

THE PRIMARY REPAIR OF WOUNDS OF MAJOR ARTERIES

AN ANALYSIS OF EXPERIENCE IN KOREA IN 1953*

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DAMAGE TO BLOOD vessels of the extremities constitutes a small but important component of war wounds. Of 2471 such wounds collected by DeBakey and Simeone² from World War II, 50 per cent of those with involvement of a major artery came to amputation. Ligation of damaged vessels was the accepted practice. They further reported 81 cases in which suture of the artery was performed. In these, the amputation rate was 36 per cent.

Shortly after the beginning of the Korean conflict, Walter Reed Army Hospital was designated as the peripheral vascular surgery center for the Army, and received a substantial number of Army personnel who had sustained traumatic arteriovenous fistulas and aneurysms. The results of reparative and reconstructive surgery of many of these lesions have been reported.^{1, 6, 7} On the basis of this experience, primary repair of damaged major blood vessels of extremities was considered practicable. Personnel trained in the technic of blood vessel repair were sent to Korea as members of the Surgical Research Team of the Army Medical Service Graduate School, and the practicability of repair of major arteries of extremities as part of the definitive surgery of war wounds was established. A total of 130 major vessel injuries were repaired, followed and reported by three members of the Surgical Research Team (Table I).³⁻⁵ The average amputation rate for these 130 vascular repairs was 11 per cent.

Ziperman⁸ analyzed the results of 234 major and minor arterial wounds collected and followed in Korea during the first nine months of 1952. His report includes the work of two members of the Surgical Research Team. He compared the over-all findings in his collected group to the results reported by DeBakey and Simeone, and reported 127 major arteries repaired by suture with an amputation rate of 21 per cent. This represents a 43 per cent decrease in amputation rate; however, both of these series are based on relatively small numbers.

This communication reports an analysis of all major vascular wounds repaired in Korea from January 1 through July, 1953 (exclusive of Navy and Marine personnel), during which time 211 major arterial injuries were detected in 205 patients. Two patients had three vascular injuries each, and two patients had two injuries each. Seventy-two of these vascular injuries (Table I) were treated by the author, and have been reported in detail.³

MATERIALS AND METHODS

Reports on all cases in the Korean theater were centralized in the Office of the Surgeon of the Eighth U. S. Army. They emanated from the forward hospitals in which the surgery was performed, and from the evacuation hospitals through which these patients later passed.

The results are tabulated as immediate and late. Such division has been necessary because this series includes 61 Korean na-

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TABLE I. *Controlled Follow-up Studies: Major Artery Repairs—Korea 1952 and 1953.*

Investigator	Cases	Amputations	
		No.	Per Cent
Jahnke (1952).....	34	3	9
Howard (1952).....	24	3	13
Hughes (1953).....	72	8	11
Total.....	130	14	11

TABLE II. *Major Vascular Injuries—Korea 1953.*

Type of Injury	Number
Lacerated.....	113
Severed.....	89
Contusion and thrombosis..	7
Spasm.....	2
Total.....	211

tional and prisoner of war patients and other United Nations' personnel, many of whom were lost to late follow-up once they left surgical and evacuation hospitals of the U. S. Army. Late follow-up studies were accomplished on other Allied patients as they were returned to vascular centers in Japan, and on American patients as they were returned to Walter Reed Army Hospital, where they were subsequently evaluated by arteriography, oscillometry, skin temperature and exercise tolerance studies.

In this over-all theater total of 211 major vascular injuries, deaths were reported, as occurring from causes other than the arterial injury, in 15 patients with 18 arterial repairs. Arteries involved in these patients were the carotid, 1; axillary, 1; common iliac, 1; femoral (unqualified), 3; common femoral, 2; superficial femoral, 3; and popliteal, 7. Since an adequate evaluation of the arterial repairs in these patients was not possible, these 18 repairs have been eliminated, leaving 193 repaired major vascular injuries in 190 surviving patients.

Regardless of efforts made to follow every patient, 62 of the 193 repairs in surviving patients were lost to long term follow-up studies because of evacuation to Korean or U.N. hospitals after operation. Thus, 193 arterial injuries were available for short term studies and of these, 131 came to later follow-up studies.

Approximately 85 per cent of the vascular wounds were caused by fragmenting missiles and 15 per cent by non-fragmenting missiles. Of all the vessels damaged,

most were lacerated, with almost an equal number severed. Only a few vessels were thrombosed or in spasm (Table II). The lower extremity was the most prevalent site of vascular injury (56 per cent), with the upper extremity a close second (38 per cent), while the neck and trunk received a very low percentage of the injuries. A distribution of injuries is shown in Table III.

