and postreconstruction assessment were more reliable methods of determining nerve injury or its absence.

Management

Initial evaluation of patients and injuries was performed in the Emergency Room. Patients arriving with abdominal or thoracic injury and severe shock were transfused with type O negative unmatched blood. After

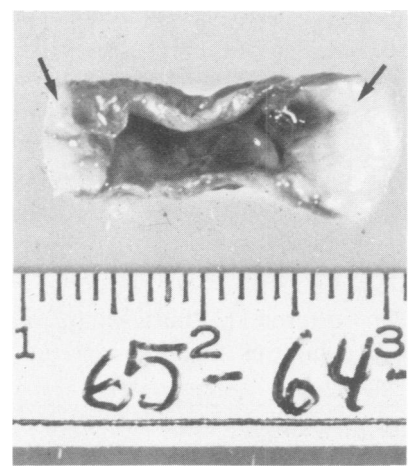

FIG. 2. Typical effect of blunt trauma upon artery—disruption and retraction of intima and media (arrows), resulting in thrombosis.

introduction of large-bore venous cannulae, central venous catheters, Foley catheter, and endotracheal tube, their wounds were explored in the operating room of the Emergency Ward. Routine intraoperative monitoring included central venous oxygen saturation measurements. Patients with arterial injuries to extremities who arrived in shock (37%, v.s.) responded to resuscitation by rapid infusion of Ringer's lactate solution. They, as were patients who were stable upon admission, were evaluated (pulses, neural function), investigated (x-ray, abdominal tap), given minor treatments (paracentesis, chest tube), and operated upon in the general operating rooms.

Preoperative Arteriography. Fifteen patients had preoperative arteriography. These included 12 patients with arterial injuries to extremities, two patients with renal artery thrombosis due to blunt trauma, and one patient with gunshot injury to the external carotid artery.

Routine preoperative arteriography has not been performed in the last 3 years. However, penetrating injury in the vicinity of a major artery in the extremity, without clinical evidence of arterial injury, was considered an indication to perform arteriography to substantiate the clinical impression and to preclude overlooking injury. Furthermore, preoperative arteriography was extremely useful when there were clinical reasons for suspecting complications of injury, aiding detection and timely and appropriate management of arteriovenous fistula, pseudoaneurysm, and causes of hemiparesis. The angiogram added no information in patients with clinically obvious injury, but only delayed arterial repair. Seven of 11 patients had isolated complete occlusion at the level of the injury (Fig. 3), and no additional information regarding the distal arterial system was obtained due to nonvisualization.

Patients with isolated extremity fracture and absent distal pulses were studied arteriographically, after reduction of the fracture, whenever feasible, even though pulses had returned. If pulses did not return, arterial trauma was presumed to have occurred. Angiograms were made in the operating room in patients with multiple fractures and suspicion of arterial injury to determine sites and effects of trauma post-reduction, unless shock required immediate intervention for associated injuries. Renal arteriography remains the only confirmatory test in patients with traumatic renal artery thrombosis because the clinical picture and pyelographic information often are ambiguous (Figs. 4 a and b).

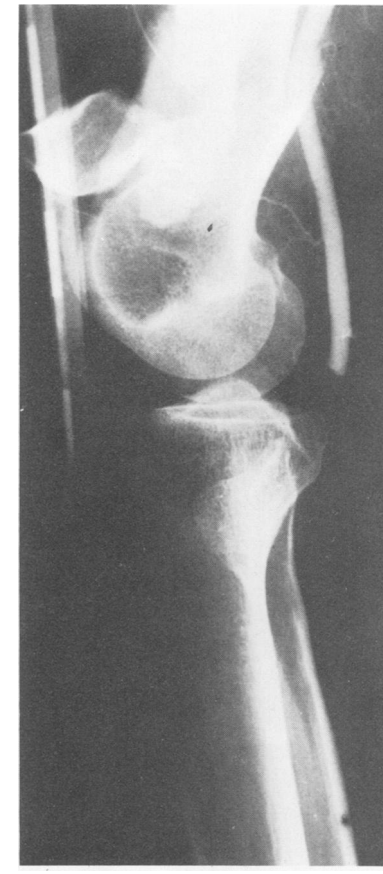

FIG. 3. Preoperative arteriogram of injured extremity without distal pulses. Angiograms are not made routinely in clinically obvious arterial injuries of extremities, for they add little information while delaying operative repair.

TABLE 2. *Clinical Presentations in 90 Patients with Arterial Injuries to Extremities*

Physical Findings	Number	%
Distal Pulse		
Absent unilaterally	59*	65.5
Present	20†	22.2
Unable to evaluate because of shock	11	12.2
Hypovolemic shock	34	37.7
Expanding Hematoma	18	20.0
External Bleeding	10	11.1
Bruit	4	4.4

* Four patients regained pulses prior to repair.
† Includes four patients with injuries to profunda femoris artery.

Intervals Between Injury and Definitive Treatment. Patients with aortic injuries were treated in the operating room of the Emergency Ward, and the interval between admission and operation was less than 20 minutes in all instances. Operative management of injuries to arteries of the neck was initiated in less than one hour, while an average of 2½ hours elapsed before operation was performed for injuries to arteries of the extremities. The longest interval (72 hours) occurred in a patient with renal artery injury due to blunt trauma, the delay caused by misinterpretation of signs and x-ray findings.

