The Epidemiology of Vascular Injury in the Wars in Iraq and Afghanistan

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Background: Blood vessel trauma leading to hemorrhage or ischemia presents a significant cause of morbidity and mortality after battlefield injury. The objective of this study is to characterize the epidemiology of vascular injury in the wars of Iraq and Afghanistan, including categorization of anatomic patterns, mechanism, and management of casualties.

Methods: The Joint Theater Trauma Registry was interrogated (2002–2009) for vascular injury in US troops to identify *specific* injury (group 1) and *operative* intervention (group 2) groups. Battle-related injuries (nonreturn to duty) were used as the denominator to establish injury rates. Mechanism of injury was compared between theaters of war and the management strategies of ligation versus revascularization (repair and interposition grafting) reported.

Results: Group 1 included 1570 Troops injured in Iraq (OIF) (n = 1390) and Afghanistan (OEF) (n = 180). Mechanism included explosive (73%), gunshot (27%), and other (<1%) with explosive more common in OIF than OEF (P < 0.05). During this period, 13,076 battle-related injuries occurred resulting in a *specific* rate of 12% (1570 of 13,076), which was higher in OIF than OEF (12.5% vs 9% respectively; P < 0.05). Of group 1, 60% (n = 940) sustained injury to major or proximal vessels and 40% (n = 630) to minor or distal vessels (unknown vessel, n = 27). Group 2 (*operative*) comprised 1212 troops defining an operative rate of 9% (1212 of 13,076) and included ligation (n = 660; 54%) or repair (n = 552; 46%). Peak rates in OIF and OEF occurred in November 2004 (15%) and August 2009 (11%), respectively and correlated with combat operational tempo.

Conclusion: The rate of vascular injury in modern combat is 5 times that reported in previous wars and varies according to theater of war, mechanism of injury and operational tempo. Methods of reconstruction are now applied to nearly half of the vascular injuries and should be a focus of training for combat surgery. Selective ligation of vascular injury remains an important management strategy, especially for minor or distal vessel injuries.

I njury to blood vessels leading to hemorrhage with or without ischemia represents a significant cause of morbidity and mortality after battlefield trauma.[1–3] The severity and volume of trauma during war serve to underscore the importance of vascular injury and its management at this time. It is considered that noncompressible hemorrhage from various types of blood vessel injury remains the leading cause of potentially preventable death on the battlefield and a leading cause of amputation.[2,3]

The rate of vascular injury in wartime has been a point of interest for over a century. Reports from as early as the American Civil War have made an effort to describe the frequency of vascular trauma (Fig. 1).[4,5] Accounts from US and British surgeons in World War I (WWI) estimated a rate of vascular injury to be 0.4% to 1.3% and DeBakey[4] dedicated a large portion of his landmark work to reporting the rate in World War II (WWII) (0.96%).[6,7] Accounts from the Korean and Vietnam wars describe the rate of vascular injury to be higher at 2% to 3% (Fig. 1).[8–12] Despite a historical emphasis on determining the burden of vascular injury on the battlefield, a report on its epidemiology in modern combat has not been made.

The wars in Iraq and Afghanistan represent the most prolonged military conflict in US history. Unlike previous wars in which estimates of injury stemmed from individual accounts or manual tracking, today's combat casualty care is supported by a Joint Theater Trauma System (JTTS). The JTTS captures casualty demographics and injury management data and information on mechanism and theater of injury. If placed in the context of the population at risk (ie, battle injuries), information from the system provides insight into the epidemiology of this important injury pattern allowing for informed training and operational planning. The objective of this study is to characterize the epidemiology of vascular injury in modern combat including description of *specific* and *operative* rates. Additional objectives include defining the anatomic patterns of vascular injury and comparison of the 2 broad management categories of repair and ligation.

