THE MANAGEMENT OF ARTERIAL INJURIES IN BATTLE CASUALTIES*

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INTRODUCTION

LIGATION WAS THE principal treatment of arterial injuries of the extremities in World War II. Gangrene followed ligation in about 50 per cent of the cases. This subject was well reviewed by DeBakey and Simeone in 1946.[3] Individual experience with arterial injuries in World War II were reported by Bradford and Moore,[1] Kirtley,[10] MacFee,[11] Preston,[14] Smith,[16] Snyder,[17] Stewart,[18] Warren[22] and Rose, Hess, and Welch.[15] Odom[13] reported arterial injuries to have caused 23 per cent of one large group of amputations in World War II. Treatment of arterial injuries by suture or with vein grafts, with or without Blakemore vitallium tubes, was often unsuccessful, probably because injuries were seldom seen earlier than ten hours after injury.

In the Korean War, helicopter evacuation of patients made surgical care possible a few hours after injury. Recent developments in the use of arterial homografts had showed their possibilities for the treatment of arterial injuries.[4, 5, 19-21] These two factors indicated that arterial repair might be possible in many battle casualties. This report presents 97 arterial injuries in 85 patients who were treated while the authors were on active military duty with the First Marine Division in Korea.

Arterial repair was considered for all "major" arterial injuries. "Major" arteries included the subclavian, axillary and brachial arteries in the upper extremity, and the iliac, femoral, popliteal and posterior tibial above the peroneal artery, in the lower extremity. The main questions were the tolerance of patients with multiple wounds for the additional operating time required for arterial repair, the hazard of infections in wounds with arterial repair, and the relation between the survival of extremities and the duration of time between injury and repair.

METHODS

Preoperative care. The majority of patients were seen four to six hours after injury. A few were seen as late as 15 to 30 hours after injury. No extremities were seen in which ischemic changes were so marked that a primary amputation was done. An arterial repair was considered on all cases regardless of the duration of injury. It was recognized that amputation might later become necessary if the ischemic changes were irreversible.

Hemorrhage was usually controlled by pressure dressings. Tourniquets were infrequently used. Packing of a wound with sterile gauze was useful for axillary and buttock wounds. The mass of gauze lying between the overlying skin and the underlying bone made external pressure more effective in compressing the injured vessel.

The diagnosis of an arterial injury was readily made in extremities that were cold, pale and pulseless. Bright red bleeding, even in small amounts, was usually indicative of an arterial injury. Small wounds with no active bleeding but associated with a history of shock at the time of injury were often found to have an arterial injury sealed by a blood clot. Some cases had no indication of a vascular injury, and the wound was found only during surgical exploration.

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TABLE I. *Distribution, Treatment and Results of 97 Major Arterial Injuries.*

Distribution		Treatment				Results	
Artery Injured	No. of Cases	Vascular Graft[1]	End-End Anastomosis	Lateral Suture	Ligation	No. of Amputations for Gangrene	Percentage Amputations
Subclavian	1	1	0	0	0	0	0
Axillary	4	2	0	1	1	0	0
Common Brachial	3	2	0	1	0	0	0
Superficial Brachial	19	2	14	2	1	1	5%
Radial and Ulnar	2	0	2[2]	0	0	1	50%
External Iliac	2	1	0	1	0	0	0
Common Femoral	4	3	0	1	0	1	25%
Superficial Femoral	29	18	4	7	0	6	21%
Profunda Femoral	3	0	0	1	2	0	0
Popliteal	24	16	4	2	2	9	38%
Posterior Tibial[3]	4	2	0	1	1	3	75%
Anterior Tibial	2	0	0	1	1	0	0
Total	97	47	24	18	8	21	22

[1] 44 arterial homografts, 3 venous autografts.
[2] 1 artery ligated, the other anastomosed.
[3] above peroneal artery.

Preoperative resuscitation was usually completed in one to three hours, even in the most severely injured cases. This was accomplished by the intravenous administration under pressure of 3000 to 5000 ml. of blood when necessary. Preoperative sympathetic blocks were not used, chiefly because completion of resuscitation was soon followed by surgical treatment.

