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QUERI

# Prevalence and Epidemiology of Combat Blast Injuries from the Military Cohort 2001-2014

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# PREFACE

Quality Enhancement Research Initiative's (QUERI) Evidence-based Synthesis Program (ESP) was established to provide timely and accurate syntheses of targeted healthcare topics of particular importance to Veterans Affairs (VA) clinicians, managers and policymakers as they work to improve the health and healthcare of Veterans. The ESP disseminates these reports throughout the VA, and some evidence syntheses inform the clinical guidelines of large professional organizations.

QUERI provides funding for four ESP Centers and each Center has an active university affiliation. The ESP Centers generate evidence syntheses on important clinical practice topics, and these reports help:

- develop clinical policies informed by evidence;
- guide the implementation of effective services to improve patient outcomes and to support VA clinical practice guidelines and performance measures; and
- set the direction for future research to address gaps in clinical knowledge.

In 2009, the ESP Coordinating Center was created to expand the capacity of HSR&D Central Office and the four ESP sites by developing and maintaining program processes. In addition, the Center established a Steering Committee comprised of QUERI field-based investigators, VA Patient Care Services, Office of Quality and Performance, and Veterans Integrated Service Networks (VISN) Clinical Management Officers. The Steering Committee provides program oversight, guides strategic planning, coordinates dissemination activities, and develops collaborations with VA leadership to identify new ESP topics of importance to Veterans and the VA healthcare system.

Comments on this evidence report are welcome and can be sent to Nicole Floyd, ESP Coordinating Center Program Manager, at Nicole.Floyd@va.gov.

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# EVIDENCE REPORT

## INTRODUCTION

### BACKGROUND

Combat blast injuries are typically categorized by the mechanism of injury.[1-5] Primary blast injuries result from the over-pressurization wave and typically affect gas-filled body structures (*eg*, lungs, gastrointestinal tract, middle ear) resulting in injuries such as blast lung, tympanic membrane rupture, abdominal hemorrhage, and concussion. Secondary blast injuries result from flying debris propelled by the blast wind and may affect any body part. Blunt force or penetrating injuries are possible. Tertiary blast injuries occur when the body is accelerated by the blast wind or pressure gradients. Any body part may be affected and typical injuries include fracture and traumatic amputation, closed and open brain injuries, and crush injuries. Quaternary blast injuries are due to other products of the explosion (*eg*, heat, light) and exposure to toxins and gases. Any body part may be affected and injuries include burns, blindness, and respiratory problems from inhaled toxic gases. Quinary blast injuries include illnesses, injuries, and diseases resulting from post-explosion environmental contaminants (*eg*, bacteria, radiation). Factors such as type of explosive, distance from the explosion, and body orientation relative to the explosion influence the impact of the explosion on the body.[4]

Despite recognition of greater use of improvised and other explosive devices in the Afghanistan and Iraq War counter-insurgency operations relative to prior conflicts, the scientific literature regarding the incidence and prevalence of explosive device induced injuries is limited. Additionally, the consequences of experiencing a traumatic brain injury (TBI) related to blast exposure versus a TBI due to other mechanisms of injury (*eg*, motor vehicle accident, fall) may be different.[3,4] Accurate assessment of the incidence and prevalence of blast and non-blast-related injuries as well as their long-term outcomes is a critical first step in injury prevention, treatment, and health system resource management. The purpose of this report is to systematically review the literature on 1) incidence and prevalence of combat blast injuries sustained during Operation Enduring Freedom (OEF), Operation Iraqi Freedom (OIF), and Operation New Dawn (OND) 2001 through 2014 and 2) the outcomes (*eg*, pain, vision loss, cognitive function, quality of life) following blast versus non-blast TBI.

We developed the following key questions for this review with input from stakeholders and Technical Expert Panel (TEP) members:

**Key Question #1:** What is the incidence of combat blast injuries associated with OEF, OIF, and OND as reported in the literature or in published reports from Department of Defense (DoD) and VA databases during the period 2001-2014?

> **Key Question #1a:** What is the incidence by blast characteristics (*ie*, primary, secondary, tertiary, quaternary, and quinary),[1,2] injury site, and injury outcome?