METHODS

Joint Theater Trauma System

This study was conducted under a protocol reviewed and approved by the US Army Medical Research and Material Command Institution Review Board. The Joint Theater Trauma Registry (JTTR) is 1 facet of the JTTS which is a prospectively gathered computer-based network supported by more than 70 personnel. The JTTS and Registry are housed and maintained at the United States Army Institute of Surgical Research at Fort Sam Houston (San Antonio), Texas. The system serves as a repository, collecting and hosting all Department of Defence (DoD) trauma-related data. The goal of the JTTS includes providing the ability to perform data-driven, process improvement in combat casualty care to decrease morbidity and mortality. Additionally, the system aims to characterize the epidemiology of injury on the battlefield to allow the DoD's training and operational projections to be more efficient and accurate. Information in the registry includes demographic, injury, and treatment data acquired at all levels or echelons of care in both theaters of war.

Currently echelons of combat casualty care are referred to as levels and range from rudimentary (level I) to comprehensive (level V). Level I care that is the most basic occurs at the point of injury and is referred to as tactical combat casualty care[3] . Level II care consists of small, forward, 10- to 15-person surgical teams located

1. REPORT DATE **01 JUN 2011**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**	
4. TITLE AND SUBTITLE **The epidemiology of vascular injury in the wars in Iraq and Afghanistan**		5a. CONTRACT NUMBER	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) **White J. M., Stannard A., Burkhardt G. E., Eastridge B. J., Blackbourne L. H., Rasmussen T. E.,**		5d. PROJECT NUMBER	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **United States Army Institute of Surgical Research, JBSA Fort Sam Houston, TX**		8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**			
13. SUPPLEMENTARY NOTES			
14. ABSTRACT			
15. SUBJECT TERMS			

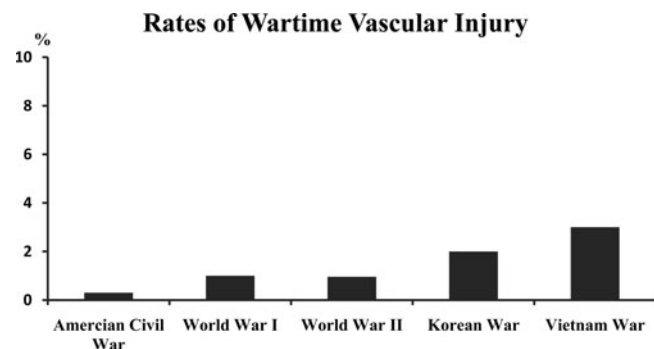| 16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT **UU**	18. NUMBER OF PAGES **6**	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**			

FIGURE 1. Historical perspective on wartime vascular injury rates.

within 30 to 90 minutes of injury in most cases. The objective of level II care is abbreviated (1 hour or less) or damage control operating; specifically to stabilize life- and limb-threatening injuries before evacuation to level III facilities. Level III care is in the form of combat support and theater hospitals. Surgical capability at level III facilities is robust and allows for the definitive, early management of combat injuries, and preparation for transcontinental aeromedical evacuation. Level IV and V facilities are medical centers outside of the theater of war. Landstuhl Regional Medical Center in Germany serves as the level IV facility for the current wars in Iraq and Afghanistan and level V care occurs at the military medical centers across the United States.

Identification of Vascular Injuries

The JTTR was searched between January 1, 2002 and September 30, 2009 utilizing abbreviated injury scale (AIS) and International Classification of Diseases, Ninth Revision (ICD-9) codes for vascular injury (arterial and venous) and vascular injury repair in US troops. Patients identified as having extremity vascular injury in the setting of immediate or traumatic amputation were excluded. The search included injuries occurring in both the Iraq (OIF) and Afghanistan (OEF) Joint Operating Areas. Injured troops were identified and sorted according to name and social security number and duplications eliminated using both name and social security number sorting techniques. Data quality was assured by having 2 dedicated vascular researchers perform sorting of data from the JTTR including elimination of duplicates before analysis. Injured casualties with more than 1 vascular injury were counted as 1 vascular injury case. Total battle-related, nonreturn to duty injuries served as a fixed denominator of significant wounding in the tabulation of rates. Nonbattle-related injuries (ie, disease nonbattle or DNBI) were not included in the denominator used for rate calculation.