Operative care. General anesthesia was most often used. Spinal anesthesia or regional brachial plexus anesthesia was used in the less severely wounded patients. A tourniquet applied at the beginning of the operative procedure permitted immediate incision of the wound hematoma, evacuation of blood clots, and isolation of the ends of the injured vessel, after which the tourniquet could be released. This use of a tourniquet appreciably shortened the operating time. Arterial occlusion was obtained with bulldog serrafine clamps or rubber catheters. Potts *ductus arteriosus* clamps were not available for most of the cases.

All grossly injured arterial tissue was removed. The intimal surface of the artery was often found to be more extensively injured than was externally apparent. Resection of additional segments of artery beyond the grossly injured area, as described by Jahnke and Seeley,[8] was not done. The arterial adventitia was removed from the ends of the vessel to facilitate suturing. The anastomoses were done with five zero arterial silk suture using a continuous everting suture by the Carrel triangulation technic.

Lateral or transverse suture repairs were done when the vessel diameter was not narrowed more than 20 to 30 per cent. End-to-end anastomoses were done for more extensive injuries in which the vessel ends could be approximated without marked tension. Extensive mobilization of the vessel ends by division of major arterial branches was not done. Arterial homografts were used when anastomosis was not possible. Three venous autografts were used early in the

TABLE II. *Treatment of 22 Brachial Artery Injuries.*[1]

Method of Treatment	No. of Cases	Viable Extremity	Gangrene	Percentage Gangrene
End-End Anastomosis	14	13	1	7%
Arterial Homograft	4	4	0	0
Lateral Suture	3	3	0	0
Ligation	1	1	0	0
Total	22	21	1	5%

[1] 19 superficial brachial, 3 common brachial injuries.

TABLE III. *Treatment of 33 Femoral Artery Injuries.*[1]

Method of Treatment	No. of Cases	Viable Extremity	Gangrene	Percentage Gangrene
Arterial Homograft	19	14	5	26%
End-End Anastomosis	4	3	1	25%
Lateral Suture	8	8	0	0
Venous Autograft	2	1	1	50%
Ligation	0	0	0	0
Total	33	26	7	21%

[1] 29 superficial femoral, 4 common femoral injuries.

TABLE IV. *Treatment of 24 Popliteal Artery Injuries.*

Method of Treatment	No. of Cases	Viable Extremity	Gangrene	Percentage Gangrene
Arterial Homograft	15	8	7	47%
End-End Anastomosis	4	3	1	25%
Lateral Suture	2	2	0	0
Venous Autograft	1	1	0	0
Ligation	2	1	1	50%
Total	24	15	9	38%

series before homografts were available. Most grafts were 4 to 6 cm. in length.

After completion of arterial repair, strong pulsations would appear in the distal vessel. The hand or foot would become pink in color, and venous filling would be apparent. Palpable pedal pulses, however, would often not return for one to four hours. Localized arterial spasm was infrequently seen. It responded well to the topical application of 2 per cent papaverine for 15 to 30 minutes, as described by Kinmonth.[9] Anticoagulants were not used, except for a dilute heparin solution used for irrigation during the arterial anastomosis.

A radical debridement of all injured tissue was done after the arterial repair was completed. The concomitant vein was ligated only when injured. The injured vein was repaired by lateral suture in a few instances in the lower extremity where multiple vein injuries had occurred. Bone and nerve injuries were treated only by debridement. The soft tissues were approximated by sutures around the repair site to surround the artery with a "viable soft tissue bed." The remaining wound was left open for closure by secondary suture in four to seven days. Anterior and posterior fasciotomies were frequently done in the leg for popliteal arterial injuries, because of the marked susceptibility of the leg muscles to ischemic necrosis.

Postoperative care. The injured extremity was immobilized for a period of three weeks, usually in a posterior plaster splint. Sympathetic blocks were done in the immediate postoperative period, but were seldom used after 24 to 48 hours. Adequate blood replacement was felt to be the most important factor in preventing peripheral vasoconstriction. Clinical experience indicated that the circulatory status of the extremity should be restored beyond question by four to six hours postoperatively. Surgical exploration was seriously considered in extremities having a questionable prognosis four to six hours after repair.

