Thoracic injuries in US combat casualties: A 10-year review of Operation Enduring Freedom and Iraqi Freedom

Katherine M. Ivey, MD, Christopher E. White, MD, Timothy E. Wallum, MS, James K. Aden, PhD, Jeremy W. Cannon, MD, Kevin K. Chung, MD, Jeffrey D. McNeil, MD, Stephen M. Cohn, MD, *and* **Lorne H. Blackbourne, MD**

BACKGROUND: Mortality from thoracic injuries has declined significantly from 63% in the Civil War to 3% in Vietnam. We reviewed the injury patterns, procedures, blood products, and mortality of US soldiers sustaining a thoracic injury during Operation Enduring Freedom and Iraqi Freedom (OEF/OIF).

METHODS: Data on US soldiers with a thoracic injury during OEF/OIF from January 2003 to May 2011 was collected from the Joint Theater Trauma Registry. Coalition forces, civilians, and soldiers killed in action were excluded. Injuries and procedures were identified using DRG International Classification of Diseases 9th Rev. and Abbreviated Injury Scale (AIS) codes. Data are presented as mean (SD). Statistical analysis used χ^2 analysis and *t* test where appropriate.

RESULTS: Thoracic injuries occurred in 2,049 of 23,797 wounded US military personnel for a prevalence of 8.6%. Mean (SD) age was 26 (6.6) years, and mean (SD) chest AIS score was 2.9 (0.9). Penetrating trauma was the most common mechanism of injury (61.5%), and explosive devices were the most common cause of injury (61.9%). Of 6,030 thoracic injuries identified, pneumothorax and pulmonary contusions were most common (51.8% and 50.2%, respectively). Of 1,541 surgical procedures performed in theater, the most common was tube thoracostomy (47.1%). Most patients with penetrating fragmentation injuries (84%) were managed with tube thoracostomy as sole therapeutic intervention. The fresh frozen plasma to packed red blood cells ratio was 0.86. Overall mortality was 8.3%. Acute respiratory distress syndrome and inhalation injury were associated with mortality ($p < 0.006$).

CONCLUSION: Most penetrating fragmentation injuries can be managed with tube thoracostomy. Mortality of patients with chest injury in OEF/OIF is higher than in Korea and Vietnam. This most likely represents advances in prehospital care, personal protective equipment, and rapid transport that have resulted in more severely injured patients arriving alive to a medical facility. (*J Trauma Acute Care Surg*. 2012;73: S514 S519. Copyright © 2012 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Epidemiologic study, level IV.

KEY WORDS: Thoracic injury; fragmentation injury; tube thoracostomy; Operation Enduring/Iraqi Freedom; US soldiers.

Historically, thoracic injuries have been a significant source of mortality in combat casualties (Fig. 1). Before World War I (WWI), the mortality rate from these wounds exceeded 50%. Positive-pressure ventilation was introduced in the late 1890s and was used to treat pulmonary edema in combat casualties during WWI.[1] Transfusions with whole blood were also performed in combat hospitals during WWI.[2] During World War II (WWII), addition of supplemental oxygen, use of penicillin, and restricted use of thoracotomy contributed to a dramatic decrease in mortality to approximately 10%.[3]

Mortality from thoracic injuries continued to decrease in the second half of the 20th century. Studies from Korea, Vietnam, and Bosnia showed further reduction in mortality related to thoracic injuries to 2% to 3%.[4–6] During the Korean War, helicopters became the main patient transport modality, and combat hospitals were established to care for wounded soldiers. This trend continued through the Vietnam War. As the transport system improved, specified echelons of medical care were developed with increasing medical capabilities at each level.[7,8]

The combat environment of Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) has differed greatly from previous conflicts. Enemy forces are not easily identified from the civilian population, and most attacks on US military forces use mortar and improvised explosive devices rather than direct attacks as seen during WWII, Korea, and Vietnam. With the addition of personal body armor, thoracic injuries have become less common during OEF and OIF compared with previous wars.[9] However, these injuries can be devastating (Fig. 2), and proper treatment is paramount to survival. The purpose of our study was to provide an overview of thoracic injuries in US military forces during OEF/OIF since 2003. In particular, we addressed the injury patterns, blood product use, reported complications, and mortality related to thoracic injuries sustained during OEF/OIF.

