Management of Arterial Injuries

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DURING the past decade, there has been a progressive increase in the incidence of both civilian and military arterial injuries.[3, 5, 6, 12] In 1964, Patman, Poulos and Shires [11] reported a series of 271 arterial injuries in 256 civilian patients. The present report is a sequential study of 571 patients from the same institution. The current study was designed to assess the effect of changing concepts on the diagnosis and management of major arterial injuries.

Case Material

A survey was made of records of 908 patients undergoing operative exploration for vascular injury during the years 1950 to 1968. This study includes those patients for whom sufficient records were available to ascertain the eventual results. The case material includes 249 patients from 1950 to 1962 and 571 patients operated upon from 1962 to 1968. Analysis of several aspects of care was undertaken. These include examination of the indications for exploration of potential vascular wounds and the influence of these indications upon morbidity and mortality. An evaluation was made of the agents producing the injuries and the various injuries encountered. Associated injuries were recorded and the effect of these injuries on the eventual outcome of the patients was assessed. Clinical signs and symptoms suggesting arterial injury were noted and preoperative arteriography as a diagnostic aid was evaluated.

The technics of vascular repair and the adjunctive methods used were analyzed to determine their influence on patency rates. Early and late complications of arterial repair were related to the specific type of repair. The causes of death and the effects of associated injuries on mortality were examined.

Results

Distribution of Injuries

The distribution of 508 significant arterial injuries in the combined series as divided into three major groups is illustrated in Table 1. There were 442 injuries of major arteries ultimately concerned with viability of the extremities, 42 injuries of major cervical arteries and 24 visceral arterial injuries. From 1962 to 1968, there were 11 visceral arterial wounds, 23 cervical artery injuries and 225 injuries of major arteries supplying the extremities.

Cause and Type of Injury

Table 2 illustrates the responsible agent and the type of injury sustained in 259 patients. Aggressive acts of violence accounted for the majority of the injuries and only a small number were due to accidents. Laceration of the vessel was the most commonly encountered injury, but complete transection was present in a significant number of patients. Arterial contusion with intramural hematoma and separation of the layers of the arterial wall was encountered in several instances.

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TABLE 1. *Distribution of Injuries*

Extremity			
Aorta	26	External iliac	11
Innominate	1	Hypogastric	7
Subclavian	23	Common femoral	11
Axillary	38	Superficial femoral	93
Brachial	78	Profunda femoral	8
Radial	58	Popliteal	17
Ulnar	39	Tibial	12
Common iliac	20	Total	442

Visceral	
Celiac	2
Splenic	2
Superior mesenteric	7
Renal	9
Hepatic	4
	24

Cervical	
Common carotid	24
Internal carotid	8
External carotid	6
Vertebral	4
	42

Associated Injuries

Associated injuries were frequently present and were often major determinants in the eventual result obtained. Significant venous injury in association with arterial injury was encountered in 90 patients (34%) and major nerve injury in 48 (18.5%). Isolated major venous injury was found in 88 cases (10.8%). Eighteen patients (6.9%) had more than one significant arterial injury. Associated wounds of abdominal viscera or lungs were present in 39% of patients.

TABLE 2. *Cause and Type of Injury*

Gunshot wound	143
Edged instruments	92
Blunt trauma	24
	259
Laceration	133
Transection	99
Puncture	18
Contusion	7
Spasm	2
	259

Diagnosis

The indications for surgical exploration for vascular injury are illustrated in Table 3. In most cases, more than one indication was present, and this usually included significant hemorrhage, anatomical proximity of the injury to major vessels and discrepancies in distal pulses.

The presence of distal pulses did not preclude the possibility of significant arterial injury. From 1950 to 1961, 69 patients with significant arterial injuries and intact distal pulses were encountered. In 40 cases, the distal pulses were normal, whereas in 29 they were decreased. In the present series, the distal pulses were unimpaired at the time of initial examination in 22 of 225 patients with proven arterial injuries.

