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# Patency of arterial repairs from wartime extremity vascular injuries

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Two abstracts describing the (1) 527 Veteran cohort and the (2) cohort with patency data were accepted at the 2020 Vascular Annual Meeting of the Society for Vascular Surgery, 17–20 June 2020, in Toronto, Ontario, Canada (not presented due to COVID-19).

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## ABSTRACT

**Background** Extremity vascular injury (EVI) causes significant disability in Veterans of the Afghanistan/Iraq conflicts. Advancements in acute trauma care improved survival and decreased amputations. The study of wartime EVI has relied on successful limb salvage as a surrogate for vascular repair. We used imaging studies as a specific measure of arterial repair durability.

**Methods** Service members with EVI were identified using the Department of Defense Trauma Registry and validated by chart abstraction. Inclusion criteria for the arterial patency subgroup included an initial repair attempt with subsequent imaging reports (duplex ultrasound, CT angiography, and angiogram) documenting initial patency.

**Results** The cohort of 527 included 140 Veterans with available imaging studies for 143 arterial repairs; median follow-up from injury time to last available imaging study was 19 months (Q1–Q3: 3–58; range: 1–175). Injury mechanism was predominantly explosions (52%) and gunshot wounds (42%). Of the 143 arterial repairs, 81% were vein grafts. Eight repairs were occluded, replaced or included in extremity amputations. One upper extremity and three transtibial late amputations were performed for chronic pain and poor function averaging 27 months (SD: 4; range: 24–32). Kaplan-Meier analysis estimated patency rates of 99%, 97%, 95%, 91% and 91% at 3, 6, 12, 24, and 36 months, respectively, with similar results for upper and lower extremity repairs. Explosive and gunshot wound injury mechanisms had similar patency rates and upper extremity injuries repaired with vein grafts had increased patency.

**Conclusions** Arterial repair mid-term patency in combat-related extremity injuries is excellent based on imaging studies for 143 repairs. Assertive attempts at acute limb salvage and vascular repair are justified with decisions for amputation versus limb salvage based on the overall condition of the patient and degree of concomitant nerve, orthopedic and soft tissue injuries rather than the presence of arterial injuries.

**Level of evidence** Therapeutic/care management, level IV.

## BACKGROUND

The increasing prevalence of combat-related extremity vascular injuries (EVI) in service members in the Afghanistan and Iraq wars<sup>1</sup> poses a significant challenge due to the complex, long-term health-care needs of these Veterans.<sup>2–5</sup> Injury severity has increased secondary to the predominance of explosive injuries.<sup>4 6 7</sup> Improvements in battlefield care improved survival in Operation Enduring Freedom/

Operation Iraqi Freedom/Operation New Dawn (OEF/OIF/OND) over the course of the wars.<sup>8 9</sup> While multiple reports document the acute care and describe limb salvage rates of patients with EVI in civilian<sup>10–19</sup> and combat<sup>1 10 20–25</sup> settings, no reports include long-term patency of EVI repairs.

Early studies of long-term graft patency after civilian EVI either did not specify method of patency determination or used physical examination and wrist/ankle-brachial indices to assess patency.<sup>16 18 26–31</sup> Recent studies<sup>32 33</sup> using duplex ultrasound reported upper (97% to 97.6%) and lower (98.3%) extremity patency at a median follow-up of 64<sup>32</sup> and 72<sup>33</sup> months. Both studies excluded early graft failures, amputations and inpatient mortality from the long-term patency results. Civilian studies more commonly report long-term limb salvage after EVI rather than arterial repair patency. However, functional outcomes of claudication and the ability to participate in vigorous physical activity in addition to limb salvage may be especially important in younger trauma patient population after EVI. Upper limb salvage rates more than 1 year after injury ranged from 86% to 100%, primarily after blunt or penetrating trauma.<sup>16 18 27 30–32 34</sup> Long-term lower limb salvage rates, excluding early amputations, ranged from 98% to 100%.<sup>27 33</sup>

Studies of EVI in OEF/OIF/OND service members reported long-term lower limb salvage rates of 74% to 82.7%<sup>3 4</sup> with higher rates of limb salvage after gunshot compared with explosive injuries.<sup>4</sup> Among previous OEF/OIF/OND studies, early upper extremity amputation rates ranged from 9.3% to 12.1%.<sup>24 35</sup> Late amputations, defined as >30 days after injury, occurred in 6.4% of lower extremities.<sup>3</sup> In contrast to civilian EVI, explosive injuries predominated in OEF/OIF/OND. While these studies report the durability of limb salvage after combat-related EVI, all previous reports relied on successful limb salvage rather than assessing arterial repair patency. A recent RAND review of limb salvage and recovery after blast injury concluded that there was very limited research on blast-related injuries to the extremities and subsequent limb salvage.<sup>36</sup> Mid-term and long-term patency for combat-related EVI repairs is unknown and may be an important outcome beyond limb salvage for this younger patient cohort likely wishing to return to more demanding physical activity levels.

To address this knowledge gap, the VA Vascular Injury Study (VAVIS)<sup>37 38</sup> identified service members with EVI and used imaging studies to determine

patency of arterial repairs in upper and lower extremities after combat-related traumatic injury. Given the predominance of explosive injuries in combat trauma and the decreased lower limb salvage rates of explosive compared with gunshot wounds,<sup>4</sup> our working hypotheses were (1) lower extremity arterial repair patency would be decreased after combat-related explosive compared with gunshot injuries, and (2) arterial repair patency would be decreased in combat versus civilian populations. This study characterizes the anatomic distribution of EVI in a wartime cohort and is one of the first to use imaging study reports to quantify the durability of arterial repairs after combat-related EVI compared with civilian samples.