PATIENTS AND METHODS

This study was conducted under a protocol reviewed and approved by the US Army Medical Research and Materiel

From the Department of General Surgery, San Antonio Military Medical Center Department of General Surgery (K.M.I, C.E.W., J.W.C), Fort Sam Houston Texas; the US Army Institute of Surgical Research (T.E.W., J.K.A., K.C.K, L.H.B.), Fort Sam Houston, Texas; the Department of Surgery, University of Texas Health Sciences Center at San Antonio (S.M.C.), San Antonio, Texas; and Department of Surgery, Uniformed Services University of the Health Sciences (J.W.C.), Bethesda, Maryland.

Address for reprints: Katherine M. Ivey, MD, San Antonio Military Medical Center, 4241 George C. Beach, Fort Sam Houston, TX 78234; email: katherine.ivey@amedd.army.mil.

DOI: TA.0b013e3182754654

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **01 DEC 2015**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Thoracic injuries in US combat casualties: A 10-year review of Operation Enduring Freedom and Iraqi Freedom**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Ivey K. M., White C. E., Wallum T. E., Aden J. K., Cannon J. W., Chung K. K., McNeil J. D., Cohn S. M., Blackbourne L. H.,**	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	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT	b ABSTRACT	c THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

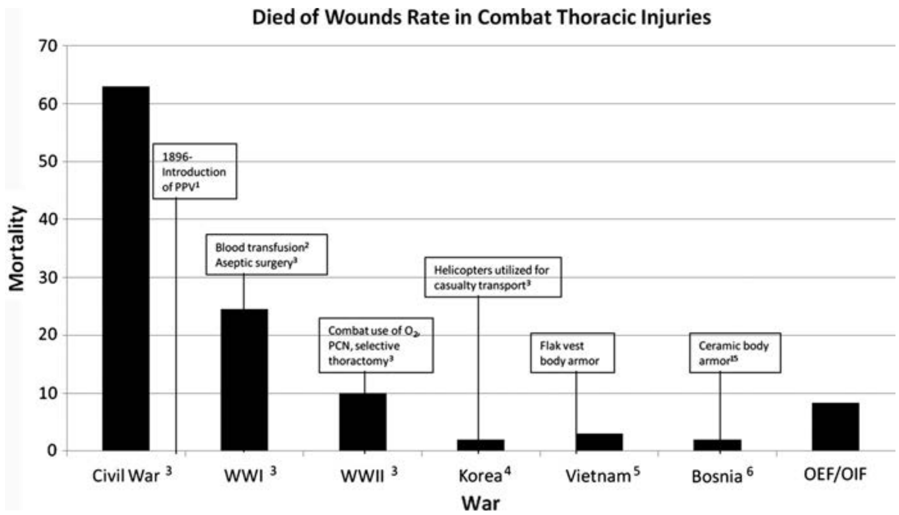

Figure 1.+-. Mortality (DOW) rate related to thoracic injuries since American Civil War. PPV, positive-pressure ventilation, O_2, oxygen, PCN, penicillin.

Command Institutional Review Board and in accordance with the approved protocol.

Joint Theater Trauma Registry

The Joint Theater Trauma Registry (JTTR) is a database established in 2001 to accumulate information on combat injuries, such as mechanism of injury, injuries sustained, blood products received, and procedures performed. This database is similar in design and purpose to the National Trauma Data Bank and other civilian trauma registries. As patients are treated throughout the evacuation chain, data are collected at each echelon of care and recorded in the database by assigned personnel. Since its inception, the JTTR has become a key component in combat trauma research and in the quality improvement of care on the battlefield.[10]

Data Extraction

The JTTR was queried for US combat casualties from all military branches, who were treated for any thoracic injury from January 2003 to May 2011. Patients who were reported as killed in action (KIA) or dead on arrival were excluded from analysis. Patients with thoracic injuries were identified using DRG International Classification of Diseases—9th Rev. (ICD-9), and Abbreviated Injury Scale (AIS) injury codes. Thoracic procedures performed in theater were identified using ICD-9 codes. Additional information gathered from the JTTR database included basic demographics, mechanism of injury, total blood products received in theater, additional injuries, Injury Severity Score (ISS), AIS, and complications.

