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Limb salvage after vascular reconstruction followed by tissue transfer during the Global War on Terror

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Background: **Combat extremity wounds are complex and frequently require an immediate vascular reconstruction in the operational environment followed by delayed tissue coverage at a stateside medical treatment facility. The purpose of this study was to evaluate limb salvage outcomes after combat-related vascular reconstruction that subsequently required delayed soft tissue coverage during the Global War on Terror.**

Methods: **Patients who incurred a war-related extremity injury necessitating an immediate vascular intervention followed by definitive limb reconstruction requiring flap coverage from combat injuries were reviewed. Patient demographics, types of vascular and extremity injuries, and surgical interventions were examined. Outcomes included limb salvage, primary and secondary graft patency, flap outcomes, and complications. Differences between upper extremities (UEs) and lower extremities (LEs) were compared.**

Results: **From 2003 to 2012, 27 patients were treated for combat-related extremity injuries with an immediate vascular reconstruction followed by delayed tissue coverage. Fifteen LEs and 12 UEs were treated. The mean age was 24 years. An explosion was the cause in 77% of patients, with a mean Injury Severity Score (ISS) of 19. An autogenous vein bypass was the most common reconstruction performed in 20 patients (74%). Other vascular repairs included a primary repair, a patch angioplasty with bovine pericardium, and a bypass with use of a prosthetic graft. Eight patients (30%) had a concomitant venous injury, and 23 (85%) had a bone fracture. Thirty flaps were performed at a mean of 33 days from the original injury. Pedicle flaps were used in 24 limbs and free tissue flaps in six limbs. Muscle, fasciocutaneous, bone, and composite flaps were used for tissue coverage. At a mean follow-up of 16 months, primary patency rates of all arterial reconstructions were 66% in the UE and 53% in the LE ($P = .69$). Secondary patency rates were 100% in the UE and 86% in the LE ($P = .48$). The overall limb salvage rate was 81%. Limb salvage rates were 66% in the LE and 100% in the UE ($P = .04$). Three amputated lower limbs (60%) had inline flow to the foot. The flap success rate was 96%. Reasons for amputation included arterial thrombosis, flap failure, persistent soft tissue infection, osteomyelitis, and debilitating peripheral nerve injuries with associated chronic pain.**

Conclusions: **Immediate vascular repair followed by delayed tissue coverage can be performed with a high (>80%) limb salvage rate after combat trauma. Limb salvage rates were higher in the UE despite equivocally high arterial patency rates. Wounded warriors can expect limb salvage by use of this international algorithm. (J Vasc Surg 2014;■:1-7.)**

The Global War on Terror (GWOT) remains the longest sustained conflict in our nation's history. The mortality during Operation Iraqi Freedom and Operation Enduring Freedom is significantly lower than in previous conflicts. Despite this improvement, service members have endured significant injuries during the past 12 years. Improvised explosive devices and other explosions have been the cause of a significant number of injuries in Iraq and Afghanistan.[1,2]

The treatment of wounded warriors with complex extremity injuries remains challenging. Patients frequently present with extensive surface area wounds with concurrent osseous, nerve, and soft tissue injuries. These technical challenges often coexist with pathophysiologic confounders such as hemodynamic instability, gross contamination, and compromised healing ability. Management uniformly involves immediate stabilization in theater. Isolated distal extremity vascular injuries (tibial, radial, or ulnar arteries) are frequently ligated without significant risk of malperfusion. However, proximal extremity vascular injuries require intervention because of a high risk of ischemia and subsequent limb loss. Patients with concurrent overlying or adjacent soft tissue defects require additional tissue coverage (Fig 1). The optimal management of this group of unique and challenging patients remains understudied.

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Fig 1. Extremities in combat theater often are treated for concomitant vascular injuries and large soft tissue defects.

The purpose of this study was to perform a retrospective review of all patients treated at a military medical treatment facility (MTF) during a 10-year period. Each sustained a complex extremity wound in theater requiring immediate revascularization followed by delayed tissue coverage. Although the feasibility of limb salvage had been established in civilian populations with critical limb ischemia and large tissue defects, this treatment strategy has never been examined in a combat population, with international participation, performed in a staged fashion. Repair type, patency rates, tissue coverage type and technique, and limb salvage rates were reviewed. A comparison between upper extremity (UE) and lower extremity (LE) injuries and outcomes was performed, and differences between outcomes were analyzed.