Data available from approximately one-third of the patients in this report showed that 40 per cent of the group arrived in shock of varying degree, and 47 per cent of the group had a tourniquet applied for an average of four hours.

Vascular injuries received a high, but not first, priority evacuation unless there was uncontrolled hemorrhage or profound shock which could not be treated prior to evacuation. The average time lag from injury to operation for all cases of vascular injury in 1953 was 9.8 hours, almost identical to that reported in 1952 by Ziperman. Approximately six hours of this time was spent reaching the hospital, and four hours in preparation for surgery. This is a reflection of the degree of injury and shock in these patients.

An anatomical surgical approach was used regardless of location of the wound. An adequate incision was always made and proximal control of the damaged vessel secured first. After excision of the damaged portion of the vessel, repair was accomplished by a continuous mattress suture with 00000 braided arterial silk everting the edges of the artery, apposing intima to intima.

TABLE III. *Total Major Vascular Repairs—Korea 1953.*

Body Region	Artery	Number	Per Cent
Neck	Carotid	7	3
Upper extremity	Axillary	13	38
	Brachial	68	
Trunk	Aorta	1	3
	Common iliac	3	
	External iliac	2	
Lower extremity	Common femoral	12	56
	Superficial femoral	68	
	Popliteal	37	
Total		211	100.0

Most of the repairs (65 per cent) was accomplished by direct anastomosis; with autogenous vein grafts (14 per cent), the second most common type of repair. Lateral suture repair followed in the third place and homologous arterial grafts in the fourth place (Table IV). Conservative non-operative treatment was practiced in some instances of non-expanding pulsating hematomas, especially of the carotid artery. Ligation was utilized only where repair was not feasible in a non-critical artery or when the patient's condition did not permit further surgical procedures.

After careful debridement, care was taken to cover the repaired vessel in order to nourish and protect it, but the wound was left open for drainage and to minimize the risk of infection. Penicillin and streptomycin were used routinely in all patients. Sympathectomy was not practiced and anticoagulants were not utilized. Following operation, only those extremities with complicating fractures were placed in casts. For a period of two weeks only limited active motion was permitted at the vascular repair site. If the wound remained clean, delayed closure was accomplished on the fourth to sixth postoperative day.

RESULTS

Of the total 193 vascular repairs in surviving patients, 26 amputations resulted. These amputations were done following repairs of the axillary artery in two cases,

brachial artery (unqualified), two; femoral (unqualified), four; common femoral, five; superficial femoral, two; and popliteal, 11; most of which are considered as critical arteries. The percentage of amputations was higher in those cases requiring grafts for repairs (Table V).

Causes for amputation were determined where possible. Seven patients were reported as having good blood flow through necrotic muscle at the time of amputation. The muscle had undergone irreversible changes prior to reconstruction of the artery. Thrombosis was responsible for three amputations, compression of the repaired vessel by a displaced compound comminuted fracture was responsible for one amputation, and vanostasis was responsible for another. The reason for amputation in the remaining 14 was not recorded. Of these, five limbs were amputated over varying periods of several days to three months following repair of the damaged artery. In one case reported here as an amputation, the patient lost only four toes, while another had a transmetatarsal amputation.

An attempt was made to correlate the rate of amputation with the presence of compound comminuted fractures but the findings are not significant. As may be expected, however, there was a direct correlation between rate of amputation and size of the wound.

Complications were encountered much less frequently than was expected. Hemorrhage from the suture line was rare. Infection at the repair site, which may result in hemorrhage or thrombosis, was rarely a problem. Latent thrombosis probably occurs more frequently than is realized but the thrombus is often slow in forming, during which time the collateral circulation increases and compensates for the major artery, thereby preventing limb loss.

One of the greatest determining factors in the final results of arterial repair is the time lapse from arterial injury to repair.

Even this can be quite variable, depending on many factors such as size of the wound, number of collaterals involved, level of the artery involved, ambient temperature, severity of shock, and anatomical variations. Although it has been shown that results are proportionally better when arterial repair is done within ten hours of injury, an extremity may undergo irreversible muscle changes much earlier or remain viable much longer, depending on the above factors. The author has previously reported five cases with major arterial injury repaired 11 to 24 hours (an average of 16 hours) after injury. At the time of amputation, all five extremities exhibited good blood flow through necrotic muscles. It was considered that time lag from injury to operation was a significant factor in those five patients.