Figure 2. Wounded soldier with penetrating fragmentation thoracic injury caused by an explosive device.

Data Analysis

Numerical data, such as age ISS, and so on, are reported as means (SD) and are analyzed using Student's *t* test. Categorical data, such as theater, sex, mortality, and so on, are presented as proportion of the total patient cohort and are analyzed using the χ^2 test. Patients with no documented surgical procedures were excluded from the analysis of interventions. Patients with missing blood product data were assumed to have not received blood products and were excluded from the analysis of blood product use.

RESULTS

Patient Demographics

From January 2003 to May 2011, there were 23,797 US military members injured in OEF/OIF, treated at US medical facilities and subsequently entered into the JTTR database. Of these, 2,048 patients sustained a thoracic injury for an overall prevalence of 8.6%. Most patients were male (97.9%) and served in the Army (75.5%). Marines had the second highest number of thoracic injuries with 19.5%; Navy was third at 2.8%; and the Air Force had the fewest (2.2%). Mean (SD) patient age was 26 (6.6) years. Mean (SD) ISS was 22.6 (14.1). ISS was less than 16 in 35.5% of patients, between 16 and 24 in 27% of patients, and greater than 25 in 37.5%. Mean (SD) chest AIS score was 2.93 (1), and median chest AIS was 3 with an interquartile range of 4. Mean (SD) ventilator, intensive care unit, and hospital days were 3.4 (7.2), 5.7 (11.2),

TABLE 1. Number of Thoracic Injuries and Percentage of Patients Sustaining That Injury

Injury	n (%)
Pneumothorax	1,061 (51.8)
Pulmonary contusion	1,028 (50.2)
Rib fractures	717 (35)
Hemothorax	615 (30)
Other chest injury	494 (24.1)
Open chest wound	264 (12.9)
Thoracic spine injury	299 (14.6)
Inhalation injury	295 (14.4)
Scapula fracture	219 (10.7)
Other major vessel injury	196 (9.6)
Lung laceration	190 (9.3)
Diaphragm	141 (6.9)
Clavicle fracture	109 (5.3)
Tracheal injury	55 (2.7)
Other heart injury	45 (2.2)
Sternal fracture	41 (2)
Heart laceration	33 (1.6)
Thoracic esophageal injury	31 (1.5)
Blast lung	28 (1.4)
Flail chest	26 (1.3)
Vena cava injury	13 (0.6)
Bronchus injury	12 (0.6)
Aortic injury	12 (0.6)

and 15 (24.3), respectively. Seven hundred eighty-six patients (38.3%) did not require mechanical ventilation. Although most injuries were combat related, 337 patients (16.4%) sustained a nonbattle-related thoracic injury.

Injury Characteristics

A total of 6,030 thoracic injuries were identified for an average of 3 injuries per patient (Table 1). Pneumothorax was the most common thoracic injury (51.8%), followed by pulmonary contusions (50.2%) and rib fractures (35%). More injuries occurred in OIF (69.8%) than in OEF (30.2%). Penetrating trauma was the most common mechanism of injury (61.5%) overall and during each year of conflict (Fig. 3). Of note, use of blast injury as a mechanism of injury decreased in 2007 when injury classification was changed to primarily blunt or penetrating. The most common source of injury was explosive devices (61.9%), followed by gunshot wound (19.4%) and motor vehicle collisions (8.6%).

Procedures Performed in Theater

There were a total of 1,541 thoracic surgical procedures reported in theater. Most procedures (87.9%) were performed at Level III facilities. The most common surgical procedure was tube thoracostomy (47.1%). Fourteen tube thoracostomies were performed at Level I and 116 were performed at Level II facilities. Other procedures performed in theater are listed in Table 2. Of the patients with penetrating fragmentation injuries to the thorax, 84% were managed with tube thoracostomy alone, whereas 16% underwent a thoracotomy. In the overall patient cohort, 18 patients (0.9%) received prehospital cardiopulmonary resuscitation (CPR), and 53 patients (2.6%) underwent CPR after arrival to the treatment facility.