Specific and Operative Groups

Group 1 was defined as the *specific vascular injury group* and consisted of patients identified by *ICD-9* or AIS codes for specific vascular injury. In this context, injured troops identified with the code hemorrhage control not otherwise specified , which implies but does not specify blood vessel injury were not included. Group 2 or the *operative vascular injury group* comprised patients that underwent an identified surgical procedure for the management of a vascular injury. Central vascular injuries that required laparotomy or thoracotomy were included in the operative and vascular repair groups. Operative procedures for vascular injury (repair or ligation) were accomplished at level II and III facilities in either theater of war. Ligation was performed as a damage control maneuver or as an acceptable alternative mostly by general or fellowship-trained trauma surgeons. After elimination of duplicate patients, the totals identified

in groups 1 and 2 were divided by battle-related injuries (nonreturn to duty) during the search period to establish specific and operative vascular injury rates, respectively (Fig. 2).

Anatomic Definitions, Mechanism of Injury, and Mortality

Analysis of group 1 was undertaken to divide vascular injuries into 2 subgroups: major (proximal) and minor (distal). For purposes of the study, major vascular injuries were those either arterial or venous identified as at or above the popliteal in the lower extremity or at or above the brachial in the upper extremity. Torso and cervical injuries were all categorized as major. Minor vascular injuries were those of arteries or veins distal to the popliteal and brachial in the lower and upper extremity, respectively. In addition to anatomic distribution, differentiation was made between arterial and venous injury, or concomitant arterial and venous injury when possible. Finally, theater of injury (Iraq or Afghanistan) was determined along with mechanism or cause of injury and died of wounds rates.

Statistical analysis included Fisher exact test to compare differences of vascular injury rates between theaters of war in addition to mechanisms of wounding. Statistical significance was accepted for P value of less than 0.05.

RESULTS

Specific Vascular Injury Distribution and Rate

Group 1 included 1570 US Troops identified as having specific vascular injury. The anatomic distribution of vascular injuries in group 1 is shown in Tables 1 and 2, divided into body region (extremity, torso, and cervical). Numbers of recorded injuries are presented after each anatomic location with a percentage that reflects the whole number in the context of 1570 injured troops with specific vascular injury. Overall, extremity vascular injuries were most common (79%; 1247 of 1570) followed by injuries to the torso (12%; 194 of 1570) and cervical (8%; 129 of 1570) regions.

The most commonly injured vessels in the extremities were distal, below the elbow in the upper extremity and below the knee in the lower extremity (Table 1) (Fig. 3). Specifically, 305 vascular injuries were documented in the distal upper extremities (19% of total) and 325 in the distal lower extremity (ie, tibial vessels) (21% of total). The most commonly injured proximal extremity segments were the femoral (n = 268; 17% of total) and brachial (n = 168; 11% of total). In the torso, the most commonly injured vessels were the iliacs (n = 61; 3.8% of total) followed by the aorta (n = 45; 2.9% of total) and subclavian (n = 36; 2.3% of total) artery and vein (Table 2). There were 21 documented injuries to the vena cava that represented 1.4% of total number of vascular injuries. In the cervical region, 109 carotid injuries were documented representing 7% of the total number of specific vascular injuries (Table 2). With respect to the 2 designated vascular injury categories, major and minor, 940 (60%) were major or proximal and 630 (40%) were minor or distal. Of all vascular injuries in group 1, 1001 (64%) were documented as isolated arterial injury, 247 (16%) documented as isolated venous,

$$\text{Specific Rate of Vascular Injury} = \frac{\text{Casualties with Identified Vascular Injury}}{\text{Battle-related Injuries (non-return to duty)}} \times 100$$

$$\text{Operative Rate of Vascular Injury} = \frac{\text{Casualties with Operation for Vascular Injury}}{\text{Battle-related Injuries (non-return to duty)}} \times 100$$

FIGURE 2. Calculation of specific and operative vascular injury rates.