METHODS

Institutional Review Board approval at Walter Reed National Military Medical Center (WRNMMC) was obtained before this study. A retrospective review of a single institutional database containing consecutively treated combat casualty care patients who sustained extremity injuries necessitating flap coverage from 2003 to 2012 was performed. Informed consent was not obtained before emergency surgeries performed in combat theater; however, it was obtained before definitive reconstruction. All patients were United States service members who were transferred after injuries incurred during combat missions in Operation Iraqi Freedom and Operation Enduring Freedom. Those patients with a vascular injury necessitating a prior vascular intervention in combat theater were reviewed. Patients who underwent immediate distal arterial ligation were excluded. All remaining individuals in the cohort sustained a proximal arterial injury and reconstruction in theater followed by delayed tissue transfer at a stateside MTF. Patients were divided into UE and LE injuries.

Basic demographic data included the patient's age and sex, comorbidities, Injury Severity Score (ISS), and mechanism of injury (MOI). Vascular interventions were reviewed, noting vessel injury, type of repair and conduit when used, subsequent intervention or revision, and patency rates. Tissue coverage procedures were documented, including type of tissue flap, transfer technique used, and donor and recipient sites.

Outcomes measured included primary and secondary arterial patency rates, flap success rates, limb salvage rates, and complications. Primary patency was defined as a reconstruction that remained patent throughout the follow-up period. Secondary patency was defined as an intervention that was patent at the completion of follow-up, including those that required an intervention to maintain or to restore patency. Flap and extremity complications were defined as complications that required operative intervention or a prolonged hospital stay for wound care. Failed limb salvage was defined as an amputation proximal to the ankle or wrist. All amputations in this cohort were secondary amputations.

The type of vascular repair, conduit, and use of a vascular shunt were at the discretion of the combat casualty care operating surgical teams. Soft tissue and orthopedic injuries were typically treated with early surgical débridement and external fixator placement for fracture stabilization. Serial tissue débridements were frequently completed throughout the course of care. The dressing types placed through the various echelons of care were not standardized, although many combat surgeons attempted negative-pressure vacuum-assisted closure dressings when feasible. On arrival to WRNMMC, the injury pattern and course of treatment were reviewed. The tissue reconstruction algorithm was dependent on the tissue defect, coverage options, and donor site availability.

A duplex ultrasound study and physical examination were performed on all patients who had an arterial surgical intervention in combat theater. All revisions were performed before tissue transfer by the vascular surgery team. Concerns for a failing graft included an anastomotic peak systolic velocity of >300 cm/s, velocity ratio >3.5, decreased distal arterial waveforms, or evidence of a technical problem with the graft or anastomosis. Ipsilateral extremity arterial angiography or computed tomographic angiography was performed on all patients before a tissue transfer procedure. This additional study confirmed patency of the vascular repair, examined the extremity distal runoff, and aided in preoperative planning for flap vessel target anastomotic sites. Follow-up consisted of a multidisciplinary approach that included trauma surgery, vascular surgery, plastic surgery, orthopedic surgery, physical medicine, and rehabilitation as well as additional service lines, depending on specific needs of each individual patient. Arterial ultrasound examinations were performed with a standard algorithm consisting of 3-month intervals during the first year, 6-month intervals during the second year, and annually thereafter.

Descriptive variables were compared by Student *t*-test for means. Categorical variables were compared as a proportion by χ^2 or Fisher exact test, as appropriate. Primary and secondary patency rates were also evaluated by Kaplan-Meier plots and compared with log-rank analysis. Significance was defined as two-tailed *P* value ≤ .05. Analysis was performed with IBM SPSS Statistics 22 (IBM Corporation, Armonk, NY).

RESULTS

From 2003 to 2012, 359 limbs in 358 patients presented to WRNMMC after combat extremity injuries requiring tissue transfer for definitive defect coverage. Of these, 273 limbs had no vascular injury. The remaining 86 limbs (24%) had a same-limb vascular injury that had been treated immediately in combat theater. Fifty-nine limbs had a distal arterial injury that was immediately ligated in theater and were excluded. The remaining 27 limbs (31%) in the same number of patients sustained a proximal arterial injury that required an intervention. Injuries occurred in the UEs of 12 patients (44%) and LEs of 15 patients (56%).