Complications

There were 1,790 pulmonary complications reported in this patient cohort. Of these, atelectasis was the most common pulmonary complication (38.9% of patients); pleural effusion was the second most common (27.3%); and pneumonia was the third (11.6%). Other pulmonary complications include pulmonary edema (8.3%), subcutaneous emphysema (5.8%), adult respiratory distress syndrome (3.5%), acute respiratory failure (1.7%), and empyema (1.2%). Venous thromboembolism (deep venous thrombosis and pulmonary embolism) were reported in 154 patients (7.9%). Nonpulmonary complications included coagulopathy (15.4%), shock (7%), bacteremia (5%), and sepsis (2.7%).

Blood Products

Blood products used in theater include fresh whole blood, packed red blood cells (pRBCs), fresh frozen plasma

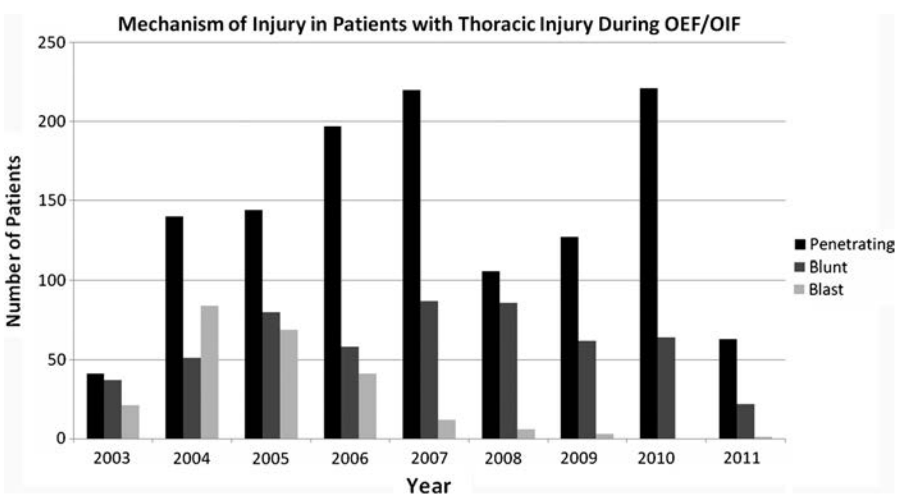

Figure 3. Thoracic injuries by mechanism per year. Of note, blast injury was considered a mechanism of injury until 2007, when injury classification changed to blunt or penetrating.

TABLE 2. Surgical Procedures Performed in Theater

Procedure	n (%)
Tube thoracostomy	964 (47.1)
Bronchoscopy	215 (10.5)
Thoracotomy	176 (8.6)
Needle decompression	134 (6.5)
Diaphragm repair	87 (4.2)
Tracheotomy	82 (4)
Major vessel ligation	45 (2.2)
Partial lung resection	44 (2.1)
Pericardiotomy	29 (1.4)
Open cardiac massage	29 (1.4)
Other lung procedures	25 (1.2)
Other heart procedures	20 (1)
Inferior vena cava filter placement	19 (0.9)
Aortic occlusion	13 (0.6)
Tracheal Repair	11 (0.5)
Lobectomy	10 (0.5)
Esophageal repair	8 (0.4)
Pneumonectomy	4 (0.2)

(FFP), platelets, and cryoprecipitate. These products were generally used at Level II and Level III facilities. A breakdown of blood product use from theater is shown in Table 3. There were 192 patients (9.4%) who received platelets in theater. The overall ratio of FFP to pRBCs was 0.86. Comparison of blood product use between survivors and nonsurvivors yielded a significantly higher amount of total fresh whole blood ($p < 0.0001$), pRBCs ($p < 0.0001$), cryoprecipitate ($p < 0.0001$), and FFP ($p < 0.0001$) in nonsurvivors. However, the FFP/pRBC ratio was not significantly different between the two groups: 0.89 in survivors versus 0.93 in nonsurvivors.