Preoperative arteriography was employed in specific instances in the diagnosis of arterial injuries. This technic has been particularly helpful in instances in which blunt trauma was the major cause of injury and associated fractures were present. Preoperative arteriography was also useful in patients with scattered pellet wounds of the leg and forearm. These injuries often required superficial debridement, but a solid indication for vascular exploration was not always present. Arteriography offered fairly reliable evidence of the presence or absence of significant arterial injury.

In patients with penetrating cervical wounds near the base of the skull, angiograms were frequently obtained prior to operation. In several cases, undetected injuries of the extracranial arteries were demonstrated with this technic.

Occasionally, arteriography failed to reveal a vascular injury. This occurred infrequently since arteriography was not routinely employed when other indications for exploration existed. In two cases, the primary indication for exploration was anatomical proximity of the wound to a major

artery and significant injury was found on exploration despite normal preoperative angiograms.

Operative Management

During exploration, wide exposure and proximal and distal control of major vessels were obtained whenever possible. Once operative control of bleeding was obtained, systemic heparinization was employed in some cases, but not continued into the postoperative period. Because of the relatively short half-life of intravenous heparin, reversal of anticoagulation was rarely performed.

When associated injuries were present, specific priorities of repair were observed. If vascular injuries were present with fractures of the long bones, the latter were stabilized prior to arterial repair whenever possible.[13] External stabilization was favored, but in those instances where this was not satisfactory, internal fixation of the bones was obtained. This technic facilitated arterial repair and reduced the possibility of arterial disruption during manipulation and fracture fixation.[1, 9]

When both major arteries and veins were disrupted, concomitant venous repair was usually performed prior to completion of the arterial repair. In the combined arterial and venous injuries, the distal arterial system was irrigated with copious amounts of cool, balanced salt solution containing a one to ten dilution of heparin. This technic retarded intravascular thrombosis by removal of the formed elements of the blood and the anticoagulant affect of the heparin.

In 249 patients, arterial repairs or ligations were undertaken and the methods employed are depicted in Table 4. Resection, debridement and anastomosis was the most commonly employed modality of repair, but in 66 cases it was possible to perform lateral arteriorrhaphy. Ligation was performed only when sacrifice of the involved vessel would not compromise distal circulation, or when repair posed a major threat to life. Replacement and graft interposition were employed in those cases where simple anastomosis would have placed undue tension on the repair. Autografts were favored and in those instances, either saphenous or cephalic vein or autogenous artery was used. Associated visceral injuries and contaminated wounds presented a contraindication to the use of prosthetic grafts and these devices were inserted only when autografts of suitable size and length were not available. Prosthetics were thus used exclusively in the aortoiliac system.

TABLE 3. *Clinical Signs Suggesting Arterial Injury*

1. Diminished or absent distal pulse
2. History of or persistent arterial bleeding
3. Large or expanding hematoma
4. Major hemorrhage with hypotension or shock
5. Bruit at or distal to suspected site of injury
6. Injury of anatomically related nerves
7. Anatomical proximity of wound to major artery

Adjunctive Methods

1. Fasciotomy. In 19% of the arterial injuries of the extremities, fasciotomy was employed. The anterior compartment of the leg was most susceptible to changes in tissue pressure producing vascular compression. When an anterior compartment fasciotomy was necessary, a three-compartment fasciotomy was performed concomitantly. The major indications for fasciotomy were delay between wounding and repair, shock, combined venous and arterial injuries, massive soft tissue damage and significant swelling of the extremities in the postoperative period.