Arterial homografts. The arterial homografts were collected under sterile conditions at autopsy less than six hours after death. They were placed in a plasma-electrolyte solution containing a dilute concentration of penicillin and streptomycin that was similar to the one used by the Navy Tissue Bank at Bethesda, Maryland. The solution was a modification of the original solution used by Gross and associates.[4] The grafts were stored in a blood bank refrigerator between 0 and 10 degrees Centigrade for a maximum of six weeks. Most of the grafts were less than four weeks of age when used. Routine bacterial cultures were not done.

Arterial ligations. Ligation of the injured vessel was done in only eight instances in the 97 injuries. Three of these ligations were done after observing excellent back-bleeding from the distal segment. Poor results were obtained in two cases. One of these had significant ischemic symptoms, and the other was amputated for gangrene. Three

TABLE V. *The Results of 44 Arterial Homografts in 42 Cases.*

Result	No. of Cases	Percentage of Total
Viable Extremity	28	67%
with patent graft	23	
with ligation for graft rupture	2	
with regrafting for graft rupture	2	
with graft thrombosis	1	
Gangrene	14	33%
with patent graft	11	
with graft failure	2	
undetermined	1	
Total Graft Complications	7	16%
thrombosis	2	
rupture	5	

cases were ligated because repair could not be done without a graft, and the vessels seemed too small to require a graft. The ischemia in two instances of profunda femoral injuries arose from a concomitant spasm of the superficial femoral artery from pressure of the hematoma. The spasm was treated with topical papaverine, following which the profunda femoral artery was ligated without sequelae.

RESULTS

The over-all results are presented in Table I. Most cases were followed four to eight weeks after surgery. Survival of the extremity seemed assured at this time, for subsequent occlusion of the artery should be comparable to delayed ligations performed for aneurysms and arteriovenous fistulae. Such ligations rarely result in gangrene.

The majority of the injuries were in the superficial brachial, superficial femoral, and popliteal arteries. The infrequency of wounds of the axillary and subclavian arteries was probably a result of the armored vests worn by combat personnel. The vests were highly effective in stopping low velocity fragments from grenades and mortar. The three profunda femoral injuries had severe ischemia from additional injuries. The four wounds of the posterior tibial artery were above the origin of the peroneal artery. These injuries had the same serious prognosis as wounds of the popliteal artery, because the small anterior tibial artery was inadequate to maintain circulation. Combined wounds of the radial and ulnar in the arm or the anterior and posterior tibial arteries in the leg have a serious prognosis.[3]

Arterial homografts were used to repair about 50 per cent of the total injuries. Three venous autografts were used. End-to-end anastomoses were possible in about 25 per cent of the cases, and lateral or transverse suture in 20 per cent.

The importance of arterial homografts is indicated by their use in almost 50 per cent of the cases. Energetic attempts to accomplish end-to-end anastomoses by division of collateral channels and mobilization of the ends of the artery were not done. Five of the 47 grafts were 3 cm. in length; these were the shortest grafts inserted. The majority of the grafts were 4 to 7 cm., and a few were 9 to 12 cm. It is doubtful that end-to-end anastomoses could have been performed in many of these cases.

Brachial artery injuries. Twenty-two brachial artery injuries are listed in Table II. Three of these were common brachial, and 19 were superficial brachial.