TABLE 1. Anatomic Location of Extremity Vascular Injuries Provided As a Whole Number and Percent of the Total 1570. Of Note, the Search Methodology Which Employs ICD-9 and AIS Codes Does Not Allow Anatomic Differentiation Between Common, Superficial or Deep Femoral Arteries of the Lower Extremity. Similarly Anatomic Specificity Is Not Provided for Distal Vascular Injuries Below the Knee (i.e. Tibial Vessels) and Below the Elbow (i.e. Radial and Ulnar Arteries) and Thus These Are Referred to As Distal Extremity Injuries

Anatomic Location	Number	% of Total (1570)
UPPER EXTREMITY		
Axillary (n = 38)		
Axillary artery	22	1.4
Axillary vein	4	0.25
Artery and vein	12	0.76
Brachial (n = 168)		
Brachial artery	154	9.8
Brachial vein	3	0.19
Artery and vein	11	0.7
Distal Upper Extremity (n = 305)		
Isolated artery	235	15
Isolated vein	40	2.5
Artery and vein	30	1.9
LOWER EXTREMITY		
Femoral (n = 268)		
Femoral artery	111	7.1
Femoral vein	49	3.1
Artery and vein	108	6.9
Popliteal (n = 143)		
Popliteal artery	70	4.5
Popliteal vein	30	1.9
Artery and vein	43	2.7
Distal Lower Extremity (n = 325)		
Artery	189	12
Vein	66	4.2
Artery and vein	70	4.4

TABLE 2. Anatomic Location of Torso and Cervical Vascular Injuries Provided As a Whole Number and Percent of the Total 1570

Anatomic Location	Number	% Total (1570)
TORSO		
Brachiocephalic (n = 13)		
Brachiocephalic artery	5	0.32
Brachiocephalic vein	5	0.32
Artery and vein	3	0.19
Subclavian (n = 36)		
Subclavian artery	14	0.89
Subclavian vein	12	0.76
Artery and vein	10	0.64
Coronary	2	0.13
Celiac	3	0.19
Superior mesenteric artery	13	0.83
Aorta	45	2.9
Vena cava (n = 21)		
Superior	5	0.32
Inferior	16	1.1
Iliac (n = 61)		
Iliac artery	19	1.2
Iliac vein	17	1.1
Artery and vein	25	1.6
CERVICAL		
Carotid (n = 109)		
Common carotid	47	2.9
External carotid	41	2.5
Common and external	21	1.3
Vertebral	20	1.3
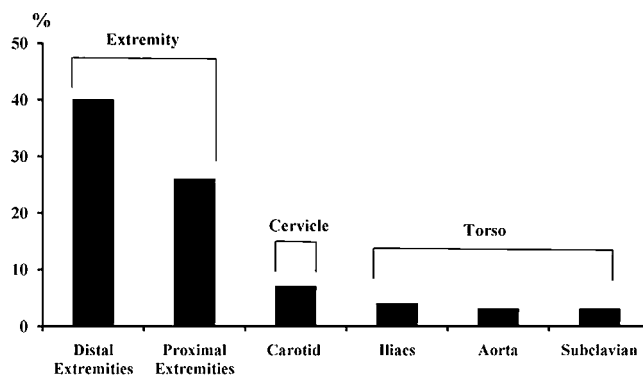
FIGURE 3. Most common vascular injury patterns in modern combat.

and 322 (20%) documented as concomitant arterial and venous. During the study period, 13,076 battle-related injuries (nonreturned to duty) occurred resulting in a specific rate of vascular injury of 12% (1570 of 13,076).

Operative Vascular Injury

Those patients in group 1 who underwent a documented operative procedure for vascular injury comprise group 2 (n = 1212). Dividing the number of patients in group 2 by the number of battle-related casualties (nonreturn to duty) resulted in an operative rate of vascular injury of 9% (1212 of 13,076). With regards to the 2 broad categories of operative management of vascular injury 54% (n = 660) of patients were documented as having undergone ligation, whereas 46% (n = 552) were documented as having had vascular reconstruction which was coded as either repair or interposition graft.