Fasciotomy through limited skin incisions was only occasionally useful. Ade-

TABLE 4. *Type of Repair*

Lateral	66
Anastomosis	107
Autograft	27
Prosthetic graft	7
Ligation	42
	249

TABLE 5. *Complications—207 Arterial Repairs*

	Occlusion	Re-op Successful	Infection
Axillary	2		1
Brachial	4	2	3
Radial-ulnar	4	1	
Renal	1		
Iliac			1
Femoral	5	4	3
Carotid	1		
Popliteal	2	1	
	19	8	8

Failure of Repair 5.2%

quate opening of muscle compartments was difficult through small incisions and the possibility of superficial nerve or vessel injury was present. In some cases, the intact skin confined underlying tissues and contributed to vascular compression.

If fasciotomy was performed promptly, it was occasionally possible to attain a primary closure of the fasciotomy wound. In other cases, it was necessary to apply split thickness skin grafts to the defects created by the fasciotomy incisions. Secondary infection of the fasciotomy wounds occurred in a small number of patients and did not add significantly to the postoperative morbidity.

2. **Management of Spasm.** Sympathectic blockade of the extremity was employed infrequently as an adjunctive measure to increase the total distal flow through potential collateral channels. It was used only as primary therapy when there was arteriographic evidence of patency of all major vessels. Chemical and surgical sympathectomy had limited application and appeared to be of little benefit in those instances in which major vascular occlusion was present.

Arterial spasm following trauma in young persons was frequently seen but was usually easily managed by mechanical or hydraulic dilatation.[7, 8] Surgical sympathectomy and the use of sympatholytic agents was occasionally rewarding.[13] Direct application of chemical vasodilators did not prove to be as successful as anticipated. In rare cases, refractory spasm was encountered and direct reconstructive technics were required. Local excision and anastomosis or graft interposition was usually employed.

TABLE 6. *Complications in Surviving Patients with Injury of Major Vessel of Extremity*

Vessel		Bleeding	Amputations
Subclavian	11		
Axillary	12		1
Brachial	32	1	
Radial and ulnar combined	8		1
Aorta	12		
Iliac	15		
Femoral	63	3	
Popliteal	12		1
	165	4	3 (1.8%)

Complications

Table 5 illustrates the complications following 207 arterial repairs. There were 19 early occlusions and eight of these were successfully reoperated upon, resulting in 5.2% failure of repair. Eight wound infections occurred in the 232 surviving patients; an infection rate of 3.5%.

Four patients with arterial injuries of the extremities bled postoperatively and were successfully managed by reoperation (Table 6). These 165 patients include only those in whom the injured vessel was ultimately concerned with viability of the extremity. Amputation was required in three of the 165 patients; an amputation rate of 1.8%. In two of those patients, removal of three digits was required, and the other patient had a below-knee amputation.

In the 232 surviving patients, the late complications of false aneurysms and arteriovenous fistulae were not encountered. This is in contrast to the previous report in which exploratory operation was not performed at the time of initial injury in 17 patients, 12 of whom developed false aneurysms and five of whom developed arteriovenous fistulae.

In 312 patients explored but without major arterial injury, there was no mortality and the only significant morbidity was a wound infection rate of 3.1%. In many of these operations, vascular exploration was performed in conjunction with debridement of a significant wound of the extremity and did not constitute the primary indication for operation.

Mortality

Twenty-seven of the 259 patients died, a mortality rate of 10.4%. This compares with an 8.5% mortality rate reported in the initial series. Table 7 illustrates the distribution and the importance of serious associated injuries which in most instances contributed to the lethal outcome. In the aortoiliac injuries, hemorrhage from the large vessels was the primary cause of death, whereas this was rarely the case in wounds of the extremities.

