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 major injury 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.

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

Joseph M. White, MD*, Adam Stannard, MRCS†, Gabriel E. Burkhardt, MD*, Brian J. Eastridge, MD*, Lorne H. Blackbourne, MD*, and Todd E. Rasmussen, MD‡

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a REPORT unclassified  
b ABSTRACT unclassified  
c THIS PAGE unclassified
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 (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,
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.

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

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.
ing a report from Clouse et al13–15 that reported a rate of nearly 5%.

In addition, 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 Kragh17 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. Beeckley et al18 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, DeBakey4 reported that 28% of arterial injuries occurred in distal or minor arteries. 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,5 includes distal or minor vessels.

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 Simeone4 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 al15–15 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,5 includes distal or minor vessels.

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The anatomic patterns of vascular injury in this study have similarities to those reported after WWII. Specifically, DeBakey4 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
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.\textsuperscript{14,17,19} In contrast during WWII, the average time from point of injury to surgical care was 12 to 16 hours.\textsuperscript{4} The observation of a higher percentage of cervical injuries confirms and extends reports from Owens and Clouse\textsuperscript{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.\textsuperscript{20–24} In 1946, DeBakey\textsuperscript{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 showing that ligation and reconstruction are currently used in nearly equal proportions to manage vascular injury. 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.

**REFERENCES**


