

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE (DD-MM-YYYY) 23 Aug 2010		2. REPORT TYPE Final		3. DATES COVERED (From - To) 25 Jul 06-27 Apr 10	
4. TITLE AND SUBTITLE Vascular Injury in the Wars in Iraq and Afghanistan				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Capt Joseph M. White, MD USA, MC, Lt Col Todd E. Rasmussen, MD, USAF M Lt Cdr Adam Stannard, Capt Gabriel Burkhardt, Col Brian Eastridge, Col Blackbourne				5d. PROJECT NUMBER FWH20060147H	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Army Institute of Surgical Research 3400 Rawley E. Chambers Avenue, Suite B Fort Sam Houston, Texas 78234-6315				8. PERFORMING ORGANIZATION REPORT NUMBER	
				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Distribution A. Approved for public release: distribution unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)

Vascular Injury in the Wars in Iraq and Afghanistan

Capt Joseph M. White, MD USA MC, Lt Col Todd E. Rasmussen, MD USAF MC,
Lt Cdr Adam Stannard, MRCS, Capt Gabriel E. Burkhardt, MD USAF MC, Col Brian J.
Eastridge, MD USA MC, Col Lorne H. Blackbourne, MD USA MC

United States Army Institute of Surgical Research, Fort Sam Houston, Texas
The Uniformed Services University of the Health Sciences, Bethesda, Maryland

Key words: vascular injury, trauma, combat wounds, blood vessel

Corresponding author:

Todd E. Rasmussen, MD FACS

Col (sel) USAF MC

San Antonio Military Vascular Surgery Services

Deputy Commander

USA Institute of Surgical Research

3400 Rawley E. Chambers Avenue, Suite B

Fort Sam Houston, Texas 78234-6315

Office: 210-916-5181

Email: todd.rasmussen@us.af.mil

Abstract

Background: Blood vessel trauma leading to hemorrhage or ischemia represents a significant cause of morbidity and mortality following injury. The objective of this study is to characterize the epidemiology of vascular injury in the wars in Iraq and Afghanistan and delineate anatomic patterns of injury, and the management categories of repair and ligation.

Methods: The Joint Theater Trauma Registry was queried (2002-2009) for vascular injury in US troops and specific (Group 1) and operative (Group 2) groups defined. Group numbers were divided by battle related injuries (non-return to duty) to establish injury rates.

Results: Group 1 included 1,570 Troops injured in Iraq (OIF) (n=1,390) 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% (1,570/13,076) 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 location, n=27). Group 2 comprised 1,212 Troops revealing an operative rate of 9% (1,212/13,076) which 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 previously reported and varies according to theater of war, mechanism of injury and operational tempo. Methods of reconstruction are now applied to nearly half of wartime vascular injuries and should be the

focus of training and combat support surgery. Ligation of vascular injury remains an important management strategy especially for minor or distal vascular injuries.

Introduction

Injury to blood vessels leading to hemorrhage, ischemia or a combination represents a significant cause of morbidity and mortality following trauma. The nature and volume of injury during war only serve to underscore the importance of vascular injury and its management at this time. It is estimated that non-compressible hemorrhage from various types of blood vessel injury remains the leading cause of potentially preventable death on the battlefield as well as a leading cause of amputation.¹

The rate of vascular injury in wartime has been a keen 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 (Figure 1).^{2,3} Accounts from US and British surgeons in WWI estimated a rate of vascular injury to be 0.4-1.3% and DeBakey dedicated a large portion of his landmark work to reporting the rate in WWII (0.96%).^{2,4,5} Accounts from the Korean and Vietnam wars approximated the rate of vascular injury to be higher at 2-3% (Figure 1).⁶⁻¹⁰ Despite the historical emphasis on and present significance of vascular injury, 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 and management data as well as information regarding mechanism and theater of injury. If placed in the context of the population at risk (i.e. battle injuries), information from the system may provide insight on the epidemiology of injury patterns allowing for more accurate 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. Additionally, the objective is to delineate anatomic patterns of vascular injury and compare the two broad management categories of repair and ligation.