**Key Question #2:** What is the prevalence of combat blast injuries associated with OEF, OIF, and OND as reported in the literature or in published reports from Department of Defense (DoD) and VA databases during the period 2001-2014?

**Key Question #2a:** What is the prevalence of blast injury by blast characteristics, injury site, and injury outcome?

**Key Question #3:** What are the short-term (up to 30 days), mid-term (30 days to one year) and long-term (greater than one year) injury outcomes (*ie*, pain, burns, limb loss, vision loss, hearing loss, vestibular dysfunction, PTSD, cognitive function, quality of life, functional status/employment, other) among US military personnel (2001-2014) who have sustained a blast-related TBI versus a non-blast TBI or a combined blast/non-blast TBI?

**Key Question #3a:** What are the short-term (up to 30 days), mid-term (30 days to one year) and long-term (greater than one year) injury outcomes among US military personnel (2001-2014) who have sustained a blast-related TBI according to blast characteristics?

## PICOTS

The Population, Intervention, Comparator, Outcomes, Timing, and Setting (PICOTS) for the review are outlined below and displayed on analytic frameworks for Key Questions (KQ) 1 and 2 (Figure 1) and KQ 3 (Figure 2)

Population: Military cohort 2001-2014

Intervention: Combat blast injury (KQ1, KQ2) or blast-related TBI (KQ3)

Comparator: Non-blast or combined blast/non-blast TBI (KQ3)

Outcomes: Incidence and prevalence of combat blast injuries by blast characteristics, injury site, and injury outcome (KQ1, KQ2); injury outcomes for blast versus non-blast or combined TBI and injury outcomes by blast characteristics for blast-related TBI (KQ3)

Timing: Any duration from time of exposure (duration to be reported if available); injury outcomes categorized as short-term (up to 30 days after blast), mid-term (30 days to one year), and long-term (greater than one year)

Setting: Any active service setting (*ie*, training, deployment).