Mortality

Overall mortality in this patient cohort (US military with chest injuries during OEF/OIF) was 8.3% (169 of 2,048). Of these, 118 (69%) died in theater, 27 (15.8%) died at Landstuhl, and 26 (15.2%) died after return to the United States. There was a higher mortality rate in OIF patients (9.2%) compared with OEF (6.2%, $p = 0.02$). In addition, there was a higher mortality rate for patients with blast injury (17.9%) versus penetrating injury (8.02%) versus blunt injury (4.57%, $p < 0.001$). Of patients who received prehospital CPR, only 16.7% survived; 25% of patients who had in-hospital CPR survived.

Factors associated with a higher mortality included inhalation injury ($p = 0.006$), acute respiratory distress syndrome ($p < 0.0001$), bacteremia ($p < 0.04$), sepsis ($p < 0.01$), coagulopathy ($p < 0.0001$), and shock ($p < 0.0001$). Pneumonia and rib fractures were not associated with an increased risk of mortality. Sex, age, ventilator days, and intensive care unit days were not different between survivors and nonsurvivors.

ISS was higher in nonsurvivors (34.7 [17.9]) than in survivors (21.5 [13.2], $p < 0.0001$). The severity of thoracic injury as graded by AIS was more severe in nonsurvivors (3.4 vs. 2.8, $p < 0.0001$). Of patients who did not survive, 42% had head/neck injuries, 33% had facial injuries, 35% had intra-abdominal injuries, 45% had pelvic/extremity injuries, and 63% had skin/soft tissue injuries. Nonsurvivors also had more severe head/neck and skin/soft tissue injuries than survivors ($p < 0.01$). Severity of abdominal, extremity, and pelvic injuries were not different between survivors and nonsurvivors.

DISCUSSION

This article provides an updated overview of thoracic injuries in US military forces injured in OEF/OIF from January 2003 to May 2011. The prevalence of thoracic injuries in US military casualties included in this study was 8.6% with a mortality rate of 8.3%. Compared with a previous study by Propper et al.,[11] our study has a higher prevalence of thoracic injury (8.6% vs. 4.9%) but a lower mortality rate (8.6% vs. 11.7%). The higher prevalence rate is likely related to the larger patient cohort in our study (2,048 vs. 565 patients[11]), which is likely caused by a combination of factors. First, the JTTR is not a real-time database: data is not entered at the time of patient injury (Schadee J, personal communication, May 2012). Thus, patients may have been injured early in the conflict, but data on their injuries were entered at a later time.

Second, in addition to using ICD-9 diagnosis codes, patients with AIS injury codes for thoracic injuries were identified and included in this study. AIS, an international coding scheme first introduced in 1971, describes both the anatomic location and the severity of traumatic injuries.[12] Severity is rated from 1 to 6 and correlates with minimal to maximal injury.[13] Inclusion of patients with AIS injury codes increased identification of thoracic injuries because not all patients had an ICD-9 diagnosis code for the related injury. Last, we included patients with nonbattle-related thoracic injuries, which accounted for 16.4% of thoracic injuries. The two most common causes of these injuries were motor vehicle collisions and falls. Awareness of these injuries should be reinforced to all deploying medical providers as well as line duty officers because these injuries could affect mission capabilities of our military forces.

The mean ISS in this study was 22.6 and was higher than the ISS of 16.1 reported by Propper et al.,[11] suggesting that our patient cohort was more severely injured. As the war progressed, the weapons and tactics used by enemy forces changed. The improvised explosive device and mortar attacks have become the weapons of choice for enemy forces during OEF and OIF. Sixty-two percent of patients in our cohort were injured by explosive devices. Use of body armor can protect the solider from direct thoracic penetration of bullets and explosive fragments.[14] Experiments using anthropomorphic human dummies have shown that there is an increase in intrathoracic pressure

TABLE 3. Total Blood Product Use in Theater

Blood Product	No. Patients (%)	Total Units	Unit Per Patient Index
pRBCs	775 (37.8)	8,549	11
FFP	711 (34.7)	7,391	10.4
Cryoprecipitate	264 (12.9)	990	3.75
Fresh whole blood	126 (6.1)	915	7.3

from the impact of the projectiles on body armor.[15] This pressure can result in minor intrathoracic injuries. In the present study, 27.5% of patients classified as "penetrating trauma" did not have a penetrating thoracic injury: they sustained penetrating injuries to other body regions, such as the abdomen or extremities, with a concurrent mild thoracic injury, such as pulmonary contusion or rib fracture.