Patient demographics are shown in Table I. The mean age of the 27 male patients was 24 years (range, 18-41 years). The mean ISS was 19, and there were no major comorbidities documented in any patient. The MOI was improvised explosive device in 16 patients, other type of explosion in five patients, gunshot wound in three patients, and motor vehicle crash in three patients. Twenty-three patients (85%) sustained a fracture in the injured limb. This was not different between the UEs and LEs. Eight patients sustained documented nerve injuries, all UE injuries. Concomitant venous injuries were identified in nine patients and had a higher incidence in the LE. Three venous injuries were ligated during the initial operation.

All 27 patients sustained a vascular injury requiring intervention (Tables II and III). The brachial artery was the most frequently injured vessel in 10 patients. The remaining two UE injuries occurred in the subclavian artery. The popliteal artery was the most frequently injured LE vessel, requiring intervention in nine patients. The remaining LE arterial injuries occurred in the superficial femoral artery (three), the common femoral artery (two), and the external iliac artery (one). Twenty patients (74%) required a vein bypass to maintain extremity perfusion. The great saphenous vein (GSV) was used for each of these limbs in a reversed configuration. Four patients underwent a primary repair of the artery. Two patients required a prosthetic graft, and one patient underwent a bovine pericardial patch angioplasty repair.

At a mean follow-up of 16 months, the primary patency rate for all arterial reconstructions was 59% and the secondary patency rate was 93%. There was no significant difference between extremity reconstruction patency rates. The UE and LE primary patency rates were not different (66% vs 53%; *P* = .69). Similarly, the secondary patency rates were also not different between the UE and LE (100% vs 87%; *P* = .48). Autogenous bypass primary patency rates were 75% in the UE and 58% in the LE and were not different (*P* = .64). The secondary patency rates of 100% in the UE and 92% in the LE were also not different (*P* = 1.00). Life-table analysis revealed no difference in primary patency (*P* = .34) or secondary patency (*P* = .19) rates between UEs and LEs (Fig 2).

Table I. Patient demographics

	UE (n = 12), No. (%)	*LE (n = 15), No. (%)*	P *value*
Male	12 (100)	15 (100)	NS
Age, years	23	25	NS
Mean comorbidities	0	0	NS
MOI			
IED	9 (75)	7 (46)	NS
Other explosion	1 (8)	4 (26)	NS
GSW	1 (8)	2 (13)	NS
MVC	1 (8)	2 (13)	NS
ISS	19.2	18.8	NS
Fracture	10 (83)	13 (86)	NS
Nerve injury	8 (66)	0 (0)	<.001
Venous injury	2 (16)	6 (46)	NS

GSW, Gunshot wound; *IED,* improvised explosive device; *ISS,* Injury Severity Score; *LE,* lower extremity; *MOI,* mechanism of injury; *MVC,* motor vehicle crash; *NS,* not significant; *UE,* upper extremity.

Four patients with GSV bypasses required revisions for various reasons. Two patients with a primary arterial repair required a subsequent revision. A pseudoaneurysm repair, an open graft thrombectomy and revision, and a percutaneous angioplasty were each performed in individual patients. Two patients had failed grafts. One patient with a prosthetic common femoral artery to contralateral superficial femoral artery bypass became infected, necessitating explantation. A second patient with an LE GSV bypass sustained a graft blowout on postoperative day 10, which required ligation.

Delayed tissue coverage procedures were performed for each patient at a stateside MTF at a median of 19 days from the injury. Thirty flaps were performed in 27 patients. Three patients with multiple LE wounds received separate coverage procedures on the same limb. Pedicle flaps were performed in 24 limbs and were the most common type of transfer technique used. Free tissue flaps were used in six limbs. Nineteen muscle flaps, 10 fasciocutaneous flaps, and one bone flap were used for extremity coverage. Three patients required composite flaps.