**Figure 1. Analytic Framework for Key Questions 1 and 2**

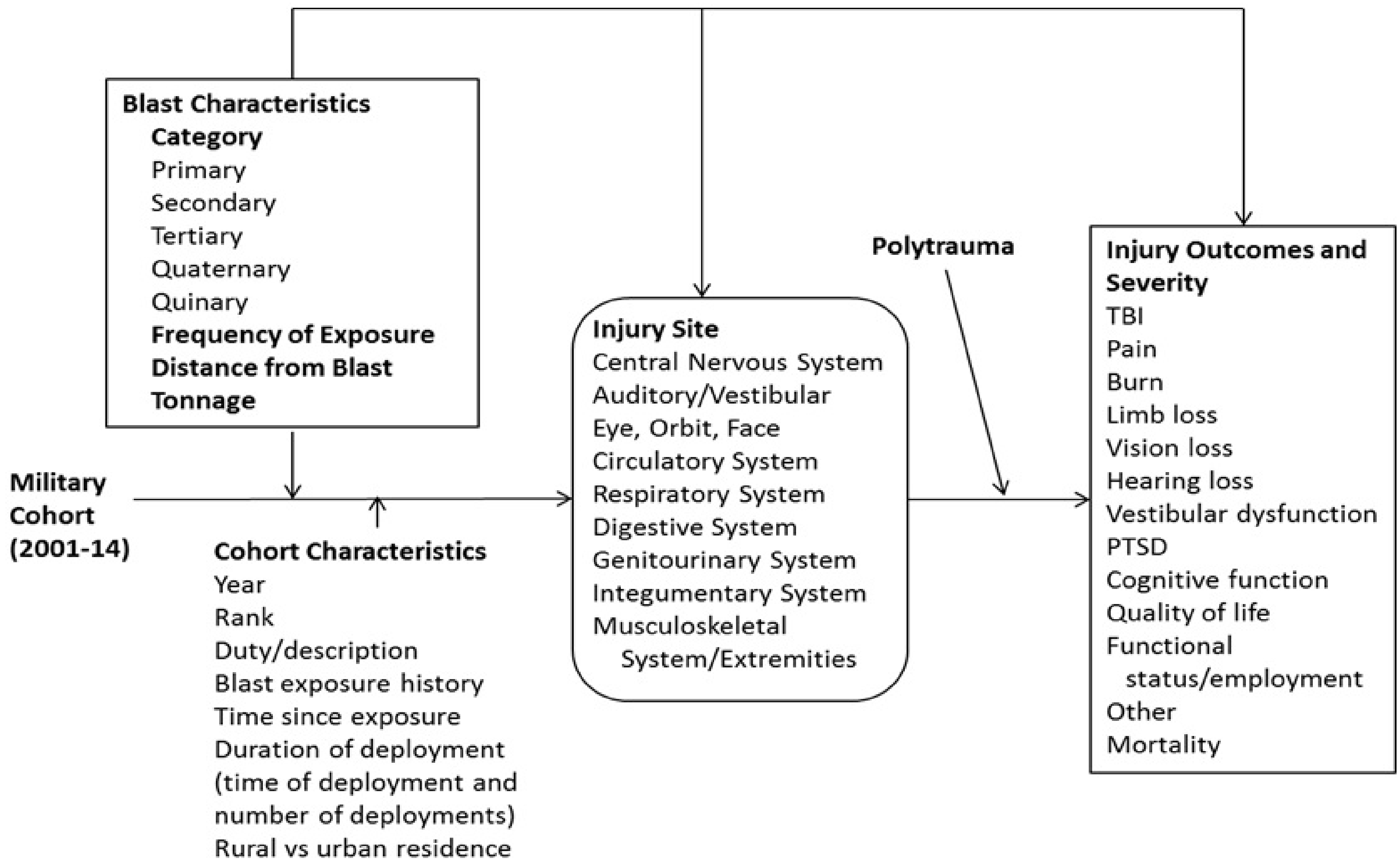
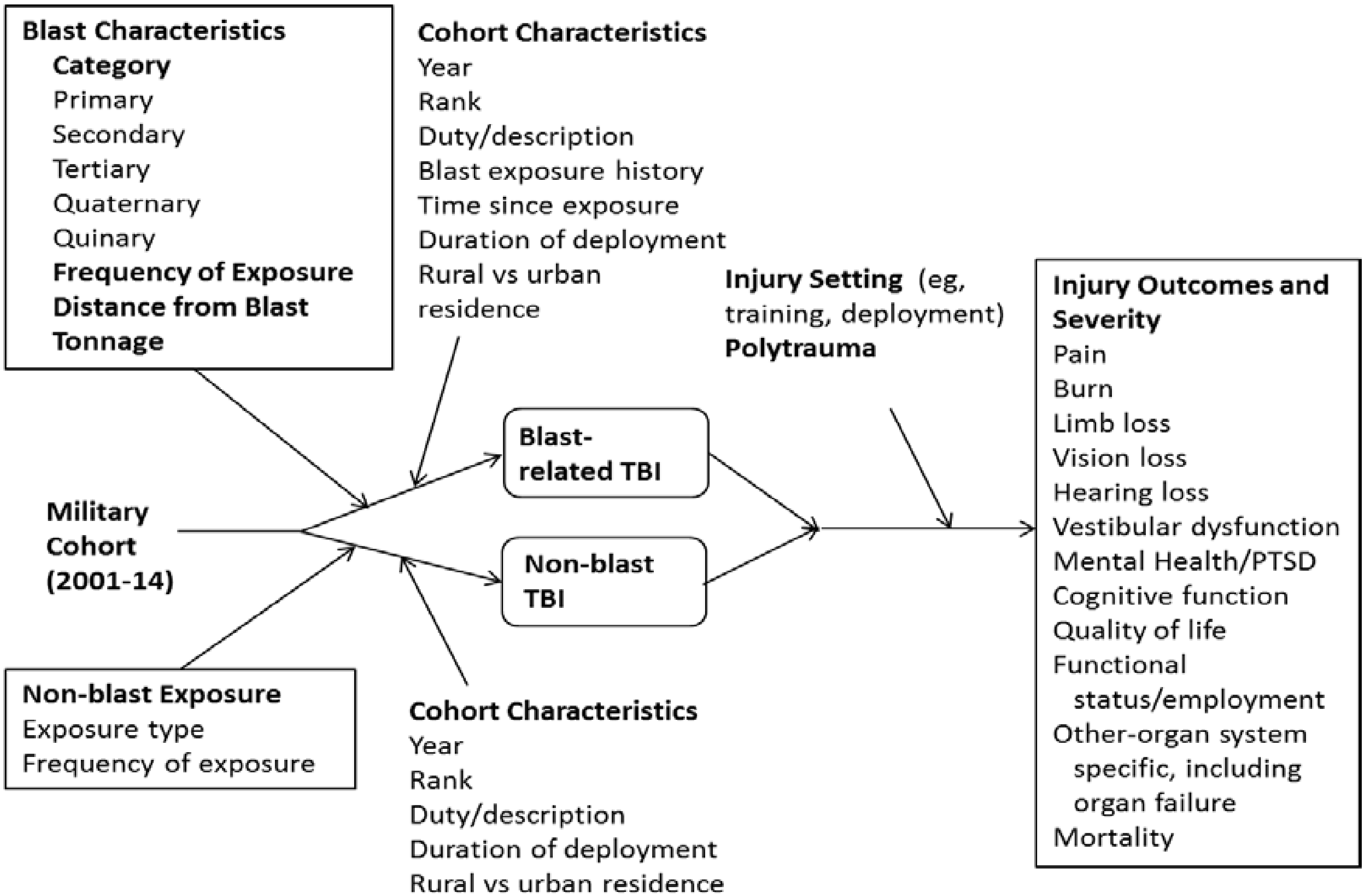