## METHODS

### Data sources and sample

Our cohort included OEF/OIF/OND service members receiving Veterans Health Administration (VHA) care (Fiscal Year 2002–2014) with EVI who underwent an initial attempt at limb salvage. Participants were identified using the Department of Defense Trauma Registry (DoDTR; formerly Joint Theater Trauma Registry),<sup>39</sup> injuries were validated using chart abstraction, and data merged with VHA data. Chart abstraction was completed in August 2018 serving as the end date for additional imaging studies. EVIs treated with amputation during the initial surgery were excluded as operative reports detailing the injuries were not uniformly available for review. Injury Severity Score/Abbreviated Injury Scale (ISS/AIS),<sup>40–41</sup> mechanism of injury, injury type, and date of injury (month/year) were derived from the DoDTR; location of injury (upper/lower extremity, venous/arterial) and method of repair were abstracted. Repairs were categorized as vein or prosthetic grafts, vein or prosthetic patches, primary repairs, stents or unknown when information was insufficient.

### Primary outcome

Arterial and venous repair patency was assessed from duplex ultrasound, CT angiography (CTA), MR angiography (MRA) and angiogram reports from DoD and VHA available for a subset of the cohort; imaging studies were not available for review. Imaging reports were reviewed by general surgery resident or vascular surgery fellow and confirmed by a board-certified vascular surgeon to determine repair patency, location of injury and repair type. Imaging report results were included when the graft or area of repair was specifically stated to be either patent or occluded, equivocal reports were excluded. Time-to-repair and graft occlusion was defined as an imaging study or clinical note documenting thrombosis, replacement of a graft or the area of arterial repair being included in an amputation. Health records for procedures and tests occurring within combat zones were incomplete and limited to month and year. Therefore, arterial repairs were included when imaging studies documented initial patency; the patency analysis excludes acute repair occlusions, amputations and repairs performed in patients with mortality during the acute treatment phase. We used the following periods to define follow-up: *short term* encompasses the first 30 days to 6 months of follow-up; *mid-term* refers to 6 months to 5 years; *long term* denotes more than 5 years.<sup>42</sup>

Initial, short-term placement of prosthetic grafts with subsequent revision to a vein graft was defined as a temporizing procedure, and the patency of the vein graft was reported.<sup>43</sup> Imaging studies documenting repair patency, even if stenoses or other issues were identified, were defined as patent. Overall patency was reported since primary, primary-assisted or secondary status could not be consistently determined. Dates were recorded as

only month and year; therefore, late amputations were defined as occurring >3 months after injury.

### Statistical analysis

We described the VAVIS cohort using frequencies (percent) for categorical variables and means (SD) or medians (quartile 1 to quartile 3) for continuous variables. Two-sample t-test or Kruskal-Wallis test was used among patients with arterial injury to compare continuous variables for those with and without patency data;  $\chi^2$  test and Fisher's exact test compared categorical variables. Distributions (frequency) of injury characteristics were summarized for EVI in the 527-person VAVIS cohort.

Time to patency and arterial injury repair data were summarized for upper and lower repairs among 140 patients with patency data. Separate Kaplan-Meier estimates were obtained to characterize patency rates for upper and lower extremity arterial repairs. Log-rank tests compared patency rates between upper and lower extremity repairs and injury mechanism. Cox regression models estimated the patency rate in association with repair type, injury mechanism and upper versus lower extremity injuries. Patency data from the Medical University of Innsbruck in civilian trauma patients<sup>32–33</sup> were compared with comparable descriptive statistics from appropriate VAVIS subgroups using Stata immediate tests (StataCorp, College Station, Texas).

## RESULTS

### VAVIS cohort

The 527 service members with EVI and an initial attempt at limb salvage (table 1) had a median age at time of injury of 23 (Q1–Q3: 21–27, range: 18–56 years) and >98% were male. The distribution of race was 82% White, 6% African American, 3% Asian and 10% Hispanic. Explosive injury mechanism was most common (63%), with gunshot wounds accounting for 32%; 73% were penetrating versus 27% blunt injuries. The ISS median was 13.0 (Q1–Q3: 10–21, range: 1.0–59.0) comprising 60% minor, 25% moderate, and 15% severe injuries. AIS extremities included 12% moderate—2, 67% serious—3, and 17% severe—4.

The service members experienced 741 vascular injuries (table 2): 317 arterial and 140 venous lower extremity injuries, and 246 arterial and 38 venous upper extremity injuries. Brachial (43%), radial (24%), and ulnar (21%) arteries and brachial (37%) veins were most frequently injured in the upper extremity. Superficial femoral (29%), tibial (25%), and popliteal (25%) arteries and superficial femoral (28%) and popliteal (23%) veins were the most common lower extremity injuries. All 527 service members were alive on discharge from the service with >99% surviving 5 years after injury. Forty percent were diagnosed with traumatic brain injury (TBI) within 5 years of injury including 14% with moderate, severe or penetrating TBI.