Flap complications occurred in five patients (18%). Two patients sustained an LE flap failure secondary to venous thrombosis or infection. Partial necrosis, flap infection, and a flap hematoma also occurred in three individuals. Non-flap complications occurred in 17 patients (62%) and were more frequent in the LEs. These included donor site hematoma, osteomyelitis, persistent soft tissue infection, chronic pain, lymphedema, and heterotopic ossification.

The overall limb salvage rate was 81%. The UE salvage rate of 100% was significantly higher than the LE salvage rate of 66% (*P* = .047). Reasons for the five LE amputations were frequently multiple and included malperfusion, flap failure, persistent soft tissue infection, and osteomyelitis. Three patients who required an amputation had a

Table II. Upper extremity (UE) injuries and outcomes

Patient	*MOI*	*Vessel injured*	*Intervention*	*Primary patency*	*Secondary patency*	*Transfer type*	*Salvage*
1	IED	Brachial	Primary	No	Yes	Pedicle	Yes
2	MVC	Brachial	rSVG	Yes	Yes	Pedicle	Yes
3	IED	Brachial	rSVG	Yes	Yes	Pedicle	Yes
4	IED	Brachial	PTFE	No	Yes	Pedicle	Yes
5	IED	Brachial	Bovine patch	Yes	Yes	Free	Yes
6	RPG	Brachial	rSVG	Yes	Yes	Pedicle	Yes
7	IED	Brachial	rSVG	No	Yes	Pedicle	Yes
8	GSW	Brachial	rSVG	Yes	Yes	Free	Yes
9	IED	Subclavian	rSVG	Yes	Yes	Pedicle	Yes
10	IED	Brachial	rSVG	No	Yes	Free	Yes
11	IED	Brachial	rSVG	Yes	Yes	Pedicle	Yes
12	IED	Subclavian	Primary	Yes	Yes	Pedicle	Yes

GSW, Gunshot wound; *IED,* improvised explosive device; *MOI,* mechanism of injury; *MVC,* motor vehicle crash; *PTFE,* polytetrafluoroethylene; *RPG,* rocket-propelled grenade; *rSVG,* reversed saphenous vein graft.

Table III. Lower extremity (LE) injuries and outcomes

Patient	*MOI*	*Vessel injured*	*Intervention*	*Primary patency*	*Secondary patency*	*Transfer type*	*Salvage*
1	Mortar	Popliteal	rSVG	No	Yes	Pedicle	No
2	RPG	Popliteal	Primary	Yes	Yes	Pedicle	Yes
3	MVC	CFA	rSVG	No	Yes	Pedicle	Yes
4	IED	Popliteal	rSVG	Yes	Yes	Pedicle	Yes
5	IED	Popliteal	rSVG	Yes	Yes	Pedicle	Yes
6	GSW	EIA	PTFE	No	No	Pedicle/pedicle	No
7	IED	Popliteal	rSVG	Yes	Yes	Free	Yes
8	MVC	SFA	rSVG	Yes	Yes	Pedicle	Yes
9	IED	Popliteal	rSVG	No	No	Pedicle	No
10	IED	CFA	rSVG	Yes	Yes	Free/pedicle	Yes
11	IED	SFA	Primary	No	Yes	Pedicle	No
12	RPG	Popliteal	rSVG	No	Yes	Pedicle	No
13	GSW	SFA	rSVG	Yes	Yes	Pedicle	Yes
14	IED	Popliteal	rSVG	Yes	Yes	Free	Yes
15	Mortar	Popliteal	rSVG	No	Yes	Pedicle/pedicle	Yes

CFA, Common femoral artery; *EIA,* external iliac artery; *GSW,* gunshot wound; *IED,* improvised explosive device; *MOI,* mechanism of injury; *MVC,* motor vehicle crash; *PTFE,* polytetrafluoroethylene; *RPG,* rocket-propelled grenade; *rSVG,* reversed saphenous vein graft; *SFA,* superficial femoral artery.

patent surgical intervention and maintained inline flow to the foot. The MOI was an explosion in 80% of patients who progressed to a secondary LE amputation.