Intertheater Comparison, Mechanism of Injury, and Mortality

The specific, or total vascular injury rate was higher in Iraq than Afghanistan (12.5% vs 9% respectively; $P < 0.05$) (Fig. 4) and the peak numbers of vascular injury occurred in Iraq and Afghanistan

in November 2004 (n = 69) and August 2009 (n = 23), respectively (Fig. 5). The specific vascular injury rates for these peak months were 15% in Iraq and 11% in Afghanistan. The majority of battle-related injuries occurred as a result of high energy wounding mechanisms such as explosive and gunshot. Overall, explosive mechanisms accounted for 73% (1143 of 1570) of vascular injuries and were responsible for a higher percentage of injuries in Iraq than Afghanistan (Fig. 6). In contrast, the proportion of vascular injuries sustained from gunshot wounds was higher in Afghanistan than Iraq [33% (60 of 180) vs 26% (360 of 1390) respectively] (Fig. 5). Anatomic distribution of vascular injuries was the same in Iraq as in Afghanistan.
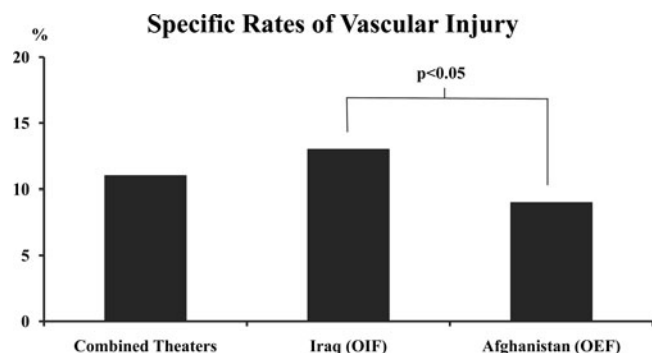
FIGURE 4. Rates of vascular injury in the wars in Iraq and Afghanistan.

The overall died of wounds rate for group 1 was 6.4% and was not different between theaters of war.

DISCUSSION

This study is the first to characterize the epidemiology of vascular injury in the wars in Iraq and Afghanistan. As such, this report demonstrates the capability of the Joint Theater Registry as part of the Trauma System to provide a comprehensive and temporal assessment of vascular injury burden in simultaneous theaters of war. Currently, vascular injury is present in 12% of those wounded in combat with the rate varying with mechanism of injury and operational tempo. Findings from this study demonstrate the most commonly injured vessels to be those of the distal extremities, followed by those of the femoral and popliteal regions. The management strategies of ligation and reconstruction are equally common.

From an historical standpoint, considerable effort has been made at times of war to estimate the burden of vascular injury on the battlefield. DeBakey and Simeone[4] dedicated a significant portion of their report to describing the rate of vascular injury to be nearly 1% during WWII. Subsequent accounts from Hughes in the Korean War and from Rich in the Vietnam War identified the rate to be slightly higher at 2% to 3%.[8–12] Early accounts from Operation Iraqi Freedom suggested that the rate of vascular injury was increased including a report from Clouse et al[13–15] that reported a rate of nearly 5%. This report included US troops and Iraqi military and civilians and originated from operative logs at 1 level or echelon III surgical hospital in Iraq.[14] Although insightful, reports from Hughes in Korea and from Rich in Vietnam, and the recent report from Clouse were biased toward the operative repair and underreported injury to distal or "minor" vessels. Furthermore, the report from Clouse did not account

for vascular injuries managed before or outside the Air Force Theater Hospital on Balad Air Base, Iraq nor did it account for injury in the Afghanistan Theater of War. The current study draws on the Joint Theater Trauma Registry to achieve a more comprehensive account of vascular injury that, similar to that reported by DeBakey,[4] includes distal or minor vessels.