### Subset of VAVIS cohort with patency data

From the VAVIS cohort of 527 patients, 37 had venous-only injuries and 490 had arterial injuries. Imaging studies to assess patency were available for 143 arterial repairs in 140 service members (figure 1). Forty-eight Veterans had an arterial repair in one arm, 89 in one leg, and three in bilateral legs. The 140 service members had a median age at time of injury of 23 years (Q1–Q3: 21–28, range: 18–56 years) with an ISS median 14.0 (Q1–Q3: 10–22, range: 4–50) and AIS extremities distribution of 7% moderate—2, 65% serious—3, and 28% severe—4. Characteristics of the 140 patients with arterial and the 350 patients without arterial imaging studies were similar, except that ISS ( $p=0.04$ ), AIS extremities ( $p<0.001$ ), VHA-rated disability and

**Table 1** Characteristics of VAVIS cohort and service members with arterial injuries with and without patency data

	VAVIS cohort	Subset with arterial injuries (490)		P value
		Patency data	No patency data	
n (%)	527 (100)	140 (29)	350 (71)	
Age at injury, median (Q1–Q3)	23 (21–27)	23 (21–28)	23 (21–27)	NS
Education				NS
High school	445 (84)	115 (82)	301 (86)	
Some college	66 (13)	21 (15)	37 (11)	
Other	16 (3)	X (<3)	12 (3.0)	
Military operation				NS
OEF	175 (33)	54 (39)	106 (30)	
OIF/OND	348 (66)	85 (61)	241 (69)	
Military service				NS
Army	357 (68)	90 (64)	239 (68)	
Marines	149 (28)	43 (31)	100 (29)	
Air Force/Navy/Coast Guard	21 (4)	X (5)	11 (3)	
Service rank—enlisted	503 (95)	131 (94)	338 (97)	NS
AIS extremities				<0.001
Minor (1)	17 (3)	0	14 (4)	
Moderate (2)	64 (12)	10 (7)	46 (13)	
Serious (3)	352 (67)	91 (65)	236 (67)	
Severe (4)	89 (17)	39 (28)	49 (14)	
Critical (5)	5 (1)	0	X (<2)	
ISS composite, median (Q1–Q3)	13 (10–21)	14 (10–22)	12.5 (10–20)	0.04
Minor (1–15)	314 (60)	73 (52)	221 (63)	
Moderate (16–25)	132 (25)	46 (33)	75 (21)	
Severe (26–50)	80 (15)	21 (15)	53 (15)	
Critical (51–75)	X (<1)	0	X (<1)	
Mechanism of injury				<0.03
Explosive	331 (63)	73 (52)	232 (66)	
Gunshot wound	168 (32)	59 (42)	99 (28)	
Other	28 (5)	8 (6)	19 (5)	
Discharge disability*	343 (65)	97 (69)	225 (64)	NS
%VA disability, median (Q1–Q3)	90 (80–100)	100 (80–100)	90 (80–100)	<0.05

\*Service members discharged due to disability.

AIS, Abbreviated Injury Scale; ISS, Injury Severity Score; NS, not significant; OEF, Operation Enduring Freedom; OIF, Operation Iraqi Freedom; OND, Operation New Dawn; Q1–Q3, first and third quartiles; VA, Veterans Affairs; VAVIS, VA Vascular Injury Study.

gunshot wound mechanism of injury were higher in patients with imaging studies.

The estimated patency rates were 99%, 97%, 95%, 91% and 91% at 3, 6, 12, 24, and 36 months, respectively, with similar results for upper and lower extremity repairs (figure 2A–C); median follow-up was 19 months (Q1–Q3: 3–58; range: 1–175). Concomitant vein, nerve and bone injuries were common (table 3). Vein grafts constituted 82% of the repairs and had a similar estimated patency of 93% compared with 81% for all other repairs. Predominant injury mechanisms were explosive (52%) and gunshot (42%) with similar estimated patency rates (figure 3A; 93% and 89%).

### Upper extremity arterial patency cohort

Forty-eight arterial repairs were performed in the upper extremities (table 3) consisting of 43 vein grafts with one each of a vein patch, prosthetic graft and stent, and two unknown. Imaging modalities of the last report used to determine arterial repair patency or occlusion included 42 duplex, 5 CTA and 1 angiogram. Occlusions occurred in three upper extremity arterial

repairs with concomitant nerve, but not venous injuries, from gunshot wounds: (1) brachial artery vein graft repair injury with fasciotomy was emergently replaced 3 months after the initial procedure, (2) a subclavian/axillary artery covered stent required several endovascular interventions with duplex findings of in-stent stenosis and occluded 31 months after initial placement, and (3) a brachial artery prosthetic graft repair was patent at 5 months and occluded at 8 months. One late arm amputation occurred 24 months after an open humerus fracture and nerve injuries with a patent brachial artery vein graft repair at 22 months after injury; graft patency at the time of amputation was undocumented.