Indications for Operation. Persistent shock, rapid, unrelenting drainage of bloody fluid through thoracotomy tubes, and expanding superior mediastinal shadow on chest x-ray indicated major thoracic vascular injury. Persistent shock and return of bloody fluid upon ab-

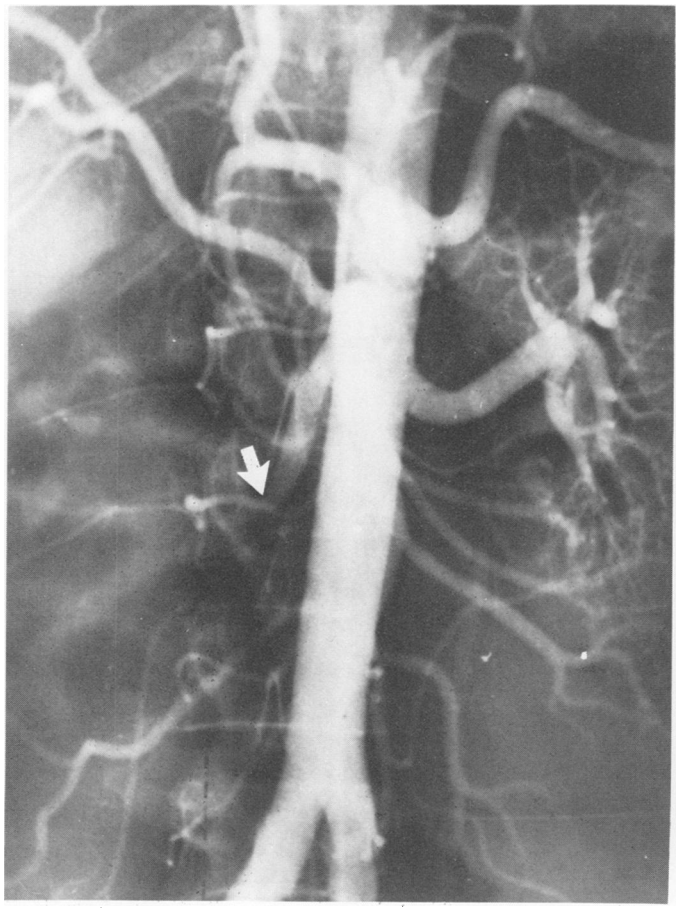

FIG. 4a. Aortogram shows tapering and occlusion of right renal artery after blunt trauma (arrow). Reconstruction was performed 72 hours after injury.

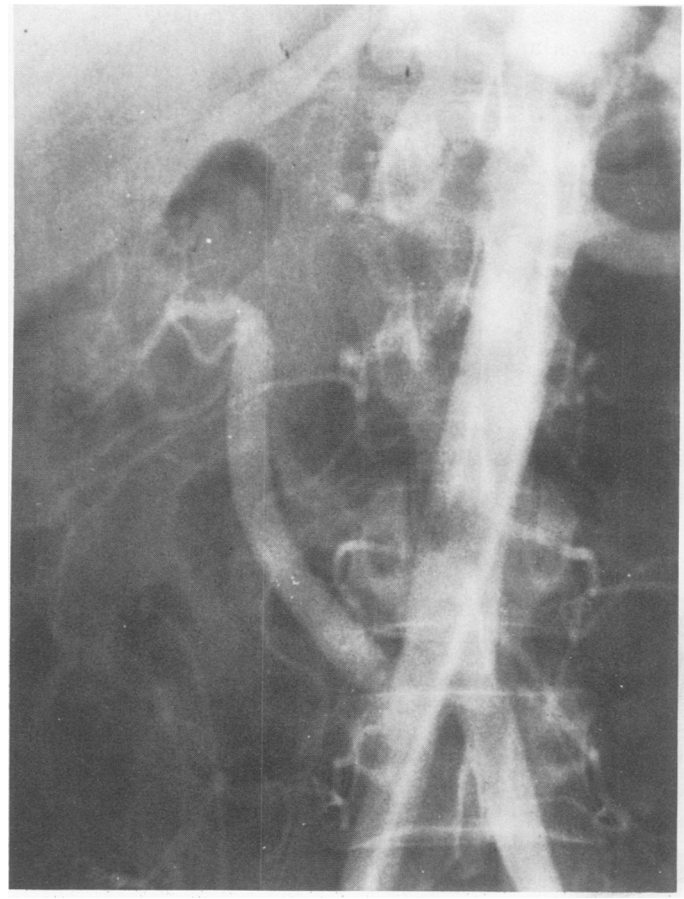

FIG. 4b. Postoperative arteriogram three weeks after surgery, showing patent Dacron graft between right common iliac artery and renal artery.

dominal tap were interpreted as abdominal vascular trauma requiring exploration. Renal artery thrombosis secondary to blunt trauma was suspected clinically and confirmed by intravenous pyelography and renal arteriography.

The indications for operative exploration of arteries of the extremities (Table 3) were transient or persistent loss of pulse, with or without evidence of ischemia, presence of large or expanding hematoma, active arterial bleeding and bruits in the area of injury. These signs were present alone or in combination. Injuries in the vicinity of major arteries were not explored in the absence of these findings; arteriography was performed instead. Patients with normal arteriograms were followed in the vascular ward and scrutinized for the development of complications of missed arterial injury. In patients with isolated fracture and absent distal pulses, the fracture was reduced and, upon return of pulse, the arterial integrity was confirmed by angiography. Patients with failure of return of pulse were subjected to operation.