Methods

Joint Theater Trauma System: The Joint Theater Trauma Registry (JTTR) is one facet of the JTTS which is an organized, computer-based network supported by more than 70 personnel. The system serves as a repository, collecting and hosting all Department of Defence (DoD) trauma-related data. The goals of the JTTS include providing the ability to perform data-driven process improvement across the spectrum of 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 within the registry includes demographic, injury and treatment data acquired at all levels of care in both theaters of war. The JTTS and registry are housed and maintained at the United States Army Institute of Surgical Research at Fort Sam Houston, Texas where Institution Review Board approval was gained prior to performance of this study. This study was conducted under a protocol reviewed and approved by the US Army Medical Research and Materiel Command Institutional Review Board, and in accordance with the approved protocol.

Identification of Vascular Injuries: The JTTR was queried between January 1st 2002 and September 30th 2009 utilizing abbreviated injury scale (AIS) and 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 SSN sorting techniques. Data quality was

assured by having two dedicated vascular researchers perform sorting of the data from the JTTR including elimination of duplicates prior to analysis. Injured casualties with more than one vascular injury were counted as one vascular injury case. Total battle-related, non-return to duty injuries served as a fixed denominator of significant wounding in the tabulation of rates. Non-battle related injuries (i.e. disease non-battle 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 codes such as hemorrhage control not otherwise specified (HCNOS) which implies 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. Following elimination of duplicates, the totals identified in Groups 1 and 2 were divided by battle-related injuries (non-return to duty) during the search period to establish specific and operative vascular injury rates respectively (Figure 2).

Anatomic Definitions, Mechanism of Injury and Mortality: Analysis of Group 1 was undertaken to divide vascular injuries into two 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 knee in the lower extremity or at or above the elbow in the upper extremity. Torso and cervical injuries were also categorized as major. Minor vascular injuries were those of arteries or veins distal to the knee and elbow 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 was determined along with mechanism or cause of injury and died of wounds rates.

Statistical analysis included Fishers exact test to compare differences of vascular injury rates between theaters of war as well as mechanism of wounding. Statistical significance was accepted for p-value of less than 0.05.

Results

Specific Vascular Injury Distribution and Rate: Group 1 included 1,570 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 which reflects the whole number in the context of the 1,570 specific vascular injuries. Overall, extremity vascular injuries were most common (79%; 1,247/1,570) followed by injuries to the torso (12%; 194/1,570) and cervical (8%; 129/1,570) 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) (Figure 3). Specifically, 305 vascular injuries were documented in the distal upper extremities (19% of total) and 325 in the distal lower extremity (i.e. 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 which 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 two 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 isolated arterial injury, 247 (16%) were isolated venous and 322 (20%) concomitant arterial and venous. During the study period, 13,076 battle-related injuries (non-returned to duty) occurred resulting in a specific rate of vascular injury of 12% (1,570/13,076).

Operative Vascular Injury: Those patients in Group 1 who underwent a documented operative procedure for vascular injury comprise Group 2 (n=1,212). Dividing the number of patients in Group 2 by the number of battle-related casualties (non-return to duty) resulted in an operative rate of vascular injury of 9% (1,212/13,076). With regards to the two broad categories of operative management of vascular injury 54% (n=660) of patients underwent ligation, while 46% (n=552) underwent vascular reconstruction which was coded as repair or interposition graft.

Inter-theater Comparison, Mechanism of Injury and Mortality: The specific vascular injury rate was higher in Iraq than Afghanistan (12.5% vs. 9% respectively; $p < 0.05$) (Figure 4) and the peak numbers of vascular injury occurred in Iraq and Afghanistan in November 2004 (n=69) and August 2009 (n=23) respectively (Figure 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 blast and gunshot. Overall, blast accounted for 73% (1,143/1,570) of vascular injuries sustained in combat. Blast mechanism was responsible for a higher percentage of vascular injuries in Iraq than Afghanistan (Figure 5). In contrast the proportion of vascular injuries sustained from gunshot wounds was higher in Afghanistan than Iraq (33% (60/180) vs. 26% (360/1,390) respectively) (Figure 5). Anatomic distribution of vascular injuries was the same in Iraq as Afghanistan (67% vs. 66%;

p=NS). 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 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 and the rate varies with mechanism of injury and operational tempo. Findings from this study show 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 in the context of all vascular injury.