The time from injury to repair in the 26 patients whose extremities subsequently required amputation varied from one to 24 hours, with a mean of 10.5 hours; almost identical with the average time lag of 9.8 hours recorded for the entire series.

Numerous patients were seen with the injured limb cold, ischemic, anesthetic, and paralytic, with the joints fixed. After arterial repair, as these limbs became warm and sensation and motion returned, they often began to swell, requiring fasciotomy. When fasciotomy was delayed, all degrees of muscle necrosis occurred, varying from microscopic areas of focal necrosis to loss of complete compartments. The flexor compartment of the forearm and the anterior tibial compartment of the leg seemed to be most vulnerable.

SHORT TERM FOLLOW-UP

If analogous groups of cases are compared, after only the limited theater follow-up studies, then we find that there were 127 major artery repairs in 1952, reported by Ziperman, with 26 cases, or 21 per cent, resulting in amputation. Of the 193 major artery repairs with limited follow-up studies in this report from 1953 there were also

TABLE IV. *Types of Repair: Major Vascular Wounds—Korea 1953.**

Repair	Number	Per Cent
Anastomosis.....	125	65
Vein graft.....	28	14
Artery graft.....	11	6
Lateral repair.....	19	10
Conservative.....	4	2
Release spasm.....	2	1
Remove thrombus.....	1	0.5
Ligation.....	3	1.5
Total.....	193	100.0

*Excluding 18 repairs in patients who died.

26 cases, or 14 per cent, which resulted in amputation; an improvement of 34 per cent in limb survival during the last year of the Korean War.

Thrombosis was reported as occurring in 29, or 17 per cent, of the total surviving unamputated patients with limited studies (Table V). No arteriograms were done in these patients during their short term studies. Thrombosis was considered as occurring when no pulse returned following arterial repair, or when a pulse had been present postoperatively and later disappeared. Failure of a pulse to return following operation may have been the result of faulty technic rather than thrombosis but the consequences are the same. Excluding the patients who underwent an amputation or died, thrombosis occurred in 15 per cent of the vessels repaired by direct anastomosis, in 30 per cent of those repaired by autogenous vein grafts, and in 63 per cent of those repaired by homologous artery grafts. Lateral repair resulted in only 6 per cent thrombosis.

LATE FOLLOW-UP STUDIES

Since 62 of the 193 repairs in surviving patients were incompletely followed, only 131 cases in which there were late follow-up studies are reported (Table VI). Counting the same 26 amputations reported in the short term followed group and which remain unchanged for this group of 131 late followed patients, the amputation rate is increased to 20 per cent.

TABLE V. Short-Term Follow-up: Total Major Vascular Repairs—Korea 1953.

Repair	Total No.	No Amputation						Died No.
		Good		Thrombosed		Amputated		
		No.	%*	No.	%*	No.	%	
Anastomosis.....	136	95	85	17	15	13	10.4	11
Vein graft.....	30	14	70	6	30	8	28.6	2
Artery graft.....	12	3	37	5	63	3	27.3	1
Lateral repair.....	20	17	94	1	6	1	5.3	1
Conservative.....	4	4	0			0		0
Release spasm.....	2	1		0		1		0
Remove thrombus.....	1	1		0		0		0
Ligation.....	6	3		0		0		3
Total.....	211	138	83	29	17	26	14	18

*Percentages exclude cases which underwent amputation or died.

An attempt to determine the exact number of thrombosis has been difficult even in this group because it has not been possible to do an arteriogram on every patient. This is a difficult procedure at best, high in the upper extremity. The volume of the pulse distal to the repair site is not always indicative of the condition of the repair. At some levels, collateral vessels are quite adequate or develop quite rapidly. Even though some patients with a poor pulse have been shown by arteriogram to have a patent but constricted repair, all patients with a poor pulse or absence of pulse following operation have been recorded in this report as thrombosed.

Thrombosis was reported in 19, or 18 per cent, of the 105 surviving unamputated patients on whom we have late follow-up studies (Table VI). Of the unamputated patients whose vessels were repaired by anastomosis, 14 per cent thrombosed. Excluding the case amputated, none with lateral repair were reported as thrombosed. In the 21 patients whose vessels were repaired by grafts, 14 autogenous vein grafts and seven homologous artery grafts were used. In this group 36 per cent of the vein grafts thrombosed, compared to 57 per cent of the artery grafts. This percentage was not surprising from previous experience with homologous artery grafts, but it was not ex-

pected that it would be as high with the autogenous vein grafts.