Procedures (Table 4). There were 113 operations upon major arterial injuries, and repair was possible in 102

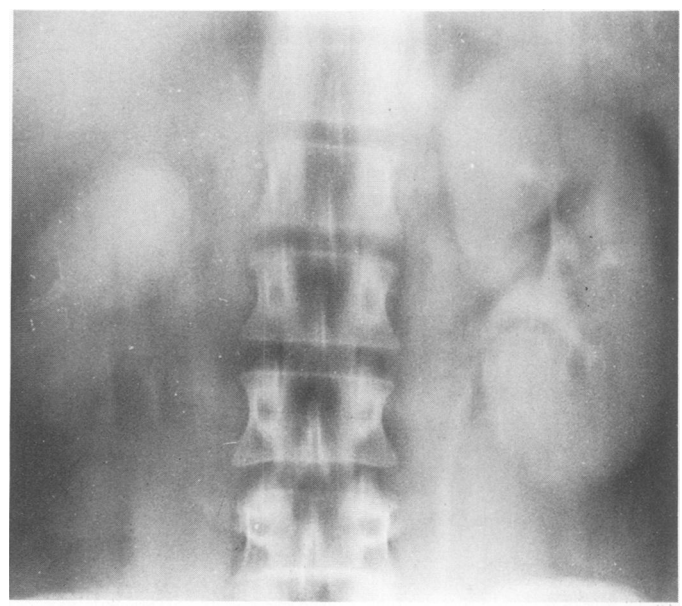

FIG. 4c. Intravenous tomo-pyelogram six months after revascularization, showing function in the right kidney five minutes after injection of contrast medium.

cases (90.2%). Thirty-two arteries were repaired simply by sutures at the site of injury. Fifty-six arteries were reconstructed by end-to-end anastomosis, with minimal resection (stab wounds with complete transection or partial transection with frayed margin, or intimal damage beyond the laceration) and, upon indication, by resection of at least one centimeter of the artery on each side of the injury (gunshot wounds and blunt trauma). Fourteen patients were treated by resection and graft replacement. Reversed autogenous saphenous vein grafting was used in 13 patients: common carotid (2), common femoral (8), popliteal (2), and brachial (1) arteries were reconstructed in this manner. In one patient with blunt trauma, a Dacron graft was placed from the right common iliac to the right renal artery. Arteries were ligated in nine patients: external carotid (1), common carotid (1), internal mammary (4), common hepatic (1), inferior mesenteric (1), and profunda femoris (1) arteries. An additional patient had ligation of the superficial femoral artery because associated massive injuries to bone and muscle were considered beyond restoration of a functional limb, and above-knee amputation was performed initially. Five of 13 minor arteries had end-to-end anastomosis; 8 were ligated. One patient with traumatic renal artery thrombosis refused treatment. Patch angioplasty was never used.

Clean, small lacerations in an artery can be managed easily with lateral repair. Irregularities or narrowing in the lumen were considered indications for resection and reconstruction to prevent turbulent or impeded flow. Frayed margins, intimal detachment beyond the lacerations, and evidence of intimal damage to the opposite wall were repaired by resection and end-to-end anastomosis. Patients with gunshot wounds required wider resections. Following resection, both ends were gently dilated, either by stripping some adventitial fibers near the edges or by using Fogarty balloon catheters, allowing end-to-end anastomosis without constriction (Figs. 5 and 6). There is reservation about the practice of routinely passing a Fogarty catheter distally to ensure absence of clots, which were found and removed in 8% of the cases. All of the distal clots were present in patients with absent pulses, and were found close to the level of the injury. If repair had been delayed, it is presumed there would have been more extensive clotting distally. Arterial anastomosis was performed, using two everting mattress sutures 180° apart, to raise a cuff to facilitate rapid, accurate placement of continuous sutures. Grafts were reserved for cases in which end-to-end anastomosis could not be done without excessive tension on the suture line despite extensive freeing of the arterial stumps proximally and distally. Vascular reconstruction is performed prior to immobilization of fractures. We prefer external fixation; occasionally internal stabilization is required.

TABLE 3. *Indications for Operations in 90 Patients with Arterial Injuries to Extremities*

Indications	Number	%
Absent Distal Pulse		
Persistent*	55	61.1
Transient	4	4.4
Expanding Hematoma Only	13	14.4
Persistent Hypovolemic Shock	11	12.2
External Bleeding Only	6	6.6
Bruit Only	1	1.1
Total	90	

* With or without other signs.

Operative Angiography. Operative angiography is recommended following all reconstructions to detect technical errors and preclude early failures. It was particularly useful to differentiate arterial spasm (Fig. 7) from distal thrombosis when pedal pulsations were not restored after completion of the reconstruction. Angiography confirms the presence (Fig. 8) or absence of more distal thrombi and obviates potential complications of blind, repeated and unnecessary invasions of artery with a balloon catheter. Angiography detects or insures the absence of additional distal arterial injury in patients.

Fasciotomy was performed in three limbs in which extreme edema had developed after blunt popliteal trauma, with undistinguished results.

In patients with injury to the common carotid artery, monitoring of internal carotid stump pressure or ipsilateral sinus oxygen saturation or both were done in two patients. In one the stump pressure was inadequate (less than 50 mm Hg, with a systolic pressure of 150 mm Hg), and an internal shunt was used. Two patients remained in shock, one from persistent local external hemorrhage, and one due to intraabdominal hemorrhage secondary to massive injury to liver and inferior vena cava. In both patients, common carotid arteries were reconstructed without monitoring or shunts. Early in the series (1968), one common carotid artery was ligated without monitoring. An external carotid artery was ligated after extraction of thrombus from the common carotid bifurcation.

TABLE 4. *Types of Repairs (126 Injuries)*

Techniques	Number	%
Major Arteries	113	89.7
Lateral Repair	32	28.2
Resection with		
End-to-end anastomosis	56	49.5
Saphenous vein graft	13	11.5
Dacron graft	1	0.8
Ligation	10	8.0
None (refused treatment)	1	0.8
Minor Arteries	13	10.3
End-to-end anastomosis	5	38.4
Ligation	8	61.6

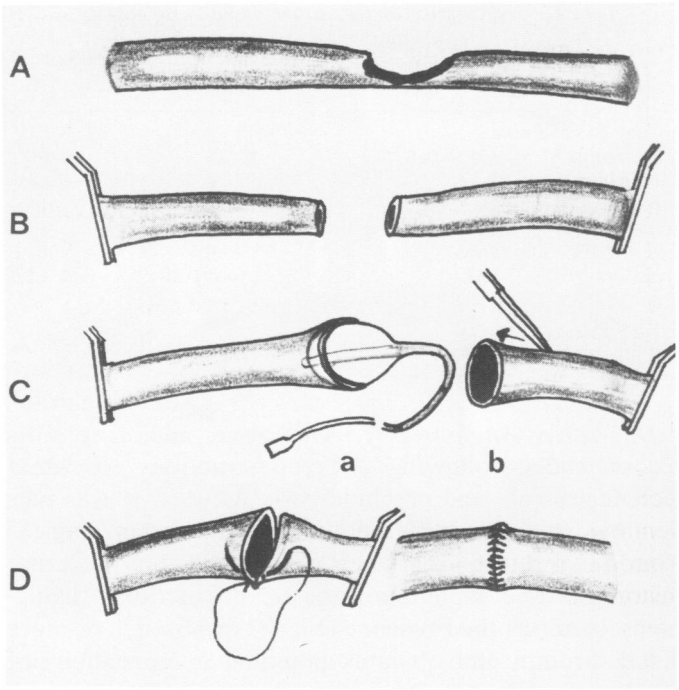

FIG. 5. a to d., (a) Loss of substance of artery. (b). Post-traumatic spasm of artery. (c) Restoration of normal caliber of lumen with intraluminal dilation or mechanical stripping of adventitia. (d). Continuous suture reconstruction with monofilament material.

Associated Injuries (Table 5)

There were 85 associated injuries. Their distribution is shown in Table 5. Ten patients with arterial injury to extremities had associated abdominal trauma requiring exploratory laparotomy for splenectomy (4) or repair of injuries to the jejunum (2), colon (3), and urinary bladder (1).

Associated venous injuries were identified in 28 patients. All 6 inferior vena cava injuries were repaired by lateral suture. Fifteen injuries in large veins of the extremities were repaired by lateral suture (7), end-to-end anastomosis (6), or short autogenous vein grafts (2).

Nerve damage was recorded in 10 instances (8.1%), but was repaired initially in only one patient with transection of the median nerve. Three of 9 nonextremity nerve injuries were managed by end-to-end or lateral repair, and no attempt at repair was made in 6 patients.

Results (Tables 6 and 7)

Among 122 patients with arterial injuries, 13 patients died, a mortality rate of 10.6%. Eight of 14 patients with aortic injuries died (53.8%). Five deaths were considered the result of associated massive abdominal injuries, even though these patients' arterial trauma had occurred in large, important arteries (common carotid (1), iliac (2), hepatic (1), and innominate arteries). No deaths occurred among patients with arterial injuries beyond the inguinal ligaments or thoracic outlet.

There were three amputations among 90 patients with 94 arterial injuries to the extremities, an amputation rate of 3.3% One was secondary to thrombosis of a vein graft for gunshot wounds of superficial femoral artery. Extensive muscle and bone trauma led to above-knee amputation in a patient with repaired superficial femoral artery injury. Local and systemic sepsis caused amputation in a third patient with a patent vein graft bridging a defect of the popliteal artery in a viable (but septic) extremity. Among 12

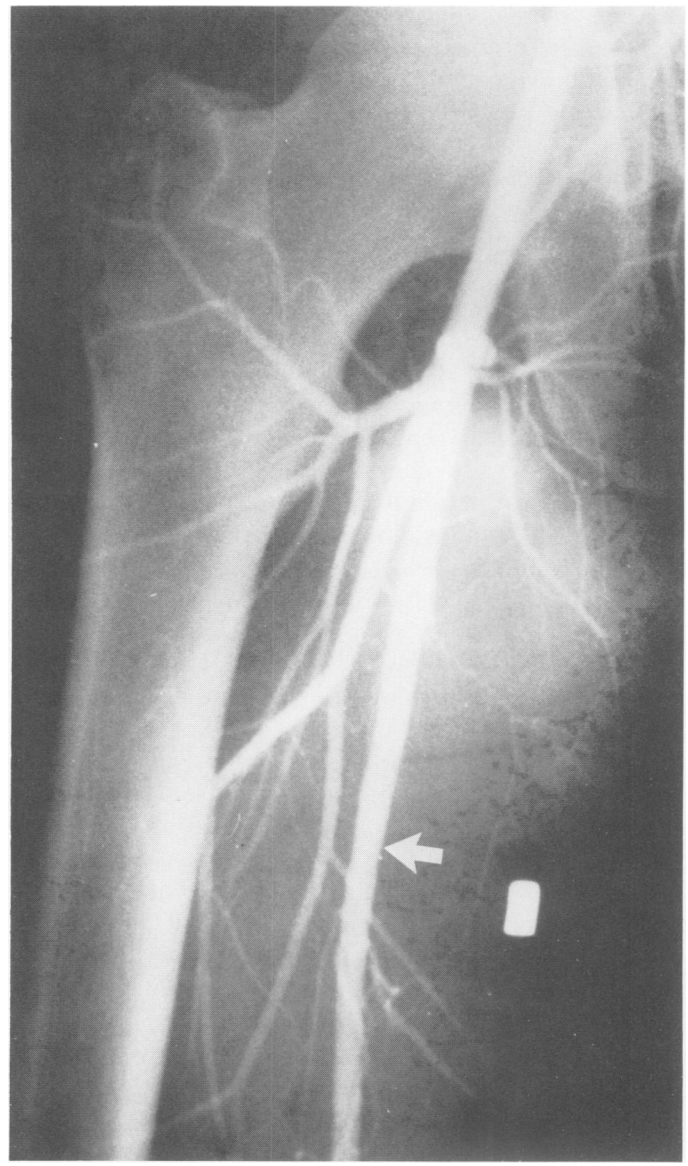

FIG. 6. Operative arteriogram showing optimal lumen resection and end-to-end anastomosis of the right superficial femoral artery. Arrow indicates the level of the anastomosis. Rectangular shadow is the retained bullet.

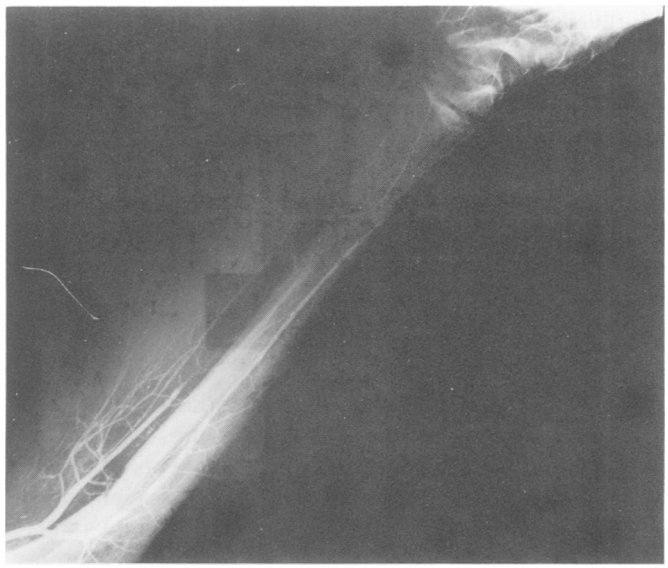

FIG. 7. Operative angiograms disclosed spasm, not intraluminal thrombus, as explanation for absent distal pulses early after operative reconstruction of traumatized blood vessel at proximal site.

patients with popliteal artery injury, only one required amputation in spite of a patent graft—a patency rate of 100% and amputation rate of 8.3%. No amputations have been necessary during the last three years of this series.

Two grafts failed. One led to amputation (v.s.). A vein graft for brachial artery trauma failed in a 7-year-old child but, because of a viable and functional extremity, no further reconstruction was attempted.

Two patients had right renal artery thrombosis due to blunt trauma. One refused surgery and has been lost to followup. The second patient's renal artery thrombosis was discovered late after pelvic fractures sustained as a pedestrian "hit-and-run" victim. A right iliac-renal artery Dacron bypass graft was performed 72 hours after admission. Two months later, postoperative arteriogram showed a patent graft, and infusion intravenous pyelogram disclosed a subnormally functioning, small right kidney (5-minute film) in a normotensive patient (Figs. 4 b and c). Peripheral vein renin concentration was normal. At 6 months, the patient developed symptomatic hypertension (190/110 mm Hg), and the right renal vein renin concentration was considerably higher than that on the left side, despite improved function by intravenous pyelography. Upon bedrest, pressure returned to normal. Peripheral renin values were normal. Right nephrectomy was performed, but the patient remains hypertensive three months after nephrectomy.

Two patients with common carotid artery transection were monitored as outlined earlier, an internal shunt being used in one patient. Both recovered without postoperative neurological deficit. Three patients were operated upon without intraoperative monitoring. One exhibited aphasia for two weeks after operation, and angiography showed nonvisualization of a branch of the ipsilateral middle cerebral artery (Fig. 9). One patient died, and death was considered due to associated massive abdominal injury. The patient treated by ligation of the common carotid had resultant hemiparesis on the contralateral side. An additional patient with external carotid injury due to gunshot wound had established hemiparesis. The cause of the hemiparesis was believed to be cerebral embolism from thrombus that was found extending from the external carotid artery into the common carotid bifurcation (Fig. 10). The patient improved subsequently and had functional extremities.

In two patients with repair of the abdominal aorta, pseudoaneurysms developed from missed posterior lacerations and were managed successfully by hypothermia and transluminal repair.

Infections at the site of injury occurred in 11 patients, mostly in extremities damaged by gunshot

FIG. 8. Arteriogram showing retained thrombus in the tibioperoneal trunk (black arrow) after initial thrombectomy. White arrow indicates the level of the anastomosis of the popliteal artery.

TABLE 5. *Adjusted Injuries (122 Patients)*

Organ	Number	%
Veins	28	22.9
Bones	18	14.7
Nerves	10	8.1
Inferior vena cava	6	4.9
Small intestine	6	4.9
Pulmonary parenchyma	5	4.0
Liver	4	3.2
Colon	3	2.4
Stomach	2	1.6
Gall bladder	1	0.8
Urinary bladder	1	0.8
Left ventricle	1	0.8

wounds and blunt trauma. All responded to local care. No thromboses or disruptions occurred.

Postreconstruction edema was marked in popliteal artery injury (66.6%; 8 of 12 cases), despite fasciotomy in three. Edema was seen in all cases of blunt trauma to extremities with multiple fractures and crushing muscle injury. In the absence of blunt injuries, the edema was especially noticeable when arterial reconstruction was delayed and ischemic signs were prominent at the time of reconstruction.

Five patients had postoperative venography showing patent venous repairs, including one with vein graft replacement of the common femoral vein. This graft showed marked narrowing at 3 weeks. Eight of the remaining 10 reconstructions remained patent by clinical evaluation and Doppler studies.

TABLE 6. *Results of Injuries and Treatment (122 Patients)*

	Number	%
Mortality	13	10.6
Edema	12	9.8
Infection	11	9.0
Amputations	3*	3.3*
Hemiplegia	2†	
Hypertension	1	

* In 90 patients with extremity injuries.

† Includes one patient who presented with hemiplegia before operation.

TABLE 7. *Amputations (94 Injuries in 90 Patients)*

	Treatment		Amputations	
Artery	R	L	R	L
Iliac	13	0		
Common femoral	8	0		
Superficial femoral	20	1	1*	1†
Deep femoral	4	1		
Popliteal	12	0	1‡	
Tibials	2	2		
Innominate	4	0		
Subclavian	2	0		
Axillary	2	0		
Brachial	14§	0		
Radial and ulnar	3	6		
Total Injuries	84	10	2	1

* Failure of vein graft.

† Ligation considered judicious because of severe crushing injury to bones, muscles, and nerves.

‡ Reconstruction remained patent but required amputation because of septic shock from severe infection.

§ One vein graft failed in a 7-year-old child; extremity remained viable and functional.

Note: R denotes reconstruction; L denotes ligation of artery.

Discussion

The results of repair of acute arterial injuries have been superior to those of ligation in preserving function as well as viability. Important concepts regarding the significance of minimal time-lag, management of shock, techniques of surgery, types of arterial injury, associated injuries, and judicious use of fasciotomy have been derived from the cumulative military experiences of the Korean and Vietnam wars.[14] The application of these principles in civilian vascular trauma has brought about high success rates and diminished morbidity and mortality.[4,8,11–13] Most civilian vascular injuries are localized, but occasional extensive trauma comparable to that of military experience, as well as the involvement of the aging population, require expertise in intra- and postoperative cardiac and respiratory monitoring and management.

Penetrating injury to the heart and the aorta is associated with more than 80% immediate mortality. Consequently, few patients survive for transit to the operating room. Patients with blood pressure over 90 mm Hg at admission have favorable prognoses (69% survival) over patients with lower pressure (31% survival)! Thirteen of the 14 patients with aortic injury arrived with no recordable blood pressure. Operating facilities within the Emergency Ward made further transit unnecessary and immediate salvage of seven patients a reality. Preoperative transfemoral introduction of an intrathoracic balloon catheter has been recommended to prevent exsanguinating hemorrhage at the time of laparotomy.[3] Occasionally aortic injury becomes tamponaded because of the adjacency of the peritoneum and diaphragm. Suspicion, detection, and repair of these injuries are rewarded with higher salvage rates and prevent the occurrence of traumatic false aneurysms. Patients with injury in the vicinity of the aorta should have aortography if their wounds are not explored. Proper interpretation of the study is equally important. Most patients with aortic injury have multiple organ trauma. Conditions are suboptimal and, while associated injuries are being repaired, posterior lacerations in the aorta can be missed, resulting in false aneurysms. Two of the survivors in this series had this complication.[2]

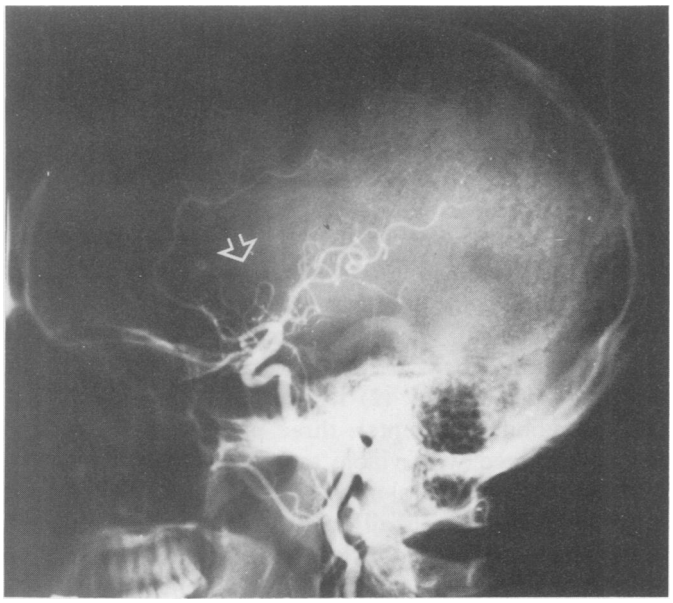

FIG. 9. Absence of visualization of branch of middle cerebral artery in patient with aphasia that disappeared two weeks after surgical reconstruction of injured common carotid artery.

Renal Artery. Most penetrating renal artery injuries are found at the time of laparotomy for trauma and can be managed by appropriate technique (lateral suture or resection with or without grafting, depending on the type and extent of the injury). Autotransplantation has been recommended when pancreatic and duodenal injuries coexist with renal artery trauma to avoid the potential complication of infection.[5] Blunt trauma is known to cause renal artery thrombosis secondary to intimal tears. Eighteen such cases have been reported, with one successful outcome not complicated by hypertension.[14] Hematuria is nonspecific and is not consistently present. Clinical suspicion, early, rapid-sequence IVP for diagnosis, and angiography for confirmation are critical factors leading to reconstruction. Failure to visualize the kidney and demonstration of occlusion of the renal artery confirm clinical suspicion. The normothermic kidney can survive up to two hours of total ischemia. However, collateral vessels may provide enough perfusion to keep the nephrons viable for days. They would be nonfunctional under these circumstances, but return of function is possible following arterial reconstruction. The presence of a nephrogram effect despite occlusion of the renal artery indicates the functional adequacy of such collateral arteries, which occasionally have been demonstrated angiographically.[9] Successful renal artery reconstruction with kidney salvage has been reported as late as 12 hours after injury. One case in this series was reconstructed 72 hours after trauma, with return of some function. The incidence of postoperative hypertension is difficult to predict, since clinical circumstances have been so varied in the few cases observed. Postoperative delayed hypertension remains a potential complication necessitating eventual nephrectomy.

Carotid Artery. The importance of adequate blood volume and hydration, of hypertension, hypercarbia, internal carotid artery stump mean pressure, and monitoring of lateral sinus oxygen saturation have been emphasized in the management of occlusive carotid lesions. These principles have been applied in trauma patients, also, with good results. Intraoperative monitoring and use of shunts become important, since the presence of shock limits blood flow from the contralateral side. Extensive carotid trauma often involves grafts, requiring cross-clamping time significantly longer than in elective carotid endarterectomy. While trauma patients are mostly in the younger age group, and the remaining extracranial circulation may be expected to be normal, it is not necessarily adapted to compensatory cross-filling. Postoperative neurological deficit may be

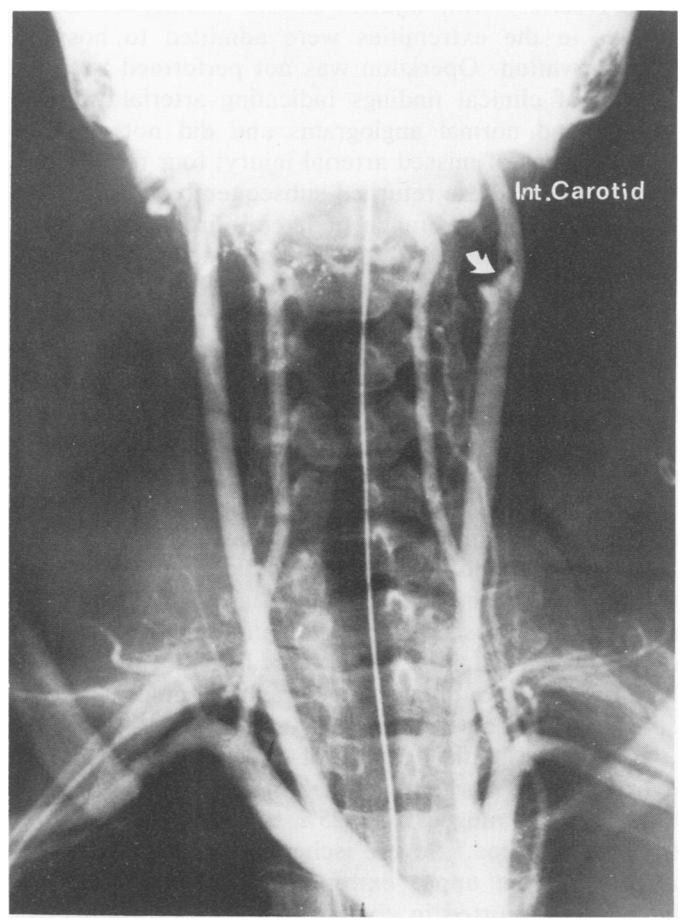

FIG. 10. Preoperative arteriogram in the patient with injury to the left external carotid artery and contralateral hemiparesis. Thrombus (arrow) extends into the internal carotid artery. (Intracranial visualization was not recorded.)

circumvented by responding to information from monitoring and the use of adjuncts and shunt as necessary. Proximal external carotid lesions can cause or contribute to the development of neurological deficit, as seen in one instance in this series.

Arterial Injury to Extremity. In most patients with trauma to the extremity, arterial injury is obvious because of ischemic signs and absent pulses. Transient loss of pulse unilaterally may be as significant as persistent loss. Four patients in this series had transient loss of pulse, and arterial injury was confirmed at exploration. Presence of pulse does not rule out arterial injury; 22.2% of our patients with confirmed arterial injury to extremities had palpable distal pulses. Large or expanding hematoma, rapid arterial bleeding, and presence of bruit were additional reliable indicators that led to clinical diagnoses of arterial trauma in these cases. Expanding hematoma may be caused by transection of a major vein (e.g., superficial femoral) or by lacerations of muscular branches of arteries.

Approximately 20 patients (not qualified for inclusion in this series) with injuries in the vicinity of major arteries in the extremities were admitted to hospital for observation. Operation was not performed because of lack of clinical findings indicating arterial trauma. Sixteen had normal angiograms and did not develop complications of missed arterial injury; four refused the study. One of these returned subsequently with arteriovenous fistula of a branch of lateral circumflex artery, treated by ligation. With this experience we have continued to limit explorations only to patients with clinical evidence of arterial injury, preferring angiography in patients with trauma close to major vessels.

Observation is recommended in one report when findings are not clear-cut (foot or hand cool rather than cold, hypesthetic rather than anesthetic, and pale rather than ashen).[11] Sympathetic block, blood transfusions, and even hyperbaric oxygenation have been recommended while delaying the decision to operate.

We have found that clinical indices are significant even when present to a slight degree. In their total absence, close observation may be undertaken. Arteriography can be obtained but is most likely to be normal. We continue to obtain angiographic confirmation of clinically ruled-out arterial injury.

Experience with ligation of arteries of the upper extremity in World War II resulted in an amputation rate that ranged from 25% to 55%, depending on the artery ligated.[8] Severe ischemic symptoms and disabilities in the upper extremity after arterial trauma have been reported in civilian injuries, and routine reconstruction is recommended.[8]

Ischemic symptoms follow ligation of the profunda femoris artery,[7] and attempts must be made routinely to reconstruct this important conduit and end artery. Recent literature has shown amply the flow capacity and contribution of this artery in chronic occlusive disease.

Occasionally associated muscular, skeletal, or neural injury is extensive, and the decision between reconstruction and primary amputation becomes difficult. We recommend initial reconstruction and debridement, with subsequent amputation if necessary. Among 4 patients with multiple injuries (fractures of femur, upper and lower tibia (3), popliteal artery transection and injury to nerves (2), crushing trauma to leg muscles (4), deeply lacerated perineum (1), and ruptured spleen requiring splenectomy (2) from falls from high places and automobile accidents), three patients subsequently were discharged with viable and functional extremities after prolonged hospital stays. One required amputation because of sepsis. In all cases, amputation was considered initially but reconstruction with debridement of damaged soft tissues, internal fixation, or skeletal traction was done.

The amputation rate after civilian arterial injury to the extremities has been reported in the proximity of 7%.[4] One series reported a lower amputation rate.[16] The over-all amputation rate in our patients was 3.3%. The lower extremities of patients in this series may have been at risk of amputation only 54 times (secondary to injuries in 13 iliac arteries, 8 common and 21 superficial femoral arteries, and 12 popliteal arteries), raising the amputation rate to 5.6%. Calculated yet another way, three amputations in 33 limbs in which superficial femoral or popliteal arteries were repaired, the percentage of amputations is 9%. However, only one of these three events followed thrombosis in a repaired vessel, reducing the presumably avoidable amputation rate to 3%, virtually the same as the overall rate, the conventional method of reporting. The amputation rate after popliteal artery trauma has been reported to be from 17%[13] to 43%.[4] In our series, it was 8.3%. No amputations have been necessary in the last three years of our experience.

Postreconstruction edema constitutes a significant problem in cases of marked ischemia and blunt trauma associated with skeletal and muscle injuries. In such cases, fasciotomy remains an open question. Some consider it an important adjuvant[13] if other conservative measures fail.

It is our policy to anticipate and to attempt to prevent edema by high elevation of the injured extremity early after trauma and treatment. The severity of edema has seemed related to injuries of popliteal space, of bone and muscle at any site, and to duration and severity of ischemia.

Edema seemed unrelated to possible loss of patency of repaired major veins. We do not perform venography

in the presence of clinically obstructed veins, wary of inducing thromboses in collateral channels. Limited experience with fasciotomy and failure to prevent edema in high-risk circumstances suggest we have yet to find better modes of timing of ideal treatment to limit severe edema in susceptible circumstances.

Occlusion of venous return reduces the arterial inflow and may compromise arterial reconstruction.[6] It also contributes to the development of postoperative edema. However, ligation of a traumatized major vein is often recommended because of the possible threat of pulmonary embolism.[12] Fifteen concomitant venous injuries were repaired in this series. The patency rate has been encouraging. Routine lung scans were not done because there were no symptoms suggestive of, or deaths from, pulmonary embolism.

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