During and after World War II, considerable effort was made to estimate the rate of vascular injury which was found to be nearly 1%.² Subsequent accounts from the Korean and Vietnam Wars identified the rate of vascular injury to be slightly higher at 2-3%.⁶⁻¹⁰ Early accounts from Operation Iraqi Freedom suggested that the rate of vascular injury was increased including a report from Clouse et al. which reported a rate of nearly 5%.¹¹⁻¹³ This report included US troops as well as Iraqi military and civilians and used the Balad Vascular Registry originating from a single level III hospital in Iraq. While insightful, reports from Hughes in Korea and Rich in Vietnam as well as the recent report from Clouse and were biased towards operative repair and underreported injury to distal or “minor” vessels. The current study uses the JTTS to achieve a more complete description of all vascular injury similar to that provided by DeBakey in 1946.

Several factors may contribute to the finding that rates of vascular injury are now 5 times previously reported. Foremost, the rate of blood vessel injury associated with modern wounding mechanisms may be higher. This possibility is supported by observations that blast is more likely to lead to vascular injury than gunshot wounds. Because blast devices result in multiple penetrating wounds in combination with blunt force, the likelihood of blood vessel injury may be greater. It is also possible that the higher rate reflects the combination of shorter evacuation times and greater survivability of wounds in modern combat. In this context, injured troops are now more likely to survive initial wounding to have vascular injuries recorded and treated. Finally, the increased rate may reflect a more finite denominator (i.e. battle-related injury, non-return to duty) which is linked to the numerator by virtue of the JTTS. A difficulty in calculating rates of injury is defining an accurate denominator and historical reports often used a denominator obtained from a source separate from the vascular injury record.

The anatomic patterns of vascular injury in this study have similarities to those reported following WWII. Specifically, DeBakey reported that 28% of arterial injuries occurred in distal or minor arteries.² The current study corroborates this observation demonstrating that 33% (518/1,570) of arterial injuries occur to arteries considered minor or distal (Table 1). Also similar is the incidence of femoral vessel injury which is reported in this study to be 17% of injuries compared to 20% during the WWII. Unlike DeBakey's report, current findings identify a higher incidence of carotid (7%) and aortic (3%) injury which may reflect the shortened evacuation times in the wars in Iraq and Afghanistan (Figure 3). Currently, in-theater data indicated that casualties arrive at surgical care facilities within 2 hours of injury and often within 45 minutes.^{12,14,15} In contrast during WWII, the average time from point of injury to surgical care

was 12-16 hours.² Understanding the anatomic patterns of blood vessels most likely to be injured is useful as training and preparation is undertaken for support of combat missions (Figure 3).

The finding that ligation and reconstruction are currently used in nearly equal proportions to manage vascular injury is a compelling observation. On one hand the fact that 46% of injury is managed with repair or bypass confirms advances made in casualty evacuation, forward surgical care and reconstructive techniques.¹⁶⁻¹⁸ In 1946, DeBakey commented that “therapeutic measures designed to save the limb are applicable, at best, in not more than 20-25% of cases” on the battlefield. Findings from this study demonstrating that nearly 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 by 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 which focused nearly exclusively on methods of restoration of flow and vascular reconstruction.^{11,12,16} The findings on ligation from the current study do corroborate the recent report by Burkhardt et al. which demonstrated the effectiveness of a selective revascularization of the most common of vascular injuries, those at the tibial level.¹⁹

This study has limitations worth noting. Because only patients who received care at a level III facility in a theater of war are entered into the JTTR, this registry does not capture all of the casualties. It is likely that a small number of troops with vascular injury who died of wounds at 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 sub-identification of vessels (i.e. second or third order vessels) 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 which can be provided and makes imperfect comparison with publications originating from detailed operative logs. Lastly, this study does not address vascular injuries in the context of amputation. As this study is focused broadly on the distribution of wounding requiring conventional management strategies, injuries associated with immediate or traumatic amputation were not included.