Upper extremity arterial repair estimated patency was 92% with median follow-up of 18 months (Q1–Q3: 5–58; table 3 and figure 2B). Concomitant vein injuries occurred in 13% of the arterial injured upper extremities; 50% were treated by ligation. Nerve injuries (63%) were more common than bone fractures (31%). Vein grafts constituted 90% of the repairs and had a patency of 97% compared with 33% for all other repairs ( $p<0.001$ ; only five repairs were in this group). Predominant



**Table 2** Distribution of upper and lower extremity vascular injuries in VAVIS cohort of 527 service members

**Upper extremity vascular injuries**

Arterial injuries		Venous injuries	
Veterans (n)	227	Veterans (n)	35
Extremity affected (n)		Extremity affected (n)	
Left	132	Left	18
Right	114	Right	20
Left only	119	Left only	15
Right only	106	Right only	19
Bilateral	2	Bilateral	1
Artery injured (n)		Vein injured (n)	
Subclavian	2	Subclavian	1
Axillary	15	Axillary	9
Brachial	106	Brachial	14
Radial	58	Radial	1
Ulnar	51	Ulnar	3
Hand	1	Superficial	7
Unspecified	13	Unspecified	3
Total arteries	246	Total veins	38

**Lower extremity vascular injuries**

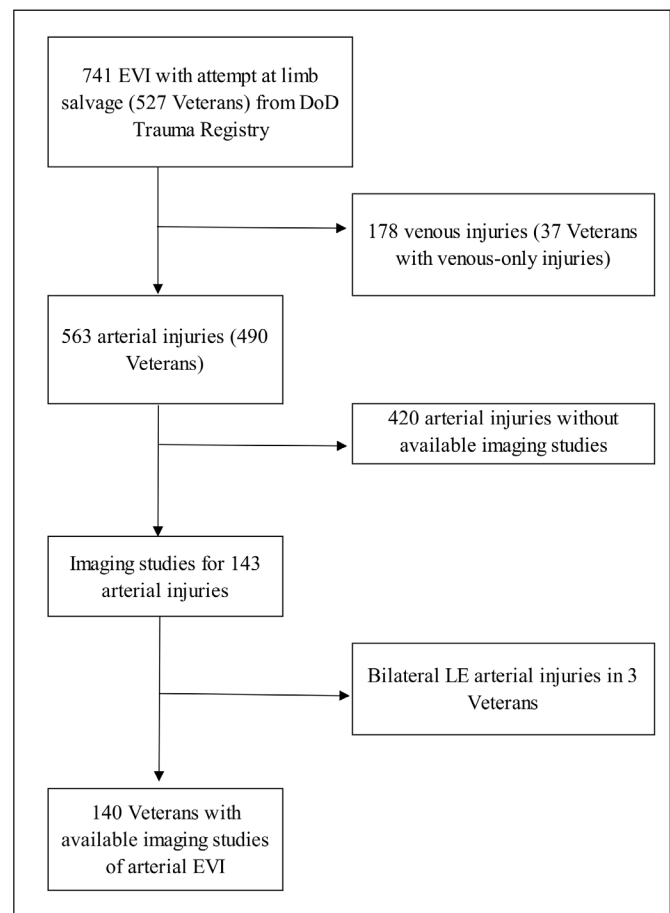
Arterial injuries		Venous injuries	
Veterans (n)	278	Veterans (n)	119
Extremity affected (n)		Extremity affected (n)	
Left	162	Left	71
Right	155	Right	69
Left only	134	Left only	55
Right only	131	Right only	58
Bilateral	13	Bilateral	6
Artery injured (n)		Vein injured (n)	
Common femoral	11	External iliac	2
Profunda femoral	9	Common femoral	14
Superficial femoral	93	Profunda femoral	4
Femoral branch	2	Superficial femoral	39
Femoral unspecified	24	Femoral branch	1
Popliteal	78	Femoral unspecified	5
Tibial/peroneal	79	Popliteal	32
Sural	1	Tibial/peroneal	21
Dorsalis pedis	2	Medial plantar	1
Medial plantar	1	Saphenous	12
Unspecified	17	Unspecified	9
Total arteries	317	Total veins	140

VAVIS, VA Vascular Injury Study.

injury mechanisms were gunshot (48%) and explosive (44%) with similar estimated patency rates of 85% and 100%, respectively (figure 3B).