TABLE VI. *The Results of 24 End-to-End Anastomoses.*

Result	No. of Cases	Percentage of Total
Viable Extremity	20	83%
anastomosis patent	17	
anastomosis thrombosed	3	
Gangrene	4	17%
anastomosis rupture	1	
anastomosis patent	2	
unclassified	1	

Arm injuries were not as extensive as those in the lower extremities. Similarly, traumatic amputations were much less frequent in the upper extremity. Only two of the 22 injuries had severe soft tissue loss; five had compound fractures. Because of the minimal soft tissue loss, it was possible to do many repairs by end-to-end anastomosis. The

TABLE VII. *The Causes of 20 Amputations for Gangrene.*

I. Local Vascular Complications	
1. Inability to restore arterial continuity	1
2. Subsequent breakdown of arterial repair	2
II. Irreversible Preoperative Ischemia from Time-Lag and Loss of Collateral Circulation	10
III. Distal Vascular Complications	
1. Arterial spasm	1
2. Massive venous occlusion	3
IV. Ligation	1
V. Unclassified	2
Total	20

TABLE VIII. *Comparison of Ligation and Repair in Treatment of Arterial Injuries.*

	Ligation (World War II: DeBakey and Simeone)		Repair (Author's Series)	
Artery	No. of Cases	Percentage Amputation for Gangrene	No. of Cases	Percentage Amputation for Gangrene
Axillary	74	43%	4	0
Common Brachial	97	56%	3	0
Superficial Brachial	209	25%	19	5%
External Iliac	30	46%	2	0
Common Femoral	106	80%	4	25%
Superficial Femoral	177	55%	29	21%
Popliteal	502	72%	24	38%

presence of vein or nerve injuries did not influence the prognosis.

The one case of gangrene was an example of inability to predict whether gangrene would follow ligation or not. The injury was in the superficial brachial artery in the upper arm with moderate soft tissue loss and good back-bleeding from the distal arterial end. Minimal soft tissue loss and good back-bleeding are often used as indications that a ligation of the injured vessel can be done. Gangrene developed in this case when a ligation was done following disruption of the anastomosis on the seventh postoperative day.

The arterial anastomosis thrombosed in three cases. The injury in each instance was in the distal arm, where the brachial artery was small. The peripheral circulation following the thrombosis seemed adequate in all instances. The size of the injured vessel may be a useful criterion as to whether an injured artery can be safely ligated or not.

Femoral artery injuries. Thirty-three femoral artery injuries are summarized in Table III. Operative exposure was obtained by lateral displacement of the sartorius muscle for injuries in the upper thigh and by medial displacement for injuries in the lower thigh. Proximal control of the blood supply in upper thigh injuries was obtained by isolating the external iliac artery above the inguinal ligament.

Nineteen of the injuries required an arterial homograft for repair. The amputation rate in this group was 26 per cent. Eight small wounds were repaired by lateral suture with full recovery in seven cases. The eighth case recovered following ligation of the artery when the suture repair disrupted on the 11th postoperative day. Ligation was not done on any injuries.

Six of the injuries had severe soft tissue loss and 11 had moderate soft tissue loss. There were nine compound fractures in the group. The amputation rate was higher in the group with severe soft tissue injuries, apparently because irreversible ischemic changes appeared more promptly because of loss of collateral circulation. The presence of vein or nerve injuries did not affect the prognosis.

Popliteal artery injuries. Twenty-four popliteal artery injuries are summarized in Table IV. Injuries of the proximal popliteal artery were exposed through an anteromedial incision well described in the textbook *Extensile Exposure* by Henry.[6] The sartorius muscle was displaced posteriorly to enter a plane of dissection posterior to the adductor magnus tendon. Injuries of the distal popliteal artery were exposed through a posterior incision that separated the heads of the gastrocnemius and soleus muscles.

Popliteal injuries were the most serious injuries seen. Fifteen of the cases were repaired with an arterial homograft; seven of these developed gangrene. The gangrene

TABLE IX. *The Relation of Gangrene to the Time Interval Between Injury and Completion of Arterial Repair.*[1]

Artery Injured	Result	Time Interval (hours) and Number of Cases for Each Interval						
		5–6	7–8	9–10	11–12	13–14	15–16	17 or more
Brachial	Viable Extremity	1	5	6	1		1	
	Gangrene	1						
Femoral and External Iliac	Viable Extremity	4	4	4	2	2		
	Gangrene	3		1	1		2	
Popliteal and Posterior Tibial	Viable Extremity		2	1	3	3		2
	Gangrene	2			2	1	1	4

[1] Only those injuries requiring an anastomosis or a vascular graft are included.

in most cases appeared to result from irreversible ischemic changes. Less extensive injuries that could be repaired by lateral suture or anastomosis had a higher survival rate.