DISCUSSION

Combined revascularization and tissue coverage is not a new concept or approach. The need for adequate perfusion followed by tissue transfer has been acknowledged as a viable option for patients with extremity tissue defects or nonhealing ulcers. Previous reports have focused largely on patients with critical limb ischemia, the large majority with peripheral vascular disease and diabetes.[3-7]

Our population of patients is different from that of prior studies. We report a unique experience examining a young healthy population of combat warriors who required an immediate arterial reconstruction in theater followed by delayed coverage at a stateside MTF. Unlike in previous conflicts, the most common injury mechanism in the GWOT has been blast injury secondary to explosions. The physiologic disturbances caused by explosions are numerous.[8-10] The auditory, pulmonary, and central nervous systems remain at greatest risk for injury from explosions.[11,12] However, the risks of explosives to a nonmangled extremity are less studied and may have underappreciated long-term consequences.

Our limb salvage rate of 81% was not different from that of other studies. However, the finding that all five amputations occurred in the LE was a notable outcome. The ISS scores were not different between patients who suffered UE and LE injuries. This is a nonspecific marker of injury severity. There were seven venous injuries in the LE, but only two were identified in the UE. A venous injury may be a surrogate for extent of limb injury and was lower than in other reports.[13] Of the five amputated LEs, three had venous injuries, one of which was ligated in theater. Conversely, eight UEs had concomitant nerve injuries. There were no documented LE nerve injuries, including the five amputated limbs. Factors that may

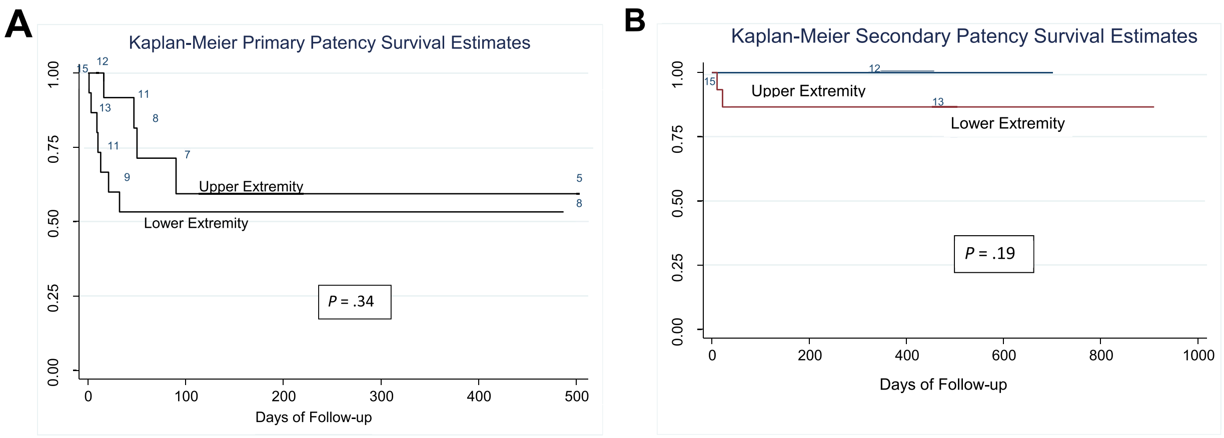

Fig 2. A, Extremity vascular reconstruction primary patency rates. **B,** Extremity vascular reconstruction secondary patency rates.

explain this phenomenon include the greater soft tissue and muscle mass in the LE compared with the UE. Patients with identified LE nerve injuries may have been treated with preferential primary amputation, whereas those with isolated vascular injury underwent attempted limb salvage. Eighty-five percent of patients in our cohort had concomitant bone fractures in the affected limb. Fractures have been shown to increase the risk of complications and limb loss, both historically and in the current GWOT.[14,15] However, there were a significant number of fractures in both the UE and LE, so this alone cannot explain the difference in limb salvage rates.

Instead, the five patients who progressed to LE amputation did so for a variety of and frequently multiple reasons. Infection remains one of the greatest risks to wounded warriors after combat trauma.[16,17] Nine patients in this cohort were treated for soft tissue infection, osteomyelitis, or both. One patient with a distal external iliac artery injury who underwent a common femoral artery to contralateral superficial femoral artery bypass with polytetrafluoroethylene became infected. This patient subsequently required a hip disarticulation. A second patient sustained a GSV bypass blowout, presumably secondary to an anastomotic infection. This was ligated, and the patient required an above-knee amputation. Two patients sustained either partial or total flap necrosis that led to amputations. Two patients had persistent soft tissue infections and osteomyelitis. The final patient underwent a pedicle flap reconstruction to the foot and subsequent amputation for unknown reasons, possibly from poor quality of life, chronic pain, or difficulty in ambulating.