TABLE 7. *Mortality—259 Patients*

Vessel		Associated Injuries
Subclavian	1	Subclavian, innominate vein, lung
Axillary	2	Subclavian vein, lung
Aorta	8	(8) Abdominal viscera (4) major vein
Renal	1	Abdominal viscera, vena cava
Iliac	8	(8) Abdominal viscera (5) major vein
Femoral	3	Multiple injury chest, head
Carotid	4	(1) Stroke, (2) intracranial injury
	27 (10.4%)	

Discussion

The decision to undertake operative vascular exploration is relatively easy when pulse discrepancy or vascular insufficiency is present, but it is clear that a significant arterial injury may exist without a detectable change in distal pulses or evidence of ischemia.[11] This combination of events is most likely to occur in injuries of the subclavian and axillary arteries and of the aortoiliac system, where large collateral beds permit distal perfusion. In a few instances, the transmission of the pulse wave may proceed relatively uninhibited in an artery in which only a partial obstruction exists. The pulse wave has a velocity of three to four meters per second, and may be transmitted through small areas of soft, intraluminal thrombus or beyond intimal flaps. It is apparent that in patients with extremity injuries in whom pulses are present and function is unimpaired, other indications for operation must be considered.

Preoperative arteriography has been a useful tool in the detection of arterial injuries.[4] In this study, the data are consistent with those reported by Lumpkin, in that extravasation of contrast material does not always occur, even though arterial injury may be present.[10] This does not detract from the usefulness of this procedure, but the existence of these misleading studies suggests that it cannot be used as the sole criterion in determining the need for exploration.

Some minor arterial injuries may heal without significant sequelae, but the late development of false aneurysms and arteriovenous fistulae constitute a major threat to viability of the extremity. Initial detection and repair of these injuries is relatively simple in comparison with the management of a well developed false aneurysm or A-V fistula.

At the time of vascular exploration, it is desirable to restore major venous continuity whenever possible. Venous stasis and swelling of the limb may contribute to failure of the arterial repair. In addition, the incidence of phlebitis and post-phlebitic sequelae is increased when major venous injuries are not repaired.[2, 12]

Failures of repair were analyzed to determine what factors may have predisposed to thrombosis of the artery. In those instances in which the injury was the result of a gunshot wound, adequate debridement is mandatory to assure a satisfactory repair. It has been suggested that inadequate debridement of the artery and the surrounding tissues may be a limiting factor in continued patency.[2, 13] There was no persuasive evidence that this contributed to the failures in this study.

There was no consistent correlation between the presence of infection and ultimate failure of the repair. With two exceptions, occlusion occurred in the immediate postoperative period and was related to technical factors. In one brachial artery repair and one femoral artery repair, infection appeared to be significantly involved in delayed postoperative thrombosis.

The failures were equally distributed among the various types of arterial repair employed and the specific technic of restoration of arterial continuity did not appear to be implicated as a factor in the ultimate thrombosis. Resection and anastomosis under tension, or stenosis at the anastomotic site was the most common cause of failure. There are, however, three instances in which interposed saphenous vein autografts failed and undue tension on the suture lines could not be implicated. In these cases, inadequate anastomosis with operative stenosis or failure to secure intimal coaptation was at fault. Lateral repair was often successful, but this appeared related to the minor nature of the injury and the lack of associated injuries more than the actual technic used to restore continuity.

Analysis of these results has emphasized several concepts. Successful management of vascular injuries demands the precise application of meticulous surgical technic. Adequate exposure and debridement are necessary before attempting definitive repair. Every effort must be made to insure intimal coaptation and restoration of normal vessel diameter. Careful attention to proper vessel length is mandatory. A search for and removal of intravascular thrombi prior to closure of the vessel will reduce the possibility of early thrombosis. When the extremity is threatened by vascular compression, prompt fasciotomy is necessary. If normal distal flow is not immediately obtained, operative arteriography is indicated. When these concepts are observed, vascular repair can usually be successfully concluded.

Summary

An analysis of 508 arterial injuries has been presented. In this study, a comparison was made of the results obtained in two consecutive series. Evaluation of the indications for operative exploration suggests assessment beyond adequacy of distal pulses, and outlines the usefulness of preoperative arteriography.

The precise application of meticulous surgical technic of wound debridement and vascular repair has been demonstrated to be essential to success. Arteriographic demonstration of adequate repair and distal flow has been very useful and is recommended.

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