DISCUSSION

Admittedly the Korean War offered many advantages over World War II in regard to vascular repair. During its latter phase the front line was relatively stable. The surgical hospitals were within six to 12 miles of the front, and we had ample air cover plus the advantage of more rapid helicopter evacuation. The expanded antibiotic armamentarium, availability of new vascular clamps, plus the experience gained in vascular surgery since World War II, all contributed to the success of vascular surgery in the Korean War. The Potts ductus and coarctation clamps contributed immensely to the success of the entire vascular surgery program.

Obviously, once an amputation was reported, the late follow-up concerning that patient's extremity was known. By far the highest percent of amputations occurred at the initial installation, and so were reported. While we have 26 amputations, or 20 per cent, reported in 131 late followed surviving patients, this percentage is believed to be too high. The 62 patients who were not counted in this percentage all had viable limbs when lost to follow-up. If these cases are included, making 193 cases with limited studies with the same 26 amputations, then the amputation rate is 14 per cent. This rate

TABLE VI. *Late Follow-up: Major Vascular Repairs—Korea 1953.*

Repair	Total	No Amputation						Died No.
		Good		Thrombosed		Amputated		
		No.	%*	No.	%*	No.	%	
Anastomosis.....	96	62	86	10	14	13	15	11
Vein graft.....	24	9	64	5	36	8	36	2
Artery graft.....	11	3	43	4	57	3	30.0	1
Lateral repair.....	8	6	100	0	0.0	1	14	1
Conservative.....	3	3		0		0		0
Release spasm.....	2	1		0		1		0
Remove thrombus.....	1	1		0		0		0
Ligation.....	4	1		0		0		3
Total.....	149	86	82	19	18	26	20	18

*Percentages exclude cases which underwent amputation or died.

is certain to be low because amputations have been recorded outside of the Korean Theater. The correct amputation rate for the entire series probably ranges between 14 per cent and 20 per cent, or possibly near the mean of approximately 17 per cent.

In order to present an accurate picture of the rate of thrombosis, findings of both the entire group of 193 patients with limited studies, and the followed group of 131 patients, have been presented. Ten thromboses are known to have existed in the 62 patients lost to follow-up. The number of thromboses in the amputated patients is unknown, so the rate of thrombosis is figured for only the living unamputated patients. When rates of thrombosis of the short term followed and late followed groups are compared, they are found to be almost identical (Tables V and VI). If these findings are any criteria to the most satisfactory methods of repair, then the preferred methods are, in order, lateral repair, direct anastomosis, autogenous vein graft and homologous artery graft. However, it must be borne in mind that lateral repair was used for only the simplest lacerations, while the more extensive wounds required a more complicated repair.

Lateral repair should be reserved for only minor, clean-cut lacerations of the artery. Large irregular lacerations are better excised with repair by direct anastomosis.

By the same token, if the damaged area of the vessel is large, it is often wiser to debride thoroughly and insert a graft, rather than to sacrifice important collaterals in order to perform an anastomosis. An anastomosis under undue tension tends to separate or to create spasm with resulting thrombosis.

Even though a number of limbs have come to amputation and others have been crippled by loss of muscle tissue or have complications of nerve injury or compound fractures, the salvage of limbs by repair of acute vascular injuries in Korea has been significant.

SUMMARY

1. An attempt was made to follow every soldier with a major artery repaired in Korea during 1953. These findings are compared to findings reported from Korea during 1952.

2. During 1953 there were 211 major arterial repairs in 205 patients recorded from the Korean War. Death occurred in 15 patients with 18 repairs. Of the surviving patients, 26 required limb amputation.

3. Of the 193 repairs in surviving patients with short term follow-up studies during 1953, amputation resulted in 14 per cent. This is an improvement of 34 per cent over an analogous series of 127 cases with 21 per cent amputations reported from 1952.

4. Sixty-two of the 193 patients were lost to follow-up, leaving 131 with late follow-up studies, of which 26, or 20 per cent, required amputation.

5. The correct amputation rate for the entire series ranges between 14 per cent and 20 per cent, or possibly near the mean of approximately 17 per cent.

6. A comparison of the rates of thrombosis in repairs with short-term studies and those with late studies shows the findings to be almost identical. If absence of thrombosis is an indication of superior methods of repair, then in order of preference they are: lateral repair, direct anastomosis, autogenous vein graft, and homologous artery graft. These results also correlate closely with the severity of the vascular wound.

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