**Figure 2. Analytic Framework for Key Question 3**



# METHODS

## TOPIC DEVELOPMENT

This topic was nominated by Ralph DePalma, MD, Special Operations Office, Office of Research and Development. Additional stakeholders included: David Cifu, MD, Chair, VHA TBI Advisory Committee; Stuart Hoffman, PhD, Scientific Program Manager for Brain Injury, Rehabilitation Research and Development Service; and Col. Todd Rasmussen, MD, Director, Combat Casualty Care Research Program, US Army Medical Research and Materiel Command. Information on the incidence and prevalence of combat blast injuries and the outcomes of blast-related and non-blast TBI may be used to allocate research funding appropriately to improve care for Veterans with blast injuries and/or TBIs.

## SEARCH STRATEGY

We searched MEDLINE (Ovid) for articles published in English from 2000 through April 2015 using separate search strategies for Key Questions 1 and 2 and Key Question 3. Our searches were designed to identify studies of combat injuries in US military personnel during OEF, OIF, and OND. The searches included the MeSH terms Brain Injuries; Wounds, Nonpenetrating; Wounds, Penetrating; Afghan Campaign 2001-; Iraq War, 2003-2011; and Military Personnel. The full search strategies are presented in Appendix A. We obtained additional articles by hand-searching the table of contents of Journal of Trauma-Injury Infection & Critical Care and reference lists of systematic reviews and other reports, and from references suggested by the topic stakeholders and TEP members.

## STUDY SELECTION

Abstracts from the MEDLINE searches were reviewed in duplicate by investigators and research associates and abstracts from the table of contents search were reviewed by a single investigator. We identified for full-text review studies of any design potentially relevant to the key questions. Two investigators or research associates independently reviewed full-text articles excluding the following:

- Studies not including US military personnel from OEF, OIF, or OND (2000-2014);
- Studies not involving combat injuries;
- Modeling studies (*eg*, mechanical/engineering models, animal studies);
- Studies not relevant to the key questions;
- Studies of treatment outcomes;
- Imaging studies or studies reporting changes in tissue (*eg*, white matter);
- Case reports;
- Studies for Key Questions 1 and 2 where the denominator was not the number deployed during the study period (*ie*, reports of injuries at a medical facility were excluded); and
- Studies for Key Question 3 that did not report outcomes of interest for blast-related TBI and non-blast TBI groups (*ie*, studies only reporting on blast-related TBI were excluded).