### Lower extremity arterial patency cohort

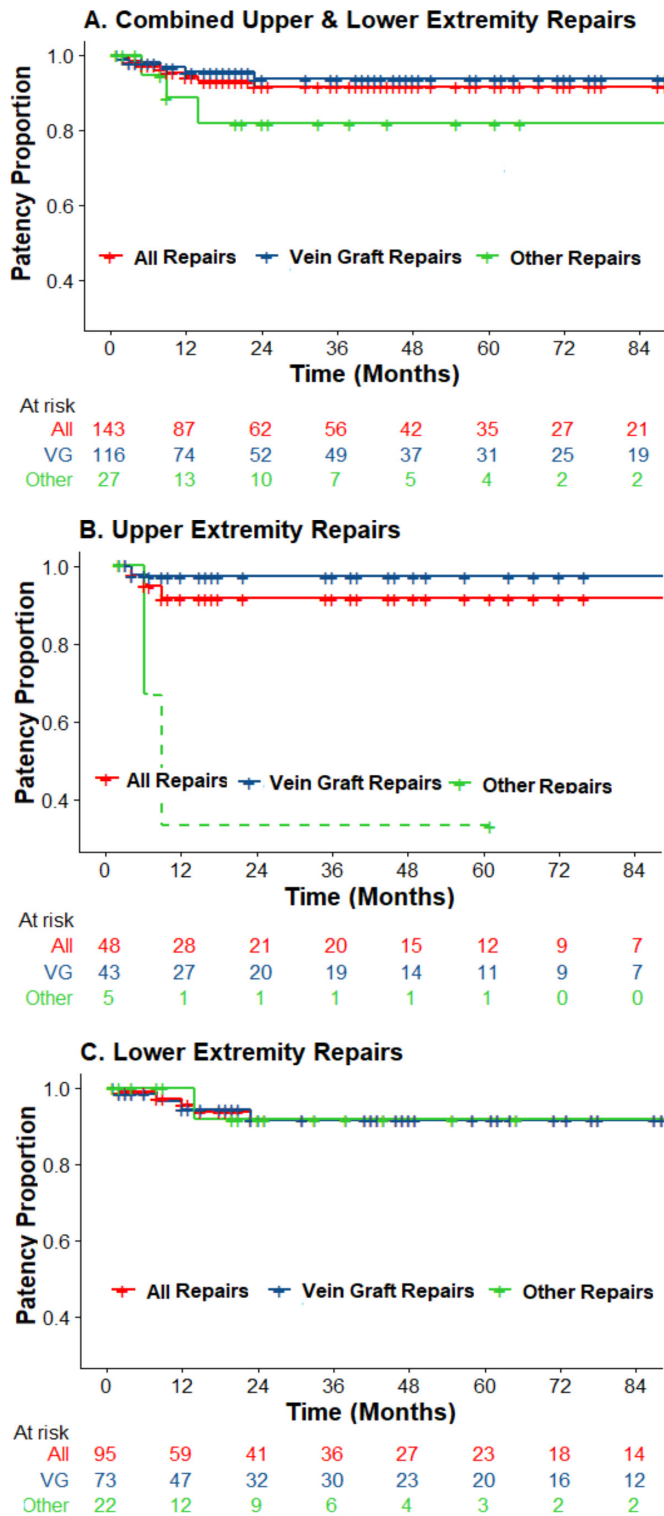
Of the 143 arterial repairs, 95 were performed in the lower extremities including 73 vein grafts, 2 vein patches, 4 prosthetic grafts, 4 primary repairs and 12 unknown. Imaging modalities of the last report used to determine arterial repair patency or occlusion included 76 duplex, 12 CTA, 5 angiogram and 2 MRA. Occlusions occurred in five lower extremity arterial repairs: (1) a common femoral artery prosthetic



**Figure 1** Patient cohort for extremity arterial repair patency data. The diagram describes the numbers of arterial repairs and reasons for exclusions for extremity vascular injuries (EVI). We identified 741 EVIs in 527 Veterans using the Department of Defense (DoD) Trauma Registry with an initial attempt at limb salvage and confirmed by chart abstraction. Venous injuries accounted for 178 of the EVIs, 37 Veterans had venous-only injuries. Of the 563 arterial injuries in 490 Veterans, only 143 arterial repairs had available imaging studies in 140 Veterans. LE, lower extremity.

graft was replaced by a vein graft at 12 months secondary to stenosis, (2) a posterior tibial artery venous interposition graft was patent at 12 months; the patient underwent a transtibial amputation at 24 months for malalignment of tibia/fibula fractures, (3) a superficial femoral-to-popliteal artery vein graft occluded at 8 months and a subsequent vein bypass was patent at 54 months, (4) a transfemoral amputation for muscle necrosis with a patent interposition popliteal artery vein graft, venous injuries and fasciotomies, the month after injury, and (5) a popliteal artery interposition vein graft and fasciotomies had a stenosis identified by duplex at 23 months; subsequent angiogram showed occlusion.

Lower extremity estimated arterial repair patency was 91% with median follow-up of 20 months (Q1–Q3: 3–57; table 3 and figure 2C). Concomitant vein injuries occurred in 28% of the arterial injured lower extremities and 44% were treated by ligation; bone fractures (39%) were more common than nerve injuries (24%). Vein grafts constituted 77% of the repairs with an estimated patency of 91% and 92% for all other repairs. The predominant injury mechanisms were explosive (57%) and gunshot (39%), both with patency rates of 91% (figure 3C).



**Figure 2** Patency for all repairs and vein graft versus other repairs in extremity arterial injury. Kaplan-Meier curves of arterial injury repairs for (A) combined upper and lower extremities, (B) upper extremity, and (C) lower extremity. Log-rank test  $p < 0.001$  for vein graft repairs versus other repairs in the upper extremity and  $p = 0.004$  other repairs in upper versus lower extremities. Similar patency rates for upper versus lower extremity all repairs and vein graft (VG) repairs as well as lower extremity vein graft versus other repairs.