The incidence of gangrene in popliteal artery injuries in association with compound fracture and severe soft tissue injury is almost 100 per cent if arterial repair is not done. Primary amputation has been the initial treatment of these injuries by many surgeons. Our experiences indicated that this form of therapy was seldom indicated, although amputation would become necessary if gangrene followed arterial repair. It was not possible to determine preoperatively on the basis of extent of injury and time lag as to whether arterial repair would be successful or not. The policy followed in such circumstances was to repair all cases that had any possibility of survival of the extremity, and then promptly amputate those in which gangrene later appeared.

Arterial Homografts. The results of 44 arterial homografts are recorded in Table V. A viable extremity resulted in 67 per cent of the cases, and gangrene in 33 per cent. The gangrene was due to graft failure in only two cases. The remaining cases were demonstrated to have a patent graft at the time of amputation. Twenty-three of the 28 surviving extremities were available for late follow-up. The other six cases were lost for follow-up because of three deaths, two graft ruptures, and one graft thrombosis, all with survival of the extremity. The majority of the patients with viable extremities and intact grafts were followed for one month or longer. One graft was found thrombosed at surgical exploration in another hospital ten months later, and thrombosis was suspected in one other graft. The remaining grafts were functioning well when last observed.

The chief dangers to a homograft in the postoperative period were wound infection, necrotic tissue adjacent to the graft, and motion at the graft site. There were two thromboses and five rupture in the first two postoperative weeks. The two thromboses were unexplained. The causes of rupture were motion at the graft site from inadequate immobilization in three cases, necrotic tissue surrounding the graft in one case, and wound infection in one case. Immobilization of the graft site for three weeks postoperatively was felt to be important. The replacement of homografts by fibrous tissue made it necessary that all grafts be surrounded by viable soft tissues. In extensive soft tissue wounds, rotation of muscle groups was necessary to cover the grafts. Free grafts of *fascia lata* failed in two cases. Two grafts that ruptured on the ninth and 14th postoperative days, respectively, were successfully regrafted. A similar procedure might have been carried out in other cases.

End-to-End Anastomoses. Table VI illustrates the results of 24 end-to-end anastomoses. The extremity survived in 20 cases, although the anastomosis thrombosed in three of these. All of the thromboses occurred in the brachial artery near the elbow, where the artery was small, and the anastomosis was done under slight tension. There

TABLE X. *The Influence of Compound Fracture on 23 Popliteal and 31 Femoral Artery Injuries.*

Injury	No. of Cases	Viable Extremity	Gangrene	Percentage Gangrene
Femoral Artery: Without Fracture	22	20	2	9%
Femoral Artery: With Fracture	9	4	5	56%
Popliteal Artery: Without Fracture	12	9	3	25%
Popliteal Artery: With Fracture	11	5	6	55%

was no demonstrable circulatory deficit in any of these cases. The other anastomoses were thought to be patent on clinical examination. Postoperative arteriograms were not made.

Amputations. The causes of 20 amputations are presented in Table VII. Nine of the arterial injuries that resulted in amputation were in the popliteal artery and two in the posterior tibial; the remainder included six superficial femoral, one common femoral, one superficial brachial, and one combined radial and ulnar. The presence of back-bleeding from the end of the distal artery was noted at the time of repair. "Good" or "fair" back-bleeding was present in nine of the 20 extremities that subsequently became gangrenous.

In only one case was inability to restore arterial continuity the primary cause of gangrene. This case rapidly thrombosed an anastomosis and then two successive arterial homografts. The cause of the thrombosis is unknown. In two cases a delayed failure of the arterial repair resulted in gangrene; one case had disruption of an anastomosis on the sixth postoperative day, and the other had rupture of an arterial homograft on the 14th postoperative day. A secondary arterial repair may have been possible in both of these cases. Successful secondary repairs were done on two similar cases.