In the civilian setting, 85% of penetrating thoracic injuries can be managed with tube thoracostomy alone,[16] whereas 10% to 15% of patients will require a formal thoracotomy.[17] These rates have yet not been studied in the current war. This study showed that 47.1% and 8.6% of patients overall were managed with tube thoracostomy or thoracotomy, respectively. For patients with penetrating fragmentation injuries to the thorax, 84% were managed with tube thoracostomy alone, whereas 16% underwent thoracotomy. Thus, most penetrating fragmentation injuries can be managed with tube thoracostomy alone.

Fluid resuscitation in trauma patients has been a focus of much research in recent years. During the Vietnam War, isotonic sodium lactate and sodium chloride were the primary resuscitative fluids.[18] However, large-volume crystalloid resuscitation has now been associated with worsening coagulopathy and higher mortality.[19,20] A recent prospective study of 3,137 patients who received crystalloid solutions during resuscitation demonstrated a twofold increase risk of mortality for patients who received 1.5 L of crystalloid.[21] A shift toward using blood products in trauma resuscitation has now developed. Current guidelines advocate an FFP/pRBC ratio of 1:1, and mortality in combat causalities is improved when ratios close to 1:1 are used.[22] In this study, the FFP/pRBC ratio was 0.86 overall, which shows excellent compliance with current Joint Trauma Theater System clinical practice guidelines. Although there was no statistical difference in transfusion ratios, patients who did not survive received more blood products than survivors because they had more severe head, face, and thoracic injuries.

In the combat environment, limited storage capacity often restricts the amount of blood products available at forward aid stations for resuscitation. During WWI, transfusions of whole blood were used regularly, and blood banking was not formalized until 1929.[2] Thus, use of "walking blood bank" from uninjured, healthy US troops is not a new concept in combat and can be used when the needs of severely injured patients exceed available resources. Whole-blood transfusions were used in 6.1% of patients in this cohort. Whole blood was also used early in OEF/OIF because isolated units of platelets were unavailable. Beginning in 2005, plasmapheresis for collection of platelets became available, which yields a unit of "apheresis" platelets from a single donor. This single apheresis unit is approximately equivalent to 5 to 6 U of pooled platelets; however, apheresis units have a brief shelf life of 5 days and require specialized equipment. Consequently, whole blood remains a viable option for surgeons treating combat casualties with devastating injuries, especially in far-forward settings.

Mortality of combat casualties is defined as either KIA or died of wounds (DOW).[23] A combat casualty is classified as KIA if he or she dies before arrival at a medical treatment facility (MTF).[23] Casualties who die after arriving at an MTF are classified as DOW.[23] This study excluded KIA and patients who were dead on arrival; thus, the mortality rate reported reflects the DOW rate. Since the Civil War, the DOW rate of patients with thoracic injuries has decreased (Fig. 1). This improved survival rate can be attributed to several medical advancements. In WWI, positive-pressure ventilation was used to treat posttraumatic pulmonary edema;[1] aseptic surgery was becoming standard surgical practice;[3] and blood transfusions were used in battlefield hospitals.[2] During WWII, combat surgeons incorporated supplemental oxygen use for both ventilated and nonventilated patients[1] as well as penicillin to treat thoracic infections.[3] Selective thoracotomy with defined indications was developed during the latter part of WWII and resulted in a lower overall mortality rate compared with mandatory thoracotomy.[3] These lessons were carried through Korea and Vietnam, where use of helicopters allowed faster transport of patients to the theater hospitals instead of first aid stations[23] and surgical intervention could be provided before irreversible physiologic derangements occurred. The flak vest worn over the thorax during Vietnam War may have reduced thoracic penetration of low-velocity projectiles. During the Somalia conflict, modern body armor further reduced the percentage of fatal, penetrating thoracic injuries.[14]