**Table 3** Follow-up (months) and associated injuries of extremity arterial repairs

Location	Upper and lower	Upper	Lower
Repairs (n)/Patients (n)	143/140	48/48	95/92
Follow-up (mean $\pm$ SD)	36 $\pm$ 40	37 $\pm$ 40	35 $\pm$ 40
Follow-up, median (Q1–Q3)	19 (3–58)	18 (5–58)	20 (3–57)
Range (months)	1–175	1–137	1–175
Occlusions (n)	8	3	5
Mean $\pm$ SD	14 $\pm$ 11	14 $\pm$ 14	14 $\pm$ 9
Range (months)	2–31	3–31	2–24
Vein graft, n (%)	116 (82)	43 (90)	73 (77)
Vein injuries, n (%)	33 (23)	6 (13)	27 (28)
Repaired/ligated	18/15	3/3	15/12
Nerve injuries, n (%)	53 (38)	30 (63)	23 (24)
Bone fractures, n (%)	52 (37)	15 (31)	37 (39)
Other injured extremities, n (%)	40 (28)	11 (23)	29 (31)

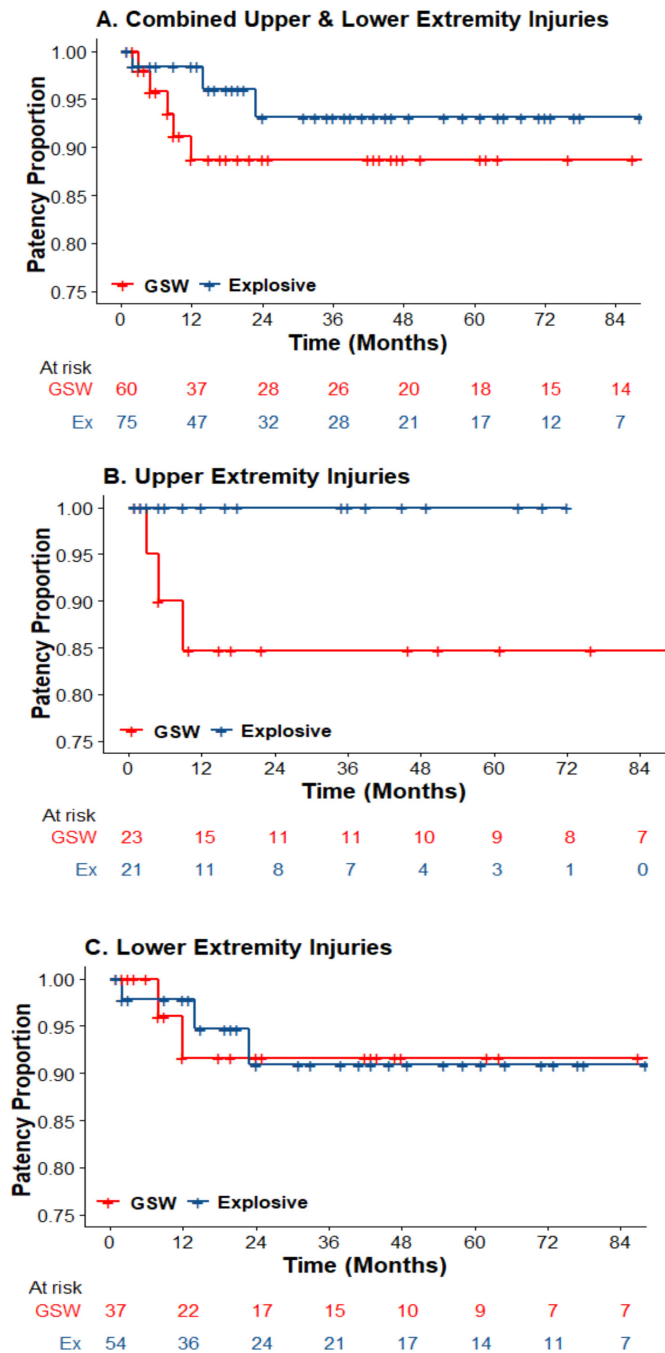
Patency includes all arterial repairs with imaging studies documenting patency. Occlusions include repairs with imaging documenting patency with subsequent (1) imaging showing occlusion, (2) notes documenting occlusion, (3) amputations including an arterial repair, or (4) replacement of an arterial graft. Q1–Q3, first and third quartiles; SD, standard deviation.

Patency of venous repairs was available for 10 lower extremity venous injuries using 4 vein grafts, 1 vein patch, 2 primary repairs and 3 unknown repairs. Mechanism of injury was 70% explosive and 30% gunshot. Repaired injuries were present in the femoral (40%), superficial femoral (40%) and popliteal (20%) veins with accompanying arterial (90%), bone (20%) and nerve (30%) injuries present in the injured leg. All 10 venous repairs were patent with median follow-up of 3 months (Q1–Q3: 1–31, range: 1–65).

Three late secondary transtibial amputations were performed in arterial injured limbs at a mean of 27 $\pm$ 4 months (range: 24–32). Amputations were: (1) gunshot wound requiring posterior tibial artery interposition vein graft patent at 12 months, amputation performed due to malalignment of a tibia/fibula fracture at 24 months, graft patency at time of amputation not documented, (2) explosive injury requiring primary repair of the popliteal artery patent at 2 months with accompanying bone fractures and nerve injury, amputation performed at 26 months due to intolerable pain and non-functional foot, popliteal artery patency at the time of the amputation not documented, and (3) explosive injury requiring femoral above-knee popliteal vein graft with accompanying bone and nerve injuries, amputation performed at 32 months for a non-functional limb; graft patent 73 months after injury.

### Variables affecting mid-term arterial repair patency

Kaplan-Meier analysis comparing upper versus lower extremities suggested lower patency for other repairs ( $p = 0.004$ ) and similar patency for all repair types ( $p = 0.83$ ), vein graft repairs ( $p = 0.41$ ), gunshot wounds ( $p = 0.40$ ) and explosive injuries ( $p = 0.31$ ). Cox regressions showed a lower patency rate for upper versus lower extremity for other repairs compared with vein graft repairs (HR associated with upper vs. lower extremity for other repairs was 14.8,  $p = 0.03$  without adjusting for injury mechanisms, HR 12.2,  $p = 0.06$  when adjusting for injury mechanisms).