Several factors may contribute to the finding that the rate of vascular injury is more than 5 times previously reported in war. Foremost, the rate of blood vessel injury associated with modern wounding mechanisms may be higher. This possibility is supported by observations in this study that explosive mechanisms are more likely to lead to vascular injury than gunshot wounds. Because explosive injury frequently results in multiple penetrating wounds at various locations and levels and blunt force, the likelihood of blood vessel injury seems to be greater after this compared to other mechanisms.[16] A study from Owens and Kragh[17] reported that explosive mechanisms now account for 78% of injuries in the wars in Iraq and Afghanistan which is the highest proportion observed in any large scale military conflict. These previously published accounts clarify in part the observations in this study and support the premise that current mechanisms of wounding account for higher rates of vascular injury.

The increased rate of vascular injury may also reflect shorter casualty evacuation (CASEVAC) times and greater survivability of wounds in modern combat. In this context, injured troops are now more likely to survive initial wounding to reach a surgical facility and have vascular injuries recorded and treated. Beekley et al[18] have shown that the use of tourniquets in combination with forward surgical care is associated with improved hemorrhage control especially in those with high injury severity scores. Similar reports demonstrate that use of tourniquets and rapid casualty evacuation are associated with greater survivability of extremity trauma, a significant proportion of which has vascular injury.[15,19]

Finally, the increased rate reported in the current study may reflect a more finite and accurate denominator (ie, battle-related injury, nonreturn to duty) that is linked to the numerator by virtue of the JTTS. One difficulty in calculating rates of injury in the past has been defining an exact or even reasonable denominator. Previous reports often used a denominator which was ill-defined and obtained from a casualty count or operational source separate from the vascular injury record. In this context, the current rates may simply be more accurate than earlier reports that, in the absence of a trauma system, overestimated the population at risk.

The anatomic patterns of vascular injury in this study have similarities to those reported after WWII. Specifically, DeBakey[4] reported that 28% of arterial injuries occurred in distal or minor arteries.[4] The current study corroborates this observation demonstrating that 33% (518 of 1570) of arterial injuries occur to arteries
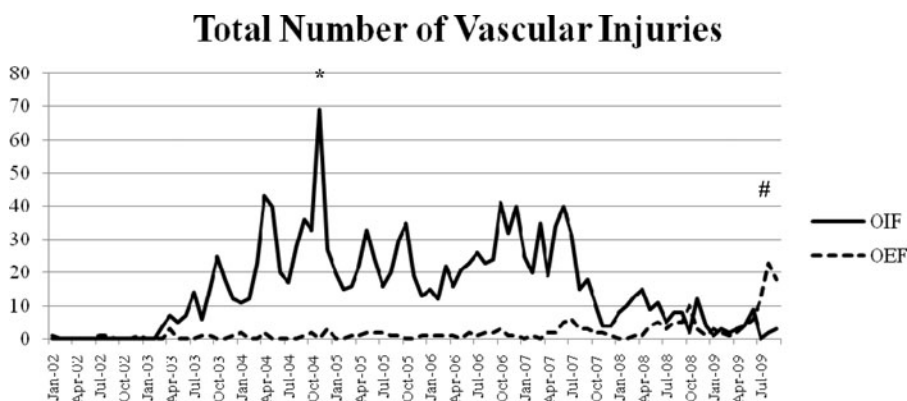

FIGURE 5. Temporal profile of vascular injuries. Numbers of vascular injuries per month in Ira (OIF) and Afghanistan (OEF) from January 2002 to September 2009. *Peak number of injuries in OIF (November 2004); # Peak number of injuries in OEF (August 2009).
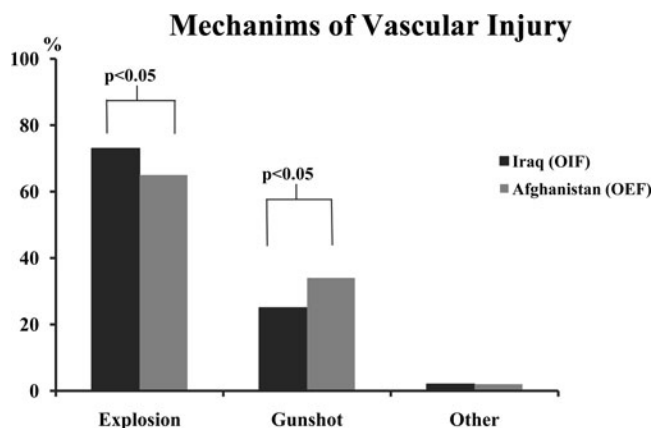
FIGURE 6. Mechanism of vascular injury in different theaters of war.