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 training and combat support surgery. Ligation of vascular injury remains an important management strategy especially for minor or distal vascular injuries.

The opinions or assertions contained herein are the private views of the author and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

References

1. Bellamy RF. The cause of death in conventional land warfare: implications for combat casualty care research. *Mil Med.* 1984; 149(2):55-62.
2. DeBakey ME, Simeone FA. Battle injuries of the arteries in World War II: An analysis of 2,471 cases. *Ann Surg.* 1946; 123(4):534-79.
3. Otis GA, Huntington DL. The medical and surgical history of the War of Rebellion, Part III, Volume II, Surgical History. Government Printing Office, Washington, 1883.
4. Love AG. The Medical Department of the U.S. Army in the World War II, Part I, Chapter 3, Government Printing Office, Washington, 1927.
5. Bowlby A, Wallace C. The development of British Surgery at the front. *Brit Med J.* 1917; 1:705-21.
6. Emergency war surgery. Third United States revision. Washington, DC: Borden Institute; 2004; 27.
7. Hughes CW. Arterial repair during the Korean War. *Ann Surg.* 1958; 147 (4):555-561.
8. Hughes CW. The primary repair of wounds of major arteries: an analysis of experience in Korea in 1953. *Ann Surg.* 1955; 141(3):297-303.
9. Rich NM, Baugh JH, Hughes CW. Acute arterial injuries in Vietnam: 1,000 cases. *J Trauma.* 1970; 10(5):359-69.
10. Rich NM, Hughes CW. Vietnam vascular registry: a preliminary report. *Surgery.* 1969; 65(1):218-226.

11. Woodward EB, Clouse WD, Eliason JL, et al. Penetrating femoropopliteal injury during modern warfare: Experience of the Balad Vascular Registry. *J Vasc Surg.* 2007; 47(6):1259-65.
12. Clouse WD, Rasmussen TE, Peck MA, et al. In-theater management of vascular injury: 2 years of Balad Vascular Registry. *J Am Coll Surg.* 2007; 204(4):625-32.
13. Rasmussen et al. Echelons of care and the management of wartime vascular injury: a report from the 332nd EMDG/Air Force Theater Hospital, Balad Air Base, Iraq. *Perspect Vasc Surg Endovasc Ther.* 2006; 18(2):91-9.
14. Chambers LW, Rhee P, Baker BC, et al. Initial experience of US Marine Corps forward resuscitative surgical system during Operation Iraqi Freedom. *Arch Surg.* 2005; 140:26–32.
15. Lakstein D, Blumenfeld A, Sokolov T, et al. Tourniquets for hemorrhage control on the battlefield: a 4-year accumulated experience. *J Trauma.* 2003; 54:221–225.
16. Rasmussen TE, Clouse WD, Jenkins DH, et al. The use of temporary vascular shunts as a damage control adjunct in the management of wartime vascular injury. *J Trauma.* 2006;61(1):8-12.
17. Gifford SM, Aidinian G, Clouse WD, et al. Effect of temporary shunting on extremity vascular injury: an outcome analysis from the Global War on Terror vascular injury initiative. *J Vasc Surg.* 2009;50(3):549-55.
18. Gifford SM, Eliason JL, Clouse WD, et al. Early versus delayed restoration of flow with temporary vascular shunt reduces circulating markers of injury in a porcine model. *J Trauma.* 2009;67(2):259-65.
19. Burkhardt GE, Cox M, Clouse WD, et al. Outcomes of selective tibial artery repair following combat-related extremity injury. *J Vasc Surg.* 2010 May 13.

Figure and Table Legend

Figure 1: Historical Perspective on Wartime Vascular Injury Rates

Figure 2: Calculation of Specific and Operative Vascular Injury Rates

Figure 3: Most Common Vascular Injury Patterns

Figure 4: Rates of Vascular Injury in the wars in Iraq and Afghanistan

Figure 5: Temporal Profile of Vascular Injuries. Numbers of vascular injuries for OIF and 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

Table 1: Extremity Vascular Injuries

Table 2: Torso and Cervical Vascular Injuries