Ten amputations, 50 per cent of the entire group, resulted from irreversible preoperative ischemia. These cases had restoration of pedal pulses following arterial repair, but nevertheless developed gangrene. They were characterized by severe soft tissue injury and a long time interval between injury and repair. In seven of the ten cases, over 14 hours elapsed between injury and completion of repair.

Seven of the ten cases were injuries of the popliteal or posterior tibial artery. The tissues most susceptible to gangrene were the anterior tibial and the gastrocnemius-soleus muscle group. Recognition of gangrene was delayed for seven to ten days in some instances because the overlying skin was viable. Serious systemic symptoms appeared in all cases with gangrene when amputation was not promptly done. A propagating secondary thrombosis in the distal arterial tree was suspected in some cases, but no gross thrombi were found in several of the limbs dissected following amputation.

A diffuse spasm in the distal arterial tree resulted in gangrene in one femoral artery injury repaired five hours after injury. The cause of the spasm is unknown. Repeated lumbar sympathetic blocks, in addition to surgical exploration with topical application of papaverine and procaine, were without benefit.

Massive venous occlusion appeared to be the chief cause of gangrene in three cases. Extensive soft tissue injuries had destroyed most of the large veins, including the long and short saphenous veins and the popliteal vein. Massive edema appearing after arterial repair progressed to gangrene within 48 to 72 hours. The arterial tree was demonstrated to be patent in the amputated extremity. There was widespread dilatation and congestion of the distal venous bed.

The one instance of gangrene following ligation was a popliteal artery injury ligated because of excellent back-bleeding. Gangrene slowly appeared over a period of three weeks postoperatively.

Deaths. There were six postoperative deaths. These included three instances of renal shutdown, one pulmonary edema, one pulmonary embolism, and one mesenteric

thrombosis. All deaths occurred between four and 14 days postoperatively. All of the fatal cases had multiple severe injuries and a long time interval between injury and completion of surgical therapy. Four of the deaths were thought to be unrelated to the arterial repair. Two deaths had an unusually long operating time and a large number of blood transfusions. Ligation of the injured vessels in these two cases might have avoided a fatal outcome.

DISCUSSION

The results indicated that arterial repair was possible for the majority of arterial injuries in combat casualties. The additional operating time required was well tolerated by most patients. Caution was indicated in patients with multiple severe injuries in whom a prolonged operating time might result fatally. Arterial repair in extremities with a questionable prognosis resulted in some extremities with gangrene in the presence of an intact arterial circulation. Prompt amputation was necessary in such cases because of severe systemic symptoms.

Arterial homografts were very useful for extensive arterial injuries. Their availability and simplicity of insertion greatly facilitated the repair of the most extensive arterial injuries. When arterial homografts were used, careful postoperative supervision was necessary for three to four weeks.

Jahnke and Seeley[8] have reported excellent results in 34 arterial injuries with only three amputations. The repairs were done with 27 anastomoses, four venous autografts, and two transverse sutures. The high percentage of anastomoses was accomplished by extensive mobilization of the ends of the injured vessel. Hughes[7] has had excellent results with similar methods in a larger series of cases.

A comparison of the incidence of gangrene following ligation and repair of arterial injuries is given in Table VIII. The improvement in results by repair is evident for all arteries; the most significant groups are

TABLE XI. *The Repair of 7 Vein Injuries.*[1]

Vein Injured	No. of Cases	Method of Repair	Result
Common Femoral	2	1 lateral suture	viable extremity
		1 venous homograft	gangrene
Superficial Femoral	1	lateral suture	gangrene
Popliteal	4	lateral suture	viable extremities

[1] All injuries, except the common femoral injury repaired by lateral suture, had an associated arterial injury that was repaired.

the brachial, femoral, and popliteal arteries. The table does not illustrate the vascular insufficiency that may result in extremities that survive ligation.

The Time Interval Between Injury and Arterial Repair. The time interval is the most significant factor in determining whether an arterial injury can be successfully repaired or not. The relationship between the time interval and gangrene are illustrated in Table IX. Only those injuries requiring a vascular graft or an anastomosis are included. The majority of arterial repairs were completed less than 12 hours after injury.