The MOI in four of the five amputees was an explosion. The destruction that occurs after a high-blast explosion is immense. We hypothesize that LEs remain at an increased risk of injury from open air explosions. Shock limb, a concept that is yet to be described in the literature, is the theory that significant vasospasm and occult soft tissue injury follow severe blast exposure. This is frequently not recognized at the point of injury, and the long-term sequelae may go unrecognized for months to years. It may increase the risk of future infection, chronic pain, heterotopic ossification, and secondary amputation. The force of the primary blast wave decreases exponentially as the distance from the explosion increases. This may explain why shock limb is more prevalent in LEs. More research is needed on the acute and long-term sequelae of explosions on the vascular system.

The majority of patients (74%) had an autogenous bypass performed with GSV. This was not surprising, given the significant soft tissue destruction that is frequently associated with extremity injuries after explosions. Frequently, large vascular defects accompany such injury patterns. The primary patency rates of the UE (75%) and LE (58%) autogenous bypasses were lower than expected and can likely be explained by several factors. Bypasses performed in theater are performed under suboptimal conditions with patients who are frequently anemic, hypothermic, and acidotic. The decision for primary amputation vs vascular reconstruction and attempted limb salvage is a challenging one, and each patient must be considered individually. However, most surgeons attempt limb salvage unless the patient is in extremis or has other injuries that preclude such an undertaking. Surgeons performing bypasses in combat theater may not be vascular trained and may be less familiar with extra-anatomic tunneling routes necessary for large tissue defects. Finally, repeated washouts and tissue débridements are necessary as the patient advances through the echelons of care.[18-20] This reflects a more significant burden of injury but may also increase the risk of early thrombosis of bypasses performed in theater.

The high secondary patency rates were likely secondary to an aggressive paradigm implemented on arrival to WRNMMC. Each patient presenting with an extremity arterial reconstruction performed in theater had an early ultrasound examination performed in a dedicated vascular laboratory. This allowed early detection of an arterial abnormality and ensured return to the operating room or interventional suite in an expeditious manner. Subsequent angiography or computed tomographic angiography was performed on every patient considered for a tissue coverage procedure. This allowed detection of a surgical problem as well as assisted in preoperative planning.

Our study is limited by its small sample size and retrospective nature. As with all treatment administered during the GWOT, there was likely considerable variation in the types of procedures performed at individual MTFs. Clinical practice guidelines are administered in combat theater; however, the implementation depends on the available resources and skill set of the surgeons.

The ISS was available and used for this study; however, it does not represent the best marker for extremity injury. Despite concerns about its reliability and reproducibility, the Mangled Extremity Severity Score has been validated in previous reports.[21,22] It was not available for this cohort but could be useful in future analyses.

Finally, functional outcomes were not measured in this cohort. The decision of amputation vs reconstruction has been reviewed in other studies and is particularly salient in this population.[23-25] Future studies from this group and others should continue to emphasize the need for comprehensive evaluations with respect to quality of life measures after revascularization in patients with limb salvage.

CONCLUSIONS

This study examined outcomes of a combat population who underwent immediate vascular reconstruction followed by delayed tissue coverage at a military MTF. In properly selected patients, a high rate of limb salvage (81%) with use of a standardized treatment algorithm can be expected and may aid in consultation with the patient. Primary and secondary vascular patency rates and successful soft tissue reconstruction rates were high in both UEs and LEs. Nonetheless, the risk of LE amputation was higher. The majority of patients did not progress to limb loss secondary to a dysvascular limb. Future studies will focus on identifying factors that improve short- and long-term outcomes from improvised explosive devices and other explosions.

AUTHOR CONTRIBUTIONS

Conception and design: KC, JS, IV
Analysis and interpretation: KC, JS, JW, IV
Data collection: KC, JS, IV
Writing the article: KC, AK, IV
Critical revision of the article: KC, JW, AK, IV
Final approval of the article: KC, JS, JW, AK, IV
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