This study reports a DOW mortality rate that is higher than that of Korea and Vietnam wars. Several factors are suspected to play a role. The most influential factor in this increase is the definition of combat casualties as described previously. Combat casualties who die after arriving to any MTF, even a Level I facility, which does not have a surgeon present, are considered DOW. In addition, modern forward surgical teams are designed to be positioned closer to the battlefield. Thus, soldiers with significant injuries who would have died on the battlefield are now being classified as DOW instead of KIA. Improvements in personal protective equipment and increased use of combat tourniquets have also played a role in that they decrease death on the battlefield and allow more severely injured soldiers to survive until arrival at the MTF. Increased mortality rate is also related to complications after injury such as bacteremia, coagulopathy, and adult respiratory distress syndrome in these severely injured patients. Development of these complications was associated with a higher risk of mortality.

Despite the higher mortality rate compared with previous conflicts, this study had a lower mortality rate compared with a previous report of OEF/OIF thoracic injuries by Propper et al.[11] (8.3% vs. 11.7%). Management of thoracic injuries likely improved as many medical personnel deployed multiple times during the course of the conflict. Previous experience with injured soldiers may have resulted in anticipation, better recognition, and earlier intervention of thoracic injuries. In addition, as the conflict progressed, permanent medical facilities were established with availability of specialty services and resources.[8] Last, protective equipment, such as body armor and armored vehicles, may have changed during the conflict to decrease the severity of injury or prevent it altogether.

This study has several limitations. First, the design of the JTTR database is an important limitation. Injuries, procedures, and complications are listed by ICD-9 or AIS code; the exact dates of operations and onset of complications are unknown. Thus, determining when a complication occurs (i.e., early or late) and what effect that has on mortality cannot be addressed by this article and warrants further study with detailed patient record review. Another limitation of this article is accuracy of data entered into the JTTR. For example, 24% of patients with penetrating thoracic injury did not list any documented procedure, such as tube thoracostomy or thoracotomy procedure. It is unlikely that combat casualties with documented pneumothorax or hemothorax were evacuated from theater without, at a minimum, a tube thoracostomy placed. In times of mass casualty events, it is plausible that some injuries or procedures are not accurately recorded. The third limitation is that the JTTR database did not contain information on US troops treated at North Atlantic Treaty Organization facilities until late 2008 (Schadee J, personal communication, May 2012); thus, data from these facilities before this time could not be included in this study. Finally, the JTTR database does not contain data on exact cause of death (Schadee J, personal communication, May 2012). Although 8.3% of patients in this cohort did not survive, it is unknown what percentage of those patients died as a result of their thoracic injury or from another injury, such as head injury or hemorrhage from multiple traumatic amputations.

This is the largest patient cohort of thoracic injuries during OEF/OIF studied to date. Thoracic injury caused by penetrating trauma from explosive devices has become the top trend. Incidence of thoracic injury is rising, but the overall mortality is decreasing from previous reports. With improved awareness of this injury pattern and capability to intervene early in the injury timeline, more lives can potentially be saved.

AUTHORSHIP

K.M.I. performed the literature searches and data analysis and interpretation; designed article figures; and was the primary author of the article. C.E.W. was instrumental in designing the study protocol and also contributed to the literature search, data interpretation, and article writing. T.E.W. wrote the study protocol, collected data, and assisted with the data analysis. J.K.A. performed all statistical analysis and assisted with the data interpretation. J.W.C. participated in the study design and article writing. K.K.C. participated in the study design and article writing. J.D.M. participated in the study design and article writing. S.M.C. participated in the literature search, study design, and article writing. L.H.B. participated in the literature search, study design, and article writing.

ACKNOWLEDGMENT

We acknowledge JTTR personnel for providing data for this study. We also thank Dr. Amy Apodaca, Ms. Janet Schadee, and Ms. Susan West for their contributions to this study.

DISCLOSURE

The authors declare no conflicts of interest.

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