## DATA ABSTRACTION

For Key Questions 1 and 2, study characteristics (data source, inclusion/exclusion criteria, cohort characteristics) and outcomes (blast injury incidence, blast injury prevalence) were extracted into evidence tables by one investigator or research associate and verified by another. For Key Question 3, study characteristics (data source, inclusion exclusion criteria, cohort characteristics, outcome measures used) and outcomes (mortality, pain, burns, limb loss, vision loss, hearing loss, vestibular dysfunction, PTSD, cognitive function, quality of life, functional status/employment, other) for blast-related TBI and non-blast TBI patients were extracted into evidence tables by one investigator or research associate and verified by another.

## RISK OF BIAS ASSESSMENT

We did not assess the risk of bias of the included studies, although risk of bias for each study was likely moderate or high due to the study design used, selective population studied, and failure to control for potential confounding factors.

## DATA SYNTHESIS

We created summary tables with incidence and prevalence results (Key Questions 1 and 2). We organized evidence tables for Key Question 3 by outcome and time since exposure (<30 days, 30 days to 1 year, >1 year, or not specified). Pooled analyses were not possible due to heterogeneity of the study populations and outcome measures.

## RATING THE BODY OF EVIDENCE

We did not formally rate the overall strength of evidence for outcomes. The typical approach to assessing strength of evidence considers consistency, precision, directness, and risk of bias of the included studies. However, because included studies were observational and there was limited reporting of outcomes of interest (*ie*, most outcomes reported in only a few studies and often using different measures), it is unlikely that strength of evidence would be anything above low. Many outcomes had insufficient evidence.

## PEER REVIEW

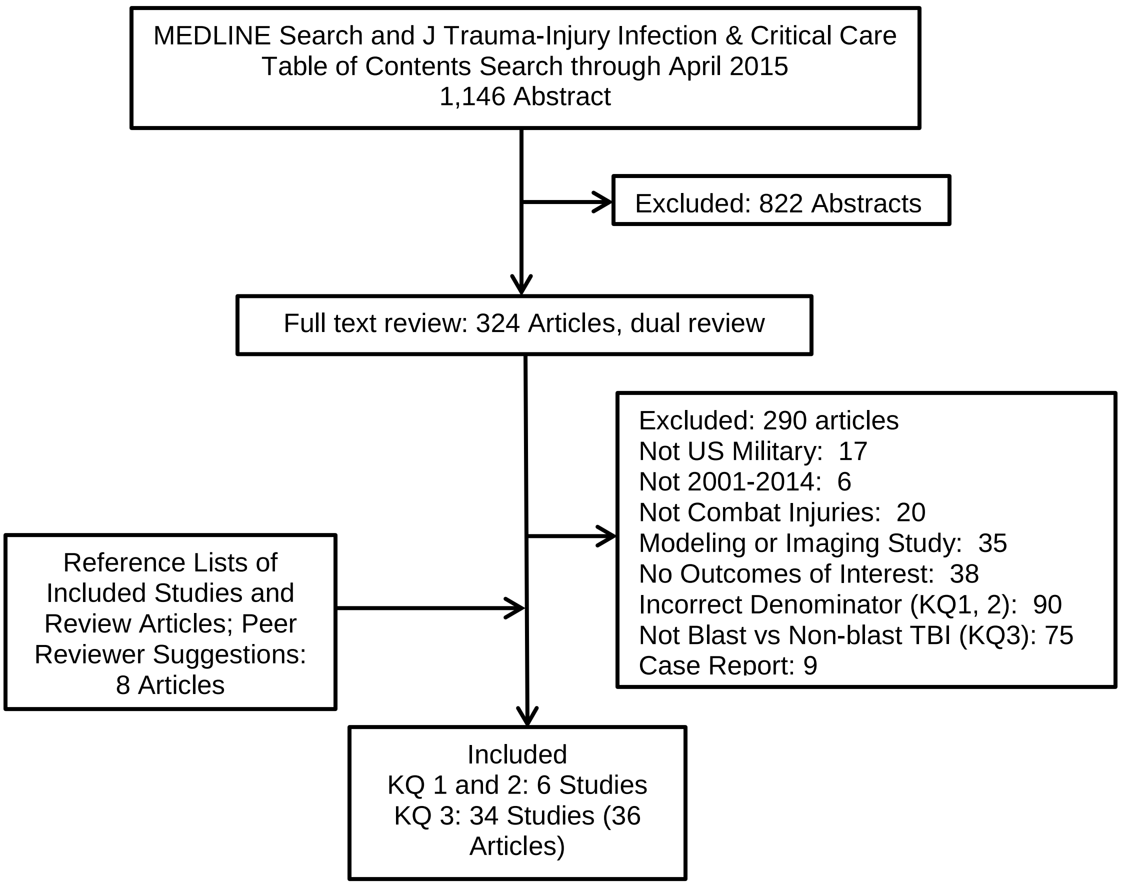
A draft version of this report was reviewed by content experts as well as clinical leadership. Reviewer's comments and our responses are presented in Appendix B and the report was modified as needed.