The time intervals for surviving and gangrenous limbs overlap between nine to ten and 13 to 14 hours. The overlap probably resulted from the amount of collateral circulation that was intact. Because of the overlap, it was not possible to predict from the time interval alone whether an arterial repair would be successful or not. Ten cases were repaired more than 15 hours after injury, with three surviving limbs. Experimental studies by Miller and Welch[2, 12] showed a 90 per cent survival of the extremity when arterial repair was done six hours after injury; the survival declined to 50 per cent for repairs at 12 to 18 hours, and 20 per cent after 24 hours.

The Influence of Fracture on Arterial Injuries. Arterial injuries with an associated compound fracture have been found to have a poor prognosis.[3] The incidence of gangrene in popliteal artery injuries with a compound fracture has approached 100 per cent, as a result of which supracondylar am-

putation has been the initial treatment in many cases. The influence of compound fracture on popliteal and femoral artery injuries is recorded in Table X. Gangrene resulted in only two of 22 femoral injuries without a fracture, but in five of nine injuries with a fracture. Popliteal injuries developed gangrene in three of 12 cases without a fracture, but in six of 11 with a fracture.

There was a total of 11 cases with a fracture that developed gangrene. The gangrene in seven of these cases resulted from the time interval between injury and repair, and in two cases from widespread venous occlusion. There was no indication that the fracture *per se* was the cause of gangrene, and accordingly, there was no indication for primary amputation. The fracture was a manifestation of severe soft tissue injury with widespread destruction of collateral channels, as a result of which the time interval during which a successful arterial repair could be done was much shorter than in cases in which there was some intact collateral circulation.

The Repair of Vein Injuries. Gangrene in three cases with a satisfactory arterial repair seemed to result from massive venous occlusion. Vein injuries in association with arterial injuries were repaired in seven subsequent cases; most of these cases had extensive destruction of collateral venous channels. The cases are summarized in Table XI. All of the four extremities survived in which both the popliteal artery and vein were repaired, but the number of cases is too small to permit any conclusions regarding the value of the venous repair. Postoperative venograms were not made. There were no instances of pulmonary embolism.

SUMMARY

1. Ninety-seven arterial injuries in 85 patients were treated by eight ligations and 89 repairs. Satisfactory repairs were obtained in 87 of the 89 cases. There were six deaths in the postoperative group, two of which may have been related to the arterial surgery.

2. The repairs were done with 44 arterial homografts, three venous autografts, 24 end-to-end anastomoses, and 18 lateral sutures.

3. Rupture or thrombosis was seen in 16 per cent of 44 arterial homografts in the first two weeks postoperatively. Most of these complications were due to preventable causes. Immediate regrafting was successfully done in two cases.

4. The amputation rate was 22 per cent. The incidence of amputation varied with the artery injured, the amount of soft tissue injury, and the time interval between injury and repair. Only one amputation was due to inability to accomplish an arterial repair.

5. The amputation rate for brachial artery injuries was 5 per cent; for femoral artery injuries, 21 per cent; for popliteal artery injuries, 38 per cent.

6. Extremities requiring a vascular graft for repair had an amputation rate of 33 per cent; those repaired by anastomosis, 17 per cent. No amputations resulted from injuries that could be repaired by lateral suture.

7. A definite time interval was not found beyond which arterial repair was futile. The majority of the arterial repairs were completed within 14 hours after injury. Three extremities survived in a group of ten that were repaired more than 15 hours after injury.

8. Back-bleeding was not an infallible criterion as to whether an extremity would survive following arterial ligation. "Good" or "fair" back-bleeding was present in nine of 20 extremities that subsequently became gangrenous.

9. Massive venous occlusion appeared to be the cause of gangrene in three cases. Repair of concomitant venous injuries seemed indicated in extensive popliteal wounds

10. The extremities with the worst prognosis were popliteal artery injuries with severe soft tissue injury, usually in association with compound fracture. The poor prog-

nosis arose from extensive destruction of collateral circulation, which shortened the period of time following injury in which an arterial repair would be successful. No indication was found for primary amputation in such cases.

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