considered minor or distal (Table 1). Also similar is the incidence of femoral vessel injury that is reported in this study to be 17% of injuries compared to 20% during WWII. Unlike DeBakey's report, current findings identify a higher incidence of carotid (7%) and aortic (3%) injury that may also reflect shortened CASEVAC times (Fig. 3). Currently, in-theater data indicates that casualties arrive at surgical facilities within 2 hours of injury and often within 45 minutes.[14,17,19] In contrast during WWII, the average time from point of injury to surgical care was 12 to 16 hours.[4] The observation of a higher percentage of cervical injuries confirms and extends reports from Owens and Clouse[14,17] both of which demonstrated a greater proportion of neck wounds than previously published.

The fact that ligation and reconstruction are currently used in nearly equal proportions to manage vascular injury is a compelling observation. On 1 hand the fact that 46% of injury is now managed with repair or bypass confirms the advances made in casualty evacuation, forward surgical care, and reconstructive techniques.[20–24] In 1946, DeBakey[4] commented that "therapeutic measures designed to save the limb are applicable, at best, in not more than 20% of cases" on the battlefield. The finding from this study that half of vascular injury is now managed with repair or bypass confirms that the window of opportunity to salvage life and limb has been extended. However, the observation that half of vascular injury continues to be managed with ligation is significant and surprising to many who may have dismissed the technique as antiquated. The frequency of ligation shown in this study offers balance to early reports from this war that focused heavily on methods of restoration of flow and vascular reconstruction.[13,14,20–24] The findings surrounding ligation highlight the importance of a recent study by Burkhardt et al[25] that reports outcomes after a selective approach to revascularization of the most common injury pattern, the distal lower extremity, or tibial level.

This study has limitations worth noting. Only patients who receive care at a level or echelon III facility in a theater of war are entered into the JTTR and as such this registry does not capture all casualties. It is likely that a small number of troops with vascular injury who died of wounds at lower echelons of care (level I or II facilities) were not included. Also this study is dependent upon the search mechanism itself which used AIS and *ICD-9* codes. Incorrect or missed coding could have led to exclusion of vascular injury cases. Both of these limitations would result in an underrepresentation of vascular injury making the rates reported in this study modest; although these same limitations could have led to an underestimation of the died of wounds rate in the study.

Unfortunately, the injury and management codes used to search the JTTR do not allow for subidentification of vessels (ie, second or third order) in an anatomic region. For example, search mechanisms do not distinguish between common, internal, and external iliac vessels all of which are coded as iliac vessel injury. In the extremity, the search is not able to distinguish between common, superficial, or deep femoral arteries or the brachial artery above or below the profunda origin. This drawback restricts the anatomic detail that can be provided and makes imperfect comparison with publications originating from more detailed operative logs. Similarly, limitations associated with the search mechanism do not allow for a detailed description of operative techniques. The greatest details that can be discerned from the current study are the broad categories of ligation versus revascularization (ie, bypass or repair). Lastly, this study does not address vascular injuries in the context of amputation. As the study is focused broadly on the distribution of wounding requiring conventional management strategies, injuries associated with immediate or traumatic amputation were not included. Despite these limitations, this study is the first of its type to characterize the epidemiology of vascular injury in modern combat. As such, this account serves as a basis for more detailed studies to be focused on the subanatomic distribution of vascular injury, specific operative procedures, outcomes, and amputations.

CONCLUSION

The rate of blood vessel trauma in modern combat is 5 times previously reported in war and varies according to theater of war, mechanism of injury, and operational tempo. Methods of reconstruction including repair or interposition grafting are now applied to nearly half of wartime vascular injuries and should be the focus of military surgical training and structuring of combat support and theater hospitals. Ligation remains an important management strategy especially for minor or distal vascular injuries and should not be neglected in training and preparatory curricula.

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