# RESULTS

## LITERATURE FLOW

Our literature searches yielded 1,146 abstracts (Figure 3). We identified 324 articles for full-text review and excluded 290. We identified an additional 8 articles by hand-searching resulting in a total of 42 included articles (6 for Key Questions 1 and 2, 36 from 34 studies for Key Question 3).

**Figure 3. Literature Flow Chart**



# KEY QUESTION #1: What is the *incidence* of combat blast injuries associated with OEF, OIF, and OND as reported in the literature or in published reports from Department of Defense (DoD) and VA databases during the period 2001-2014?

## KEY QUESTION #1A: What is the *incidence* by blast characteristics (*ie*, primary, secondary, tertiary, quaternary, and quinary), injury site, and injury outcome?

# KEY QUESTION #2: What is the *prevalence* of combat blast injuries associated with OEF, OIF, and OND as reported in the literature or in published reports from Department of Defense (DoD) and VA databases during the period 2001-2014?

## KEY QUESTION #2A: What is the *prevalence* of blast injury by blast characteristics, injury site, and injury outcome?

### Overview of Studies

We identified 6 studies meeting inclusion criteria for Key Questions 1 or 2. These studies included data from 2001 to 2011; 5 used the Joint Theater Trauma Registry (JTTR)[6-10] and one used Department of Defense tabular reports.[11] Three of the JTTR studies were based on the same cohort of deployed service members with one reporting overall casualties,[8] one reporting musculoskeletal casualties,[7] and one reporting spinal injuries.[9] The JTTR (now the Department of Defense Trauma Registry [DoDTR]) was established in 2004 and contains information on all casualties (individuals lost to the theater of operations due to illness or injury) treated at US military medical facilities in and outside the combat zone. All but one study, which focused on the troop surge in Iraq,[6] included casualties from both Iraq and Afghanistan. The mean ages of service members in the study cohorts ranged from 26 to 30 years and 92% to 99% were male (k = 5 reporting). In the 4 studies that reported branch of service and rank, 78% to 100% were from the Army and the large majority (up to 93%) were from enlisted ranks. None of the studies provided information on deployment details including assigned or actual duties. Additional details are presented in Appendix C, Tables 1 and 2.

### Key Question #1. Incidence

The National Institute of Mental Health has defined incidence as the number of new cases of a condition, symptom, death, or injury that develop during a specific time period.[12] We included registry studies that reported incidence of combat blast injuries for the deployed population (Table 1).

One study reported incidence of explosion (*ie,* improvised explosive device, mortar, rocket propelled grenade) injuries for the years 2005 to 2009.[8] Soldiers killed in action or sustaining non-battle injuries were not included in the analysis. The number of service members deployed and years of service were obtained through the Defense Manpower Data Center. The incidence was 4.5 explosion injuries per 1,000 deployed in 2005, 3.5 per 1,000 in 2006, 4.0 per 1,000 in 2007, 1.7 per 1,000 in 2008, and 1.7 per 1,000 in 2009. The slight increase in 2007 corresponded to the troop surge. Findings were also reported by country (Afghanistan versus Iraq).[8] In 2005 explosion injury incidence was higher in Iraq but beginning in 2008, the incidence was higher among soldiers deployed in Afghanistan