**Figure 3** Patency for gunshot wound versus explosive injury in extremity arterial injury. Kaplan-Meier curves of arterial injury repairs for (A) combined upper and lower extremities, (B) upper extremity, and (C) lower extremity. No significant differences in arterial repair patency between gunshot wounds (GSW) and explosive (Ex) injuries in the upper or lower extremity using the log-rank test.

### Similar arterial patency after civilian and combat extremity arterial injury

Upper extremity arterial repair patency was similar (96.9% vs. 93.8%) between civilians<sup>32</sup> and the VAVIS subgroup of all upper extremity repairs (online supplemental table 1 and figure 2B). Arterial repairs using vein grafts were similar in the upper (97.6% vs. 97.7%) and lower (98.3% vs. 94.5%) extremities after civilian and combat injuries (online supplemental table 2 and figure 3).

## DISCUSSION

Mid-term patency of arterial repair after combat-related EVI is excellent. This finding justifies assertive attempts at vascular repair and limb salvage in the acute setting, and the decision to amputate should be based on the degree of concomitant nerve, orthopedic and soft tissue injuries. Two major outcomes of EVI are repair patency and limb salvage. Arterial repair patency may be especially important in this younger cohort of Veterans accustomed to engaging in vigorous physical activity. EVI studies in OEF/OIF/OND Veterans reported early upper<sup>24,35</sup> and lower<sup>1-4,10,20-23</sup> extremity outcomes and long-term lower extremity salvage rates,<sup>34</sup> but not mid-term patency, which is the focus of this report. This cohort study identified OEF/OIF/OND service members with EVI and used imaging studies to estimate mid-term arterial repair patency and limb salvage, with median follow-up of 19 months. While there are multiple diagnostic options to assess patency, duplex ultrasound was the most commonly used in this cohort accounting for over 87.5% of upper extremity and 80% of lower extremity injury imaging studies. Explosives (52%) and gunshot (42%) were the most common mechanisms of injury. Arterial injuries were often associated with concomitant vein, nerve and bone injuries (table 3). Despite previous reports of decreased lower limb salvage after explosive injuries, patency rates were similar for arterial repairs for explosive injuries and gunshot wounds (figure 3), suggesting that associated injuries were the driving factor in amputations after explosive injuries. Vein grafts were the most common repair type with excellent estimated mid-term patency of 97% and 91% for upper and lower extremities, respectively. In contrast, all other types of repairs had similar lower extremity patency (figure 2C) and decreased upper extremity patency (figure 2B). Additionally, late amputations occurred secondary to functional limitations and chronic pain, not compromised vascular patency.

### Arterial upper extremity civilian trauma

Studies from the Medical University of Innsbruck reported patency rates of 93% to 99% for repairs of upper extremity arterial injuries<sup>32,33,44</sup> in the setting of civilian trauma. Concomitant upper extremity injuries for the entire cohort (including patients lost to follow-up) included 17% venous,<sup>44</sup> 36% to 43% nerve,<sup>32,33,44</sup> and 60% to 72% orthopedic<sup>32,33,44</sup> injuries. The current study had a similar rate of concurrent venous (13%), with higher rates of nerve injuries (64%) and lower rates of bone injuries (32%). Long-term patency determined by duplex imaging and excluding early repair failures, amputations and patient mortality reported 97% (65 patients), 97.6% (42 patients) and 96% (60 patients) patency for arterial injuries with a variety of injury mechanisms/repairs,<sup>32</sup> venous interposition graft repairs,<sup>33</sup> and blunt trauma,<sup>44</sup> respectively, with median follow-up ranging from 61 to 72 months after injury. No late upper extremity amputations were performed. Neurologic complications resulting from blunt injuries were associated with more lasting functional deficits compared with penetrating injuries; however, patency rates between blunt and penetrating trauma were similar<sup>32</sup> and comparable to patency rates of all upper extremity arterial repairs and after vein graft repairs in the current study.

### Arterial lower extremity civilian trauma

Klocker *et al*<sup>33</sup> reported on lower extremity arterial injuries with vein graft repairs in 90 civilian patients. Blunt injuries (91%) predominated with concomitant nerve (29%) and orthopedic injuries (83%). The current study had comparable rates of nerve



injuries (24%) and lower rates of bone injuries (39%). Patency assessed by duplex imaging on 59 (66%) patients was 98.3% and one late transfemoral amputation caused by progressive peripheral arterial disease resulted in a limb salvage rate of 98% with median follow-up of 72 months, similar to the 91% patency of lower extremity vein graft repairs and 97% limb salvage rate in the current study.

### Military arterial EVI

Long-term follow-up of combat-related EVI has primarily focused on functional outcomes<sup>2 38 45</sup> and limb salvage<sup>3 4</sup> in the lower extremities. Functional outcomes are challenging to assess given the wide variety of injuries, including TBI. Scott *et al*<sup>2</sup> reported on 5-year outcomes in service members sustaining primarily blast EVIs and found 43% to have unfavorable outcomes and poorer quality of life than the general population. Survey responses from a subset of the VAVIS cohort<sup>38</sup> extended follow-up to 10 years and demonstrated decreased mental health outcomes compared with population norms, similar to Scott *et al*.<sup>2</sup> In contrast, VAVIS found improved physical health outcomes that were similar to population norms suggesting Veterans are able to adapt to physical disabilities over time.<sup>38</sup> Secondary amputations defined as occurring after an initial attempt at lower extremity limb salvage, and further categorized as early or late (>30 days) after injury, occurred at rates of 11.3% and 5.7%, respectively, at median of 6.3 years of follow-up in 530 US service members.<sup>3</sup> Sharrock *et al*<sup>4</sup> used military trauma registries from the USA and UK to identify 597 service members with lower extremity arterial injuries to study limb salvage. The overall 74% limb salvage rate at 5.5 years of follow-up included mostly primary (no initial attempt at limb salvage) and both early and late secondary amputations, with the majority of secondary amputations occurring within 30 days after injury. Amputation rates were significantly lower after gunshot wounds compared with explosive injuries for both primary and secondary amputations, 13.0% versus 1.7% and 18.8% versus 9.4%, respectively, despite having similar acute arterial repair patency rates. Late secondary amputations were performed due to functional limitations (80%) and chronic pain (50%).<sup>3</sup> The current study is consistent with these results, having a predominance of explosive injuries with similar estimated patency rates for gunshot wounds and explosive injuries. The most common level of amputation was transtibial<sup>3 4</sup> similar to the three transtibial-level amputations occurring >3 months after injury (97% limb salvage rate) secondary to functional limitations and pain in our study. Taken together, these studies support the conclusion that long-term limb salvage depends on the severity of concomitant nerve, soft tissue and orthopedic injuries, as early<sup>4</sup> and mid-term revascularization patency rates are similar across injury mechanisms.

### Challenges of long-term follow-up

The DoDTR<sup>39 46</sup> was instrumental in documenting casualties and providing data to improve combat casualty care. However, long-term follow-up for Veterans remains challenging for several reasons. First, studies using VHA and DoD data face multiple regulatory barriers and require access to data across two very different formats.<sup>47</sup> Second, Veterans use multiple sources of healthcare.<sup>48</sup> We did not have access to TRICARE or healthcare records from other healthcare systems. Finally, Veterans accessing VHA care tend to have lower socioeconomic status, have less education, are more likely to be unemployed or underemployed, and are more likely to report poorer physical

and mental health than Veterans who do not use VHA care.<sup>49</sup> Veterans with imaging studies had higher ISS/AIS and VHA-rated disability compared with those without patency data, suggesting that service members with more severe injuries are using the VHA for long-term care. Previous reports have documented the long-term disability of Veterans with extremity injuries<sup>6 7</sup> and EVI.<sup>2 3 38</sup> Thus, our reliance on VHA records for follow-up may have biased our sample toward a sicker, poorer population of Veterans. Prior studies with full access to DoD records have documented short-term outcomes of EVI repair in combat settings including early occlusions and amputations after an initial attempt at repair.<sup>1 10 20–25</sup> The motivation for the current study was to extend these outcomes despite the regulatory challenges and data access limitations.

### Limitations

The study was limited by reliance on retrospective data, as documentation was sometimes incomplete. Determining arterial repair surveillance rates as a process of care was limited as non-VHA/non-DoD data were not available and may partially explain the mean (36 months) and median (19 months) patency follow-up despite injuries occurring over 5–10 years ago. We were unable to categorize patency as primary or secondary due to the possibility of an intervention occurring between imaging studies. The dates of injury, interventions and imaging studies were limited to month and year; therefore, overestimation of patency within the first 1–2 months may be present for injuries occurring later in the month. Long-term limb salvage is dependent on multiple factors, including the neurologic and musculoskeletal consequences of the injury. The use of antiplatelet and anticoagulation medications that may affect repair patency after traumatic injury was not available. The studies<sup>32 33</sup> in the civilian literature used to compare arterial patency had longer median follow-up than the current study. The VAVIS sample was younger and possibly fitter at the time of injury, and the mechanism of injury differed being primarily from armament blasts and roadside improvised explosive devices and gunshot wounds compared with predominantly blunt injuries among civilians. Thus, although patency rates appear similar between the Veterans and the civilians, the comparison is more useful to put the postmilitary experience in context. The small sample sizes and high patency rates limit the ability to verify hypothesis 2 between the civilian studies<sup>32 33</sup> and current study. We did not find comparable patency studies in the literature on combat-related arterial injuries.

### CONCLUSIONS

EVI and associated injuries have high rates of morbidity and disability<sup>2–4</sup> among Veterans of OEF/OIF/OND. Service members underwent successful arterial repair with excellent mid-term patency rates for upper and lower extremity injuries, regardless of mechanism, based on review of arterial imaging studies. Late amputations were rare and mainly performed for associated fractures and nerve injuries resulting in functional limitations and chronic pain, despite a patent arterial repair. Upper extremity vein graft arterial repairs had superior patency to other types of repairs and should be used whenever feasible, while considering the patient's overall condition. These results suggest that decisions in the acute setting for amputation versus limb salvage should be based on the overall condition of the patient and the degree of concomitant nerve, orthopedic and soft tissue injuries rather than the presence of arterial injuries, given the excellent mid-term patency of arterial repairs. This evidence justifies



continued assertive attempts at vascular repair and limb salvage in the acute postinjury period.

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