Aortic and Other Arterial Injuries

JAMES D. HARDY, M.D., F.A.C.S., SESHADRI RAJU, M.D.,
WILLIAM A. NEELY, M.D., F.A.C.S., DON W. BERRY, M.D.

Three hundred sixty arterial injuries in 353 patients are reviewed. They covered a wide spectrum of injuries and included 36 aortic injuries and 19 cases of carotid trauma. The mortality rate of 12% was in large part due to aortic injuries. Shock was the predominant cause of death. Infection was the most frequent nonfatal complication. Pulmonary complications were surprisingly uncommon. With methods and techniques discussed in the paper, 90% satisfactory end results were achieved. The amputation rate was 6% where extremity injuries were involved.

From the Department of Surgery, The University of Mississippi Medical Center, and University Hospital, Jackson, Mississippi

THE PRIMARY RECONSTRUCTIVE repair of arterial injuries has become firmly established in surgical practice in this country ever since the Korean conflict. Moreover, the management of arterial trauma is usually a rewarding exercise for the vascular surgeon since the patients are often young, heal well with few complications, and the technique is frequently challenging. Nevertheless, if minimal morbidity and mortality are to be expected, there must be meticulous deference to certain principles unique to this type of surgery. In addition, exclusive clinical features and complications along with the special management techniques required to deal with them have helped to accord clinical distinctiveness to arterial trauma in surgical practice. We propose to review some aspects of this discipline in the light of our own experience with 353 patients and to delineate our approach to certain problems, the solution of which remains controversial. Illustrative case reports will be cited when appropriate.

Clinical Material

Three hundred sixty arterial injuries in 353 patients were treated in the University of Mississippi Hospital between 1957 and mid 1974. The anatomic distribution and mechanism of injury are shown in Tables 1 and 2 respectively and in Figures 1 and 2. The extremities were involved in roughly two-thirds of the cases (60%). As might be expected, stab injuries were more frequent in the upper limb (39 cases) than in the lower limb vasculature (14 cases). Blunt trauma was the cause of injury in 48 cases, more than three-fourths of which were associated with bone fracture or joint dislocation. Of special interest were 20 cases of iatrogenic arterial injury which included mechanisms as ubiquitous as brachial artery injury from cardiac catheterization, as well as uncommon types such as common iliac arteriovenous fistula following intervertebral disc surgery, femoral artery dissection due to sharp instrumentation during total hip replacement, and internal mammary arteriovenous fistula following attempted subclavian venipuncture. Fifty-one per cent of the patient population reviewed was 30 years or younger in age. The distribution of 36 aortic injuries and 19 carotid vascular injuries are depicted in Figures 4 and 7 respectively. There were 19 popliteal artery injuries which represented 5% of the total cases treated. Thirty-seven of the firearm injuries treated were shotgun injuries. The incidence of arteriovenous fistulae was 10% (38 cases). The aforementioned groups will be treated in greater detail, due to the special problems associated with their management.

Types of Arterial Injuries

The types of arterial injury inflicted and associated injuries are listed in Tables 4 and 6 respectively and in Figure 3. Unusual but not uncommon types of injury included 2 instances of arterial spasm without thrombosis, 3 cases of true arterial aneurysms due to weakening of the vessel wall by blunt trauma, and 5 cases of missile embolism (Table 5). It will be noted that major veins were involved in approximately one-fifth of the cases, 50% of which developed into arteriovenous fistulae. Roughly the same number of gastrointestinal injuries, bone fractures, and neurological injuries occurred.

Manifestations of Arterial Injuries

Presenting clinical features of the case material are shown in Table 3. Nearly one-fourth of all cases pre-

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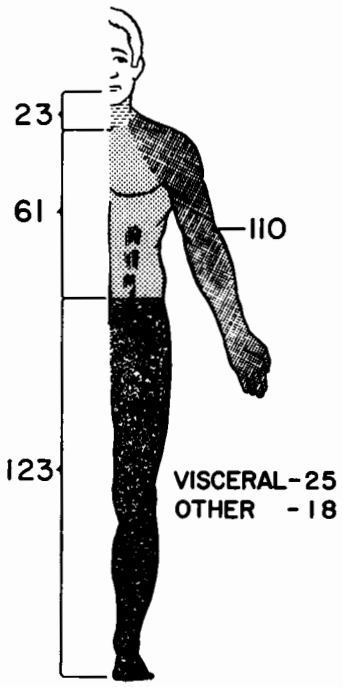

FIG. 1. Anatomic distribution of 360 arterial injuries.

sented in shock. Of special interest, local hematoma or other evidence of external hemorrhage was present in initial clinical examination in only 31% of all involved injuries. Among vascular injuries of the upper and lower extremities, 25% presented with color or temperature change, 47% with absent distal pulse, 11% with decreased distal pulses but approximately 20% of the cases had good distal pulses in spite of major arterial injury.

Considering the absence of striking physical signs and the presence of misleading ones in some cases, it is not surprising that arteriography was necessary to establish a more precise diagnosis. This was done in 168 instances (52% of the total cases).

Some uncommon manifestations of arterial injury included subclavian steal due to missile obstruction of the first part of the left subclavian artery, transient cerebral ischemia and coma due to carotid injury, and bullet embolism.

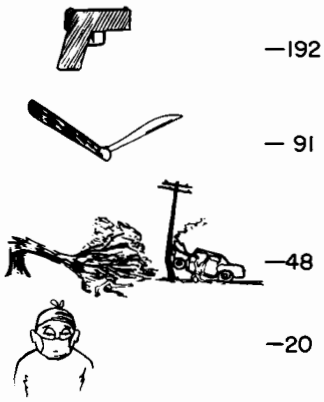

FIG. 2. Mechanisms of arterial injury in 353 patients. Not shown are 9 injuries due to miscellaneous or undetermined causes.

TABLE 1. *Distribution of 360 Aortic and Arterial Injuries in 353 Patients*

	No. of Cases
Aortic	
Thoracic	14
Abdominal	22
Upper Limb	
Axillary and Branches	23
Brachial and Branches	75
Lower Limb	
Femoral and Branches	84
Popliteal and Branches	32
Head, Neck and Base of Neck	
Carotid	19
Subclavian	12
Other	8
Chest (excluding the 14 aortic injuries)	27
Abdomen	
Non-visceral (excluding the 22 aortic injuries)	18
Visceral	26
Total:	360

Specific Arterial Injuries

Aortic Injuries

The anatomic distribution of 36 aortic injuries is shown in Figure 4. The majority of the cases were due to gunshot wounds, but included 7 cases of deceleration injury in motor vehicle accidents. Three patients with aortic injury were dead on arrival at the emergency room. Eleven others were moribund and died in surgery before repair could be achieved. In 22 patients arterial repair was effected, with fabric grafts being used in 5 instances. In the other 17 patients, aortic bleeding was controlled by lateral suture. Six of these patients who underwent satisfactory repair died in the postoperative period. The overall mortality rate in this group of injuries was 58%. Excluding those who died on the operating table, the mortality rate was still high at 35%. An analysis of the 7 patients who died postoperatively showed that two patients died due to shock, and in 5 others the mechanism of death was attributable to sepsis. Acute tubular necrosis was the overriding factor in 3 patients, and gastrointestinal bleeding occurred in 2. The high incidence of sepsis in this group of patients was not surprising, as all but two cases of abdominal aortic injury had coincidental gastrointestinal or pancreatic injury. Among the 15 sur-

TABLE 2. *Method of Arterial Injury in 360 Cases*

Firearms		
Gunshot	155	
		192
Shotgun	37	
Stab Wounds and Lacerations		91
Blunt Trauma		
Automobile	29	
		48
Other	19	
Iatrogenic		20
Miscellaneous, unknown		9
Total:		360

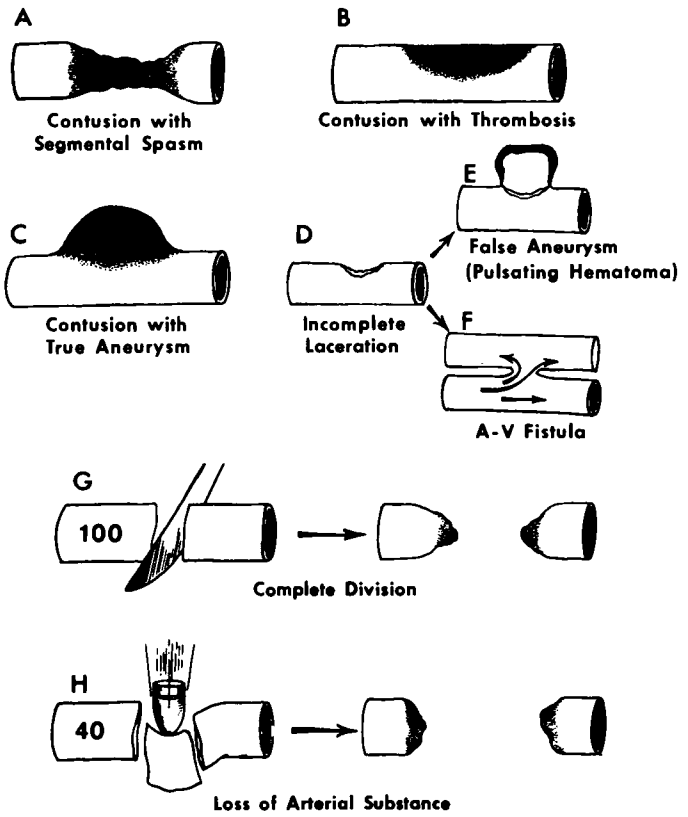

FIG. 3. Types of arterial injury.

vivors, 4 patients had serious complications; 2 had acute tubular necrosis which ultimately resolved, and 2 had bullet embolism. The overall incidence of acute tubular necrosis in this group of patients was therefore high (5 cases). In the two patients with missile embolism, the site of entry was the ascending aorta; surprisingly, both of these patients survived.

Traumatic Rupture of Aorta: The Widened Mediastinum Following Trauma. J.P.G., an 18-year-old male, was involved in a motor vehicle accident, when he was thrown against the dashboard. He was taken to a local hospital where he was carefully examined and found to have stable vital signs. He was fully conscious and was in mild discomfort. Physical examination revealed no obvious evidence of injury. However, chest roentgenogram revealed a widened upper mediastinum, and his local physician correctly made the diagnosis of ruptured aorta. He. was rapidly transferred to the University Hospital *via* helicopter, where on arrival an aortogram showed a tear in the descending thoracic aorta just distal to the left subclavian artery. The patient's condition had continued to be stable, but he was rushed to surgery where he underwent a left thoractomy. Continuous bleeding was occurring through a small hole in the parietal pleura adjacent to the aorta. Partial cardiopulmonary bypass was instituted by cannulation of the femoral artery and a vena caval catheter introduced through the femoral vein. The aortic rupture was complete through all the layers of the aorta save for a thin layer of adventitia which had prevented exsanguination. The false aneurysm was successfully resected and aortic continuity restored by using a woven Dacron graft. The patient had an essentially uncomplicated postoperative course except for pulmonary atelectasis which resolved with the usual measures.

Comment. Since the clinical features of aortic rupture secondary to blunt trauma[22] have become widely known, the necessity of aortography in suspected instances is now well recognized. Considering the nature of the aortic injury and the thin adventitial covering of the false aneurysm, it would seem preferable to perform aortography through the axillary artery rather than the femoral in retrograde fashion. However, in our experience, the retrograde technique has been generally safe. Others have suggested the so-called forward technique of arteriography by introducing the dye into the right at-

TABLE 3. *360 Arterial Injuries–Presenting Features**

	Percent Presenting
Absent Pulse	33% (47%[a])
Decreased Pulse	8% (11%[a])
Good Pulse despite arterial injury	13% (20%[a])
Color or temperature change in extremity	17% (25%[a])
Gangrene	> 1%
Shock	25%
Hematoma	19%
Hemorrhage	12%
Pulsatile mass or bruit	17%
Other	1%

*Some presented with more than one feature.
[a]Calculated as % of extremity injuries only.

TABLE 4. *360 Arterial Injuries–Type of Injury*

Type of Injury	No. of Cases
Laceration	111
Perforation, Transection and Loss of Arterial Substance	140
False Aneurysm	39
Arteriovenous Fistula	38
Contusion and Thrombosis	21
True Aneurysm	3
Vasospasm	2
Burn	1
Missile Embolism	5

TABLE 5. *5 Cases of Missile Embolism.*

Missile	*Wound of Entry*	*Site of Lodgment*
.22 Gunshot	Ascending aorta	Brachial
.22 Gunshot	Ascending aorta	Popliteal
Shotgun	Carotid	Middle cerebral
20 G Shotgun	Superficial femoral	Distal post tibial
.22 Gunshot	Atrium	Deep femoral

TABLE 6. *Arterial Trauma—Major Associated Injuries In 360 Cases*

Associated Injury	% Cases
Major Veins	21%
Gastrointestinal	20%
Other Abdominal Viscera	6%
Bone	17%
Nerves	17%
Muscle and Tendons	7%
Urinary Tract	4%
Lung	4%
Other	1%

rium.[3,22] This technique generally results in poor quality arteriography and has not been found optimal in our experience. Excellent contrast delineation of the aorta is essential in this syndrome, since even the slightest intimal irregularity immediately beyond the left subclavian takeoff calls for prompt exploration. The aortic injury is often more extensive than suggested by aortography. Procrastination, because aortographic changes are minimal or because the patient is stable, can be disastrous as delayed rupture of the injured aorta is well recognized. Occasionally in some fortunate instances, an unrecognized aortic rupture will present with a false aneurysm after a lapse of a few years. Other diagnostic difficulties in traumatic rupture of the aorta include the presence of a spuriously widened mediastinum, often seen in the anterior-posterior projections of a plain chest film, which is often the only projection available in a seriously injured patient. Occasionally aortic rupture may be present with a normal mediastinal contour on radiography. When aortic injury is suspected in a stable individual, it has been our policy to carry out expeditious aortography to better localize the site of injury.[3] Elective surgical approach to the ascending and descending aorta varies. However, in a considerable proportion of our patients with aortic injury, especially secondary to penetrating trauma, preliminary diagnostic maneuvers were impossible, and expeditious surgery, sometimes in the emergency room itself, was called for as a lifesaving measure. Under such circumstances it is our policy to open the chest through a median sternotomy with the patient positioned at 45 degrees left lateral position. The incision can be extended into the left chest through the fifth intercostal space if access to the left ventricle, aortic arch, or descending aorta is required. Emergency cannulation for cardiopulmonary bypass is also possible with the patient in this position. As noted by others[8] this approach is versatile but carries a higher morbidity than the regular median sternotomy or the standard left thoracotomy incisions. If injury to the descending aorta is established preoperatively, we employ a left thoracotomy incision. The question of whether or not to use a bypass during cross-clamping of the aorta remains in dispute, but we continue to use a bypass of one type or another.

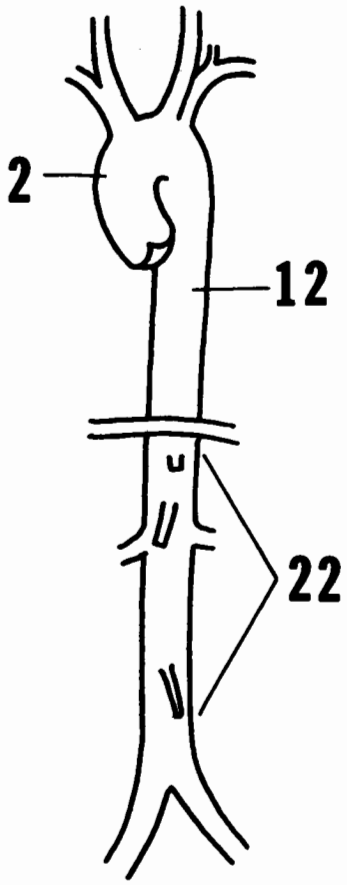

FIG. 4. Anatomical distribution of 36 aortic injuries.

Injury to Abdominal Aorta With Loss of Right Kidney: Temporary Perfusion of Left Kidney. W.G., a 23-year-old man, had been operated upon in another hospital for gunshot wounds of the abdomen. The patient had had multiple small bowel perforations which were closed and had undergone a colostomy for a colon injury. At that time a retroperitoneal hematoma had been noticed which was non-expanding and non-pulsatile and the surgeon had elected not to explore it. The patient had had a protracted hospital course during which time his colostomy had been closed and he had required two further operations for release of intra-abdominal lesions. He appeared to be doing well for awhile but felt ill and saw his local physician again. At this time a pulsatile abdominal mass was noted and the patient's blood pressure was recorded as 220/160 mm Hg. An intravenous pyelogram showed a non-functioning right kidney. At this time he was referred to the University Medical Center for further management. An arteriogram revealed a 12 cm false aneurysm of the aorta, a contracted right kidney fed by capsular and ureteric collaterals and non-visualization of the right renal artery. He was taken to surgery where the proximal clamp had to be applied above the left renal artery, which was supplying the only surviving good kidney of this patient. Dissection was difficult and the total aortic cross-clamping time approached two hours. During

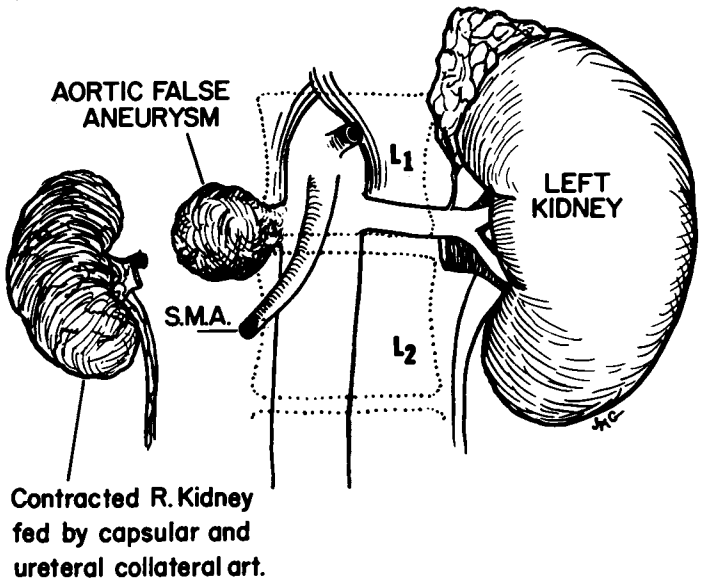

FIG. 5. Aortic false aneurysm resulting from gunshot wound. The right renal artery was almost completely destroyed.

this time the left renal artery was intermittently perfused with a cold solution for renal preservation. The right kidney was one-third the size of the left kidney, and it was decided to remove it since no usable part of the right renal artery was found for distal anastomosis. The method of repair with re-implantation of the left renal artery is shown in Figures 5 and 6. The patient had a benign postoperative course in the hospital and has been normotensive ever since.

Comment. It is possible that this patient would not have lost his other kidney if the retroperitoneal hematoma had been explored at the initial operation. In addition, he was subjected to the risk of a difficult and hazardous second procedure. From a technical standpoint, it is usually easier to repair an arterial injury immediately after its occurrence, before fibrosis renders dissection difficult.

The case also illustrates successful renal preservation of the patient's only remaining kidney despite a total aortic cross-clamping time of over two hours. With increasing experience and effective techniques for renal preservation during renal transplantation, it should rarely be necessary to carry out nephrectomy for major renal vascular injury. If satisfactory repair were not immediately possible, this could be done at leisure on the perfusion apparatus and the organ later re-implanted into the patient if optimal conditions obtained.

Carotid Injuries

The 19 carotid injuries that were seen are represented diagramatically in Figure 7. These included three instances of carotid cavernous sinus fistulae secondary to trauma. Three patients presented with contralateral hemiplegia, and 5 others with either shock or hemorrhage from the neck wound. In 3 other patients the presence of a bruit over the carotid led to the diagnosis of vascular injury. In the remaining 5 patients there were no specific symptoms or signs attributable to the carotid injury, but the diagnosis was made on the basis of arteriography or exploration. In all but 4 cases the mechanism of injury was a gunshot wound. There was one case each of stabbing, motor vehicle accident, iatrogenic cause due to arteriography, and a burn. The burn was third degree involving the head and neck; the trachea was almost completely destroyed and there was involvement of both carotids. Secondary bleeding from disruption of the right and left carotids occurred on the third and sixth post-burn days respectively. In each instance the carotid was debrided and replaced with a Teflon prosthesis. However, the patient did not survive his pulmonary complications secondary to tracheal destruction. All other patients survived reconstructive surgery.

Surprisingly, in 11 patients the carotid was the sole major cervical injury detected. In 8 other patients there was involvement of the internal jugular vein; in 3 instances, trachea; in 2 instances, cervical cord; and the cavernous sinus was involved 3 times.

Operative Technique

In 6 cases end-to-end repair was resorted to, and in 3 others lateral suture adequately restored continuity. Fabric grafts were used in 4 instances. However, we favor

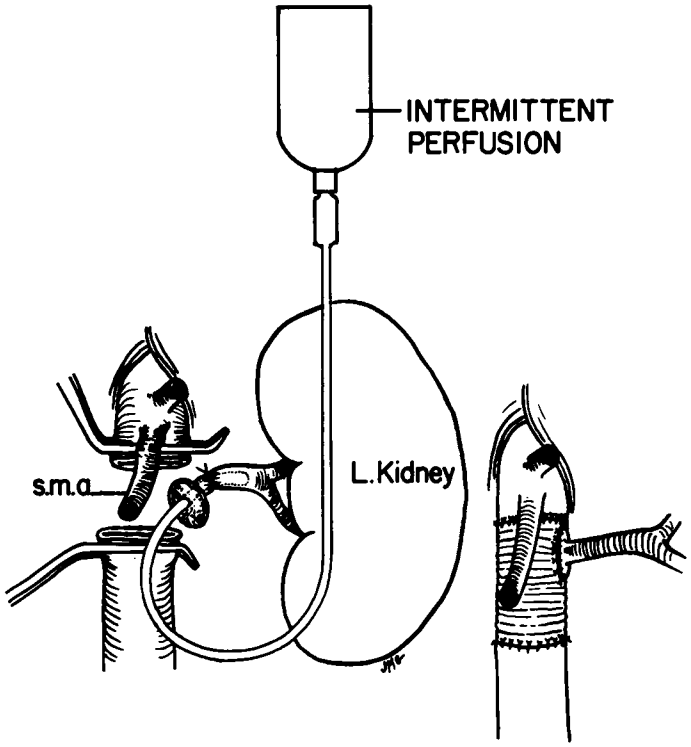

FIG. 6. Renal preservation in repair of aortic false aneurysm.

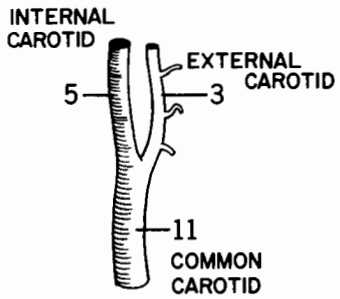

FIG. 7. Distribution of 19 carotid injuries.

saphenous vein graft now: recently we employed such a graft in a case of carotid injury, which is not included in this series due to the short followup period. Except for the 3 cases of arteriovenous fistulae and one case of false aneurysm, significant carotid flow through the injured artery was not noticed at the time of surgery. The total time of compromised perfusion (time of injury to repair) varied from a few hours to as long as 70 days. No temporary shunts were used during surgical repair except in one instance of carotid false aneurysm, with already established hemiplegia at the time of surgery. There were no postoperative neurological deficits attributable to the lack of an intraoperative shunt in any of our patients, although in one instance there was temporary loss of visual acuity for a short time probably due to a small embolus. The 3 patients with preoperative hemiplegia secondary to their carotid lesions all improved following reconstructive carotid surgery. In one patient the neurological improvement was dramatic and swift following surgery; this patient will be discussed subsequently. All 3 patients with internal carotid cavernous sinus fistulae underwent ligation of the internal carotid and ophthalmic arteries. In one instance muscle embolization was also used.

Problems Peculiar to Carotid Injuries

Carotid Injury With Hemiplegia: Restoration With Repair. E.P.S., a 62-year-old man was referred to the University Hospital 48 hours after receiving a stab wound to the right side of his neck. During emergency surgery by the referring physician a tracheostomy was done, and the common carotid injured by the stab was mass ligated. There was rapid progression of left hemiplegia following this procedure, and when seen in the emergency room at the University Hospital, the patient was moribund with Cheyne-Stokes respiration and hyperthermia (105°F). He was taken to surgery immediately where the mass sutures were removed, and stab wounds in the internal and common carotid arteries were repaired. The patient had considerable arteriosclerotic disease of the bifurcation and, therefore, an endarterectomy was carried out successfully. At the end of the procedure there was excellent backbleeding from both the external and internal carotids, and on removal of the clamps excellent pulsations in the internal carotid were present. Almost immediately after recovering from anesthesia, the patient started moving his left side which had previously been completely paralyzed. The neurological recovery was so rapid that by the next morning the patient was well oriented. He was discharged on the seventh postoperative day for further followup by his local physician.

Comment. The immediate problem in management of carotid artery injury is to maintain the airway despite the expanding cervical hematoma. A tracheostomy is undesirable as vascular surgery is probable. Every attempt should be made to intubate the patient, which may be very difficult due to deviation of the larynx and trachea by the hematoma. An experienced anesthesiologist is required. We have not found it necessary to carry out arteriography in the presence of an obvious arterial injury in the neck. Immediate exploration is indicated. There is little controversy regarding management of carotid injuries without neurological deficit;[2,4,12] carotid repair is uniformly advocated. There is little enthusiasm for the use of intraoperative shunts in this group of patients. We have seldom used one. There is, however, controversy[4,11,12,25] regarding the choice of treatment for a patient who has hemiplegia following carotid injury. In a great majority of these patients the injury is located in the internal carotid, compromising even the collateral flow from the external carotid. It has been feared that revascularization may lead to the development of a hemorrhagic infarct.[25] This seems to have been the experience of many[11,25] but not all[4] who have had experience in this area. As the above case shows, our own experience has been favorable. Reasons for discrepancies in experience are unclear. In some patients with complete clotting of the internal carotid system extending intracranially, it may be impossible to restore perfusion by this route. Fogarty catheterization of the internal carotid is not advocated for fear of distal lodgment of clots. At any rate, the catheter will not usually negotiate the carotid siphon. Our present approach to internal carotid injuries with thrombosis is to re-establish continuity only if the thrombus can be evacuated easily and good backbleeding is obtained. Otherwise, ligation is the treatment of choice. Ligation is advocated by many for all carotid injuries presenting with hemiplegia. For blunt trauma even a nonoperative approach has been proposed. Clearly, the ideal treatment for this difficult group of patients awaits further study and experience.

Some patients with serious carotid injury may initially present with no serious symptoms.[7] On this basis the routine exploration of all neck wounds without the delay of arteriography is in practice in some centers.[7,9] We and others[20] have approached this problem somewhat differently. All neck injuries with clinical evidence of major vascular or other injury are immediately explored. In other patients where the clinical picture is benign, we

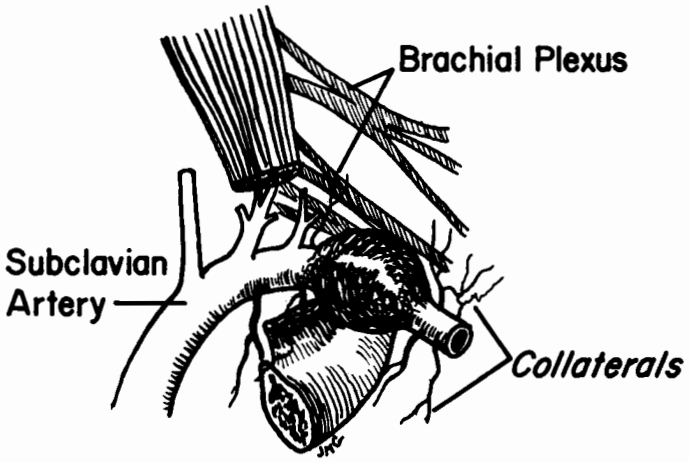

FIG. 8. Rich collaterals around subclavian axillary complex. Proximal control is sometimes ineffective in this location.

have performed panendoscopy supported by esophagogram and arteriography. If these are negative, the patient is spared surgery.

Subclavian, Axillary and Brachial Injuries

There were 110 injuries of upper extremity vessels including 12 subclavian injuries. Arterial injury due to blunt trauma had a decreasing relative incidence from subclavian to the brachial. Three of a total of 12 subclavian injuries were due to blunt trauma. Two of 23 axillary artery injuries and 3 of 75 brachial artery injuries were caused by blunt trauma. Apparently this discrepancy in incidence is due to the relatively fixed position of the subclavian artery over the thoracic inlet, making it susceptible to blunt trauma. Due to the mobility of the arm, the brachial artery was apparently spared. Gunshot wound was the most common method in injury of the three vessels. Of special interest was the incidence of three false aneurysms of the subclavian artery which were not diagnosed early elsewhere, due to the misleading and deceptive presence of a radial pulse. When diagnosed late, brachial plexus palsy was present due to compression. As this type of paralysis renders the arm refractory to rehabilitation, arteriography in all instances of penetrating injury to the shoulder girdle and thoracic inlet should be routinely carried out.

The surgical approach to the subclavian axillary complex varied according to the level of injury. Left anterolateral thoractomy, midsternotomy, supraclavicular incision, and an infraclavicular incision with or without clavicular resection were carried out as needed. Occasionally a combination of these incisions as a trap-door type of thoracotomy was used. Even though proximal control was routinely obtained, frequently it was of only marginal benefit. Rich collateralization around the subclavian axis can result in profuse bleeding despite proximal control (Fig. 8).

Significant Indications for Arteriography. First Rib Fracture: Brachial Plexus Injury. A 10-year-old girl jumped out of an automobile moving at high speed. When brought to the emergency room she had multiple lacerations and abrasions. She was conscious, in no great pain, and the only functional abnormality detected at this time was confined to the region of the right shoulder and upper extremity. She could not move her right arm and did not have sensation present in the upper extremity. Examination revealed complete brachial plexus palsy. She also had absent radial and brachial pulses in the affected extremity, but a weak subclavian pulse could be felt in the supraclavicular area. Roentgenographic examination of cervical spine, thoracic outlet, and right shoulder region revealed no bony abnormality. She was taken to surgery and underwent a successful resection of a centimeter length of thrombosed axillary artery. Reanastomosis was by end-to-end suture (Fig. 8). At the time of surgery the brachial plexus was carefully examined and was found to have been completely avulsed with dorsal ganglia and roots from the vertebral column. Neurological repair was obviously impossible. Postoperatively she had excellent upper limb pulses but continued to have distressing loss of function due to the neurological deficit.

Comment. Since the brachial plexus and its primary branches are closely wrapped around the subclavian axillary artery complex, trauma resulting in brachial plexus injury should also be suspected of involving the adjacent artery. Careful examination of distal pulses is indicated, and if found normal, an arteriogram must be done to prove the absence of vascular injury. In the presence of obvious vascular injury, preoperative arteriogram will be very helpful. Thus, in either case, an arteriogram is indicated in this type of injury involving the brachial plexus.

A similar indication for arteriography exists in cases of trauma resulting in fracture of the first rib.[24] The first rib is rigidly articulated, and further closely protected by the overlying muscles and bones of the shoulder girdle. The first rib apparently is among the most well-anchored structures in the bony thorax and is seldom fractured by trauma. Detectable fracture of the first rib usually indicates that the causative blunt trauma was of great violence and severity. Since the subclavian and axillary arteries are closely related to the first rib, it is not surprising that a high incidence of vascular injury in this area occurs with first rib fractures.

Abdominal Visceral Arteries

There were 26 visceral arterial injuries of which 4 were hepatic, 8 renal, 5 splenic, and 9 other types. Two of the 4 patients with hepatic artery injuries died in shock. Of the eight renal artery injuries, two were due to blunt trauma, one being a tornado victim. There were 4 nephrectomies and two deaths in the group. All but one of the 4 patients who underwent primary repair of the renal artery sur-

vived. Renal vascular hypertension was not documented in any of the survivors.

Femoral Arteries

There were 22 common femoral arterial injuries, 51 superficial femoral, and 11 injuries of the profunda femoral artery. Four injuries of the profunda femoral occurred at its origin, usually with some destruction of the common and superficial femoral arteries. In one patient, the compound saphenous vein graft, as shown in Figure 9, was used to reconstruct all the three vessels involved.

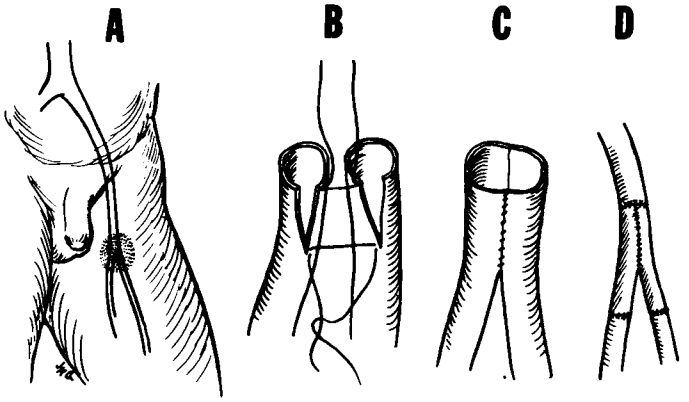

FIG. 9. Compound saphenous vein graft for reconstruction of deep and superficial femoral arteries.

Popliteal Artery Injuries

Nineteen popliteal artery injuries were amenable to reconstructive arterial surgery. In addition, one case of shotgun wound to the popliteal fossa resulted in primary amputation as the extremity was mutilated beyond repair. The major mechanism of injury was gunshot wound, 3 of which were due to shotguns. There were 2 stab wounds to the popliteal artery and an additional 7 cases resulted from blunt trauma. Associated injuries included 4 posterior dislocations of the knee, 3 fractures of the femur, and one fracture of the tibia. All the shotgun wounds were associated with femoral fractures. All cases of popliteal artery injury presented with a cold, ischemic foot with uniform loss of pedal pulses except for one case which proved to be a false aneurysm of the popliteal artery with patent distal runoff. In all other instances at operation the artery was found to be either lacerated or transected. The type of arterial repair consisted predominantly of end-to-end anastomosis (11 cases), but three saphenous vein grafts and 2 Teflon grafts were used in 5 other cases. In one instance, lateral suture provided adequate repair. There were two cases (both of which resulted in amputation) in which proximal ligation and sympathectomy were used as procedures of choice. In the first instance, which was due to blunt trauma, the proximal artery was isolated but a considerable portion of the popliteal artery was completely destroyed and the distal end had retracted deep into the posterior compartment. Reconstruction was not considered feasible, as the injury was 4 days old, and proximal ligation of the artery resulted. In the other instance the cool extremity was the presenting feature, associated with posterior dislocation of the knee but an arteriogram revealed an intact popliteal artery with distal circulation. Instead of exploring the artery, a sympathectomy was done in the mistaken belief that an absence of radiological lesion insured anatomical integrity. Following eventual amputation, pathological examination revealed a lacerated popliteal artery which had subsequently thrombosed. The amputation rate was exceedingly high in this group, amounting to 30% including the single instance of primary amputation already cited. Of the other patients, all but two had good distal pedal pulses following surgery; one had a warm, non-ischemic foot, and the other had a cool foot with marginal circulation. During followup the latter patient had not had ischemic symptoms. There was one instance of causalgia which was successfully treated by sympathectomy.

Several features in this group of patients were analyzed in view of the high amputation rate. Three of the 5 patients who underwent amputation clearly had the longest ischemia time (from injury to restoration of circulation) of the whole group: 3 days, 4 days, and 4 days respectively. In the majority of others, the average ischemia time was 6 to 12 hours, but there were two instances in which the ischemia time was 24 hours and 40 hours respectively. Both of the latter cases had satisfactory end results. There were other similarities between the 5 amputated cases with regard to certain clinical features. All 5 cases were either due to severe blunt trauma, or shotgun wounds which resulted in extensive disruption of the popliteal fossa along with accompanying veins and the bones of the region. In all of these cases primary arterial repair was inadequate, or ultimately became compromised due to other reasons. In one instance the popliteal artery was ligated without repair; in another, lateral injury of the popliteal was missed and no repair was done; in two others the saphenous vein graft ultimately stopped functioning due to extensive muscle necrosis; and in one instance there was secondary bleeding leading to ligation of the saphenous vein graft. There were 4 posterior dislocations of the knee in the entire group of 19 popliteal injuries, and in 2 of the 4 patients amputation ensued. The delay in diagnosis of the arterial lesion accompanying this treacherous injury has been documented by others.[18]

Arteriovenous Fistulae

The distribution of 38 arteriovenous fistulae that were seen primarily after trauma are represented in Figure 10. In addition, 3 arteriovenous fistulae occurred as a com-

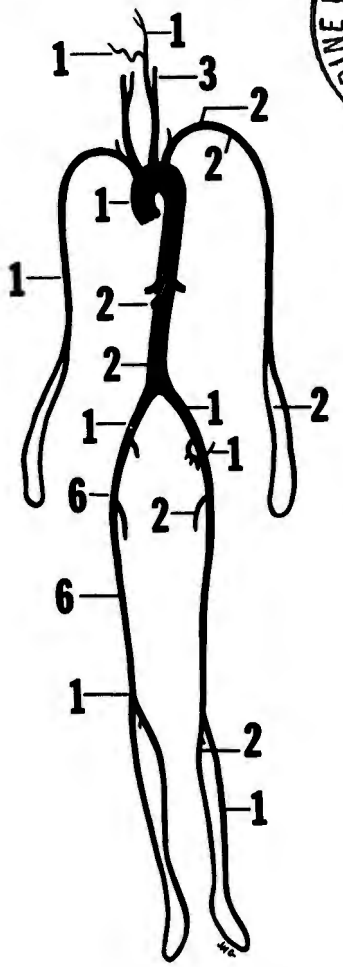

FIG. 10. Anatomic distribution of 38 arteriovenous fistulae.

plication of arterial surgery for trauma. In all but 4 instances the causative agent had resulted in a penetrating wound. Gunshot wounds were responsible for the majority of cases. There were two carotid-cavernous sinus fistulae due to blunt trauma. Considering the overall preponderance of arterial injuries occurring in the extremities, it is not surprising that more than 50% of all arteriovenous fistulae occurred in this location. The most common form of presentation was a detectable bruit or a palpable thrill. A palpable mass was detected over the fistula in some instances. In 5 instances congestive heart failure was present, almost always due to fistulization of a major artery and vein either in the trunk or head and neck. The single exception was a large fistula between the common femoral artery and vein. There was only one infected fistula in this series.

There was considerable delay in diagnosis. The interval between occurrence of the injury and repair varied from a few hours to several years. There were seven cases in which 4, 5, 12, 16, 20, 30, and 34 years respectively passed from the time of injury before repair was effected. Thirty-six of the 38 patients underwent surgery; two patients refused operative correction. At the time of surgery in 5 cases, a false aneurysm was found in association with the fistula. All 5 were excised. True proximal arterial dilatation (Fig. 11) or aneurysm associated with long standing cases[10] was encountered in 3 patients in this series. The predominant method of repair was division or excision of the fistula combined with reconstruction of the artery and the vein as well (25 cases). Saphenous vein grafts were necessary in 4 cases and in one instance during the early experience a juvenile aortic homograft was used. In 11 cases, due to the functional insignificance of the artery involved, or due to inaccessibility of the artery for reconstructive repair (*e.g.*, internal carotid), ligation of the feeding artery and if possible the vein as well was the major surgical procedure. Using these techniques, all but two patients had satisfactory closure of the fistula with excellent results. In these two exceptions, residual bruits were discovered postoperatively but there was little functional impairment. Among those patients who ultimately got an excellent result, two patients were re-explored due to hemorrhage, one patient had a wound infection, another patient required sympathectomy for causalgia. The use of a sterile stethescope at operation can increase the certainty that all fistulae have been closed, an especially important consideration in shotgun injuries.

FIG. 11. Aneurysmal dilatation of left iliac vessels in a patient with left deep femoral arteriovenous fistula. There was a 34-year delay between injury and repair.

FIG. 12. "Pock mark" lesion of artery due to shotgun injury.

Discussion—Special Problems

Blunt Trauma to Extremity

The vast majority of blunt trauma to vessels of the extremity are associated with bone fractures. While the diagnosis of arterial injury in this instance seldom poses difficulties to the alert clinician, the orthopedic problem can provide diagnostic diversion to the unwary and the arterial injury may go unnoticed. Sometimes surprisingly mild blunt trauma can cause vascular injury and thrombosis without evidence of bone, soft tissue, or skin injury. An arteriogram is essential in these instances to localize the precise site and extent of the thrombosis. At operation, the external appearance of the artery can sometimes be deceptive when no external evidence of contusion or discoloration is seen. If thrombosis is localized and rich collaterals are present, distal pulsations may be misleadingly present. It has been shown that the intima of the artery is more susceptible to the effects of trauma than are the other coats.[13] Consequently, intimal injury and thrombosis may be more extensive and may not extend to the adventitia. A surgical procedure varying from thrombectomy to resection of the artery may be required depending upon the extent of the injury.

Shotgun Injuries

The 37 shotgun injuries reviewed in this series presented a wide range of problems which were extensive and often serious. Almost invariable association of extensive skin, soft tissue, nerve and comminuted bone injury was impressive. The vascular injury itself was often due to multiple pellets with destruction of a long stretch of artery (Fig. 12), often requiring a vein graft for repair. Wound debridement and the orthopedic part of the procedure assumed equal importance with the arterial repair. The dead muscle had to be excised back to bleeding tissue, but judgment was required to retain enough viable tissue to provide a bed and cover for the vascular reconstruction. The infection rate was high with a significant incidence of secondary bleeding from the artery, usually requiring high ligation. The amputation rate following shotgun injury was three times the rate for other types of injury. Frequently, even when a successful vascular repair and wound healing had been achieved, the repaired extremity was difficult to rehabilitate due to concomitant nerve injury.

When a combination of these numerous adverse factors co-exist in a shotgun injury, it may be judicious occasionally to carry out primary amputation.

Fractures with Arterial Complications

Apart from arterial and bone injury from the same blunt trauma, it is well known that fractures occasionally are primary causative agents for arterial injury (Fig. 13). The actual method of vascular injury may be due to a wide variety of pathological mechanisms.[21] Not infrequently the diagnosis of arterial injury is delayed or entirely missed. In the upper limb the association of Volkman's contracture with supracondular fractures is well known. When acute arterial injury occurs in association with bone fractures, irrespective of the causative mechanism, priorities as well as the type of management are unsettled. Stablization of fractures before arterial repair is widely advocated in the literature.[19,21] The rationale for this sequence is to forestall injury to the vascular repair by an unstabilized fracture. We ourselves have been more concerned with speedy restoration of distal perfusion and have usually given primacy to the arterial repair before the orthopedic procedure. Soft tissue debridement which is speedily accomplished is undertaken at the same time as the arterial repair, and

FIG. 13. Brachial artery injury due to fracture of the humerus.

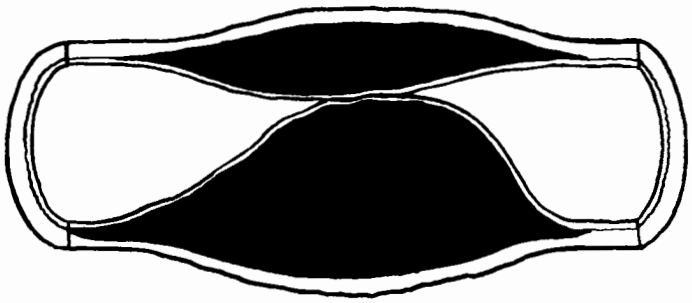

FIG. 14. Iatrogenic injury; limited arterial dissection from arterial puncture.

general anesthesia with full muscle relaxation is necessary. Preliminary fracture reduction is rapidly accomplished if bone fragments are in the way. After satisfactory restoration of blood flow, final reduction and other orthopedic procedures which may be necessary are carried out. In our experience, we have not had occasion to regret this inversion of the sequence generally advocated by others. Additionally this had the important merit of reducing time of distal ischemia, which may be crucial in such locations as a popliteal artery.[6,18] Some authors have improvised a compromise, using a preliminary thrombectomy, heparinization before the fracture is stabilized, and the arterial repair then carried out last.[21] One group has advocated temporary arterial shunts while the orthopedic procedure is accomplished.[6] We have used the temporary shunt once, but prefer primary arterial repair. The vast majority of fractures encountered in this series were stabilized by external fixation for fear of infection associated with compound and comminuted fractures. Internal fixation may be used in arterial injuries associated with simple fractures. The experience in Viet Nam[19] tends to support this general approach.

Iatrogenic Injuries

The problem and variety of iatrogenic arterial injuries have shown an alarming increase in recent years. This is undoubtedly due to the recent increase in diagnostic radiographic, therapeutic, and monitoring procedures requiring arterial puncture. Brachial artery injuries due to cardiac catheterization are frequently seen. Perhaps a larger number of patients with an absent or weak pulse but with a viable warm extremity after catheterization do not come to the surgeon's attention. We have infrequently seen children with femoral arterial occlusion following cardiac catheterization. Another type of injury which is being increasingly seen in the intensive care unit is a cyanotic hand from a radial artery cannula for pressure monitoring. Generally, there are no perfusion problems of the hand if the cardiac output is in the adequate range. In the several cases we have seen, viability of the hand has been maintained with improvement in the patient's general status, and we have not often had to treat gangrene from this complication. One instance of carotid injury from subintimal infection of contrast material for arteriography is included in this series. Other bizarre instances of iatrogenic arterial injury that we have witnessed include carotid thrombosis from an attempted internal jugular venipuncture, subclavian-internal mammary arteriovenous fistula during placement of a central venous pressure line, and femoral arterial occlusion due to sharp instrumentation that was being used in total hip replacement. The arterial pathology in the last instance was a limited dissection with thrombosis. (Fig. 14).

Thrombosis and Spasm

Early vascular literature is replete with instances of vascular spasm relieved with return of pulse. The advent of arteriography has revealed these instances of "spasm" to be due usually to arterial thrombosis and intimal disruption.[21] Return of the pulse was probably due to collaterals. At operation a spastic artery is almost invariably associated with thrombosis, and an arteriotomy should be done. In this series there were only two instances of true arterial spasm without thrombosis. In the same context, sympathectomy and sympathetic blocks have been of little value in the managment of acute arterial injuries in our experience.

Retroperitoneal Hematoma: To Explore or Not Explore?

Judgment is required in deciding whether or not to explore retroperitoneal hematoma.[1,5,23,27] There is little choice but to explore a retroperitoneal hematoma which is expanding, pulsatile, and a source of blood volume loss. On the contrary, some advocate nonexploration when these criteria are not present.[14] It has been argued that a majority of nonpulsatile retroperitoneal hematomas are due to self-limiting venous injuries and meddlesome exploration can be the cause of further hemorrhage. In our experience significant retroperitoneal arterial injury may be present even when the hematoma is small, nonexpanding and nonpulsatile. Sometimes pulsations may be difficult to perceive, and expansion may not yet have occurred. Based on these considerations, we now favor exploration of most retroperitoneal hematomas provided other relative contraindications are absent. For example, we would be reluctant to explore a benign appearing retroperitoneal hematoma when there is massive peritoneal contamination or when a bleeding diathesis secondary to massive transfusion exists. Immediate repair of significant arterial injury is generally easier than would be the case at a later time. Arteriography can be very helpful in such patients.

Early Graft Thrombosis: Prompt Exploration

Intraoperative graft thrombosis is almost always due to technical problems with the vascular anastomosis. Revision of the anastomosis is called for with the aid of

arteriograms if necessary. Resorting to artificial methods of maintaining patency, such as heparinization in the face of technical problems, usually does not succeed for more than a few hours. Causes of late thrombosis of the graft, such as poor inflow and run-off seen in arteriosclerotic disease, are usually absent in the surgery of arterial trauma. Unrecognized retention of thrombus in the distal arterial tree, and involvement of the graft from infection, are the most frequent causes of late graft thrombosis in this type of surgery. The overall incidence of graft failure has been very low in our experience with traumatic arterial surgery (3%).

Fasciotomy: Timing and Techniques

Fasciotomy is an invaluable adjuvant to arterial surgery in the extremities, especially when considerable swelling of the operated limb is expected.[15] Such instances would include extensive soft tissue injury after a shotgun blast, injuries compromising venous drainage of the limb, or injuries associated with prolonged shock or a long ischemia time. To be effective, fasciotomy has to be performed early. It is also useful in advancing the level of amputation distally where, despite aggressive arterial reconstructive surgery, limb circulation remains marginal. It should be emphasized in this context that fasciotomy should never be used as a temporizing measure when a vascular procedure is indicated. We generally prefer subcutaneous fasciotomies done through small skin incisions over both the anterior and posterior compartments of the leg. Occasionally the peroneal compartment as well as the deep posterior compartment are added. When skin constriction is a factor in vascular compromise, we have not hesitated to do extensive transcutaneous fasciotomies. We have occasionally used the fibulectomy method[15] of decompressing the leg compartments, when extensive comminuted bone injury is present.

Graft Materials

Since infection is the most common nonfatal complication, grafts of any type should be avoided. Fabric grafts were used infrequently when the saphenous vein was inadequate in size or otherwise unavailable. Cephalic or other veins were used only occasionally, since they are technically difficult to handle and are prone to aneurysmal dilatation. Compound saphenous vein grafts (Fig. 9) can be constructed to replace medium-sized arteries.

Anticoagulation? Dextran?

We routinely administer heparin parenterally during the operation for arterial trauma. This has been more reliable than local heparinization. Intraoperative hemorrhage has seldom been a problem, and protamine may be administered for reversal. At times the heparin has been allowed to disappear gradually with metabolic degradation. In contrast, postoperative heparinization causes bleeding and is not used. When support to maintain arterial patency is required, we have generally used low molecular weight dextran for 48-72 hours. Increased oozing from raw areas can be a problem but has been controlled by wound drainage for a brief period postoperatively where indicated.

Fogarty Catheterization

We commonly employ Fogarty catheterization in the distal artery in cases of arterial trauma, even when backbleeding is excellent. It is general knowledge that such backbleeding does not rule out the presence of distal thrombus, and this has been our experience. Occasionally, we have used catheter thrombectomy of the associated vein. There is some evidence that the amputation level is beneficially advanced distally by temporary maintenance of venous patency.[18]

Special Technical Considerations

Not infrequently after arterial repair distal pulses are not immediately felt but become obvious after a period of hours, even days. Under these circumstances it is important to confirm arterial patency by an intraoperative arteriogram. In the postoperative period persistence of patency can be conveniently ascertained by using the ultrasonic flow probe. We have found serial measurements of ankle pressures with the ultrasonic flow probe very useful in indicating the state of perfusion.

Drains are generally avoided after arterial surgery, but they are sometimes unavoidable and we have not hesitated to use them when indicated. Usually a closed system of drainage is preferred, and they are removed usually by 48 hours.

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Discussion

Dr. Frank Spencer (New York, New York): I appreciated the opportunity of reading this impressive manuscript beforehand, for with the 350 cases reported, it is not possible to analyze the data in the short time available for presentation. The manuscript clearly represents a significant contribution to the field of arterial injury.

I will make a few specific comments. First, arterial spasm was rare, recognized only twice among 350 cases. I think most patients would benefit if this term virtually disappeared, for the word "spasm" often connotes a harmless condition that will improve without operative therapy. In most patients the more serious injury of contusion, disruption of the intima, and thrombosis is present which clearly requires operation for correction.

A second point is the increasing usefulness of angiography. In someone with multiple penetrating injuries, as from shotgun pellets, uncertainty can readily exist about whether an arterial injury is present. An angiogram is the simplest method to exclude an arterial injury, as opposed to either watchful waiting or widespread surgical exploration of the artery in question.

Uncertainty remains about the best therapy for injuries of the carotid artery. One question is whether a shunt should be used at the time of operation. This was not used by Dr. Hardy with good clinical results. Another question concerns therapy if a neurologic injury is present. The one patient reported to have been hemiplegic for two days, with recovery after arterial repair, is impressive. Others have reported fatal hemorrhagic infarcts following arterial repair in such instances. This remains one of the frontiers for further study.

Iatrogenic arterial injuries are becoming increasingly frequent. A few cases are described in the manuscript resulting from cannulation of the radial artery. Although this is a popular technique, we have at least two patients in New York in which amputation resulted from the procedure, one patient requiring amputation of all four fingers. Another one was barely retrieved by reoperating and reanastomosing the radial artery.

Injuries of the popliteal artery remain an unsolved problem. The amputation rate for popliteal arteries in this series is 30%, similar to that in most reports. I personally think, supported by Dr. Hardy's movie, that when there is extensive loss of soft tissue, with fracture of the bone and loss of the popliteal vein, that attempts at primary repair should be abandoned. Instead I believe one of the extra-anatomic bypasses should be performed as an initial procedure to maintain viability for a few weeks while healing of the primary wound can be obtained. Subsequently elective reconstruction of the popliteal artery can be done in much more favorable circumstances. I should emphasize that this is a theoretical concept, for I do not believe significant data are yet available for this approach.

I would question the authors about the use of heparin. I personally would not recommend its use for most artery injuries because of the associated bleeding. Infection was a common complication in this series, though usually responding to treatment. I wonder if bleeding, hematoma formation, and wound drainage may have contributed to the frequency of infection. A second question is the frequency of secondary wound closure. In most arterial injuries, there is usually a significant degree of contamination; so after arterial repair, as demonstrated repeatedly in different military conflicts, secondary wound closure can be effectively employed with a very low incidence of infection.

Finally, I wonder if it was ever possible to retrieve a patient with an infected arterial repair short of an extra-anatomic bypass? This is the critical problem in vascular surgery. Arterial repair can almost always be done, for usually the arteries injured are normal arteries in young people. Infection, however, remains a dreaded problem, for it usually results in either loss of limb or life.

Dr. G. Rainey Williams (Oklahoma City, Oklahoma): We are all indebted to Dr. Hardy and his productive department and I think this will be another significant contribution to our knowledge. I'd like to make two points. The first has to do with concern about the policy of liberal exploration in the expectation that vascular injury may be present. Dr. Hardy did not mention this, but we have followed Dr. Shires' advice in this regard and have been interested in knowing whether or not this is justified. (Slide) This summarizes our experience with positive and negative exploration for vascular injury in the past several years. You will note that, despite a marked increase in the number of explorations, the percentage of positive explorations has remained about the same. Analysis of the negative explorations has led us to the position that the very low mortality and a 31% incidence of significant associated injuries justifies continuing the policy of routine exploration.

Second, I would like to present an unusual patient. A young woman was admitted to our hospital several days after an automobile accident. She sustained multiple injuries and, on the third or fourth hospital day, underwent open fixation of an ankle fracture. The operator noted that the wound did not bleed vigorously when the tourniquet was removed and a day or two later the toes were noted to be frankly gangrenous. The patient was referred to our institution and promptly underwent aortography. (Slide) This film shows a fairly abrupt cut-off in the midabdominal aorta and this subtraction study reveals delayed filling of the distal aorta and iliac vessels, This closed transection of the intima of the abdominal aorta with obstruction was easily repaired. Its earlier detection might have resulted in salvage of the foot.

Again, we appreciate this report by Dr. Hardy and his associates.

Dr. Daniel B. Nunn (Jacksonville, Florida): I want to call to your attention an unusual aortic injury, namely, dissection of the abdominal aorta following nonpenetrating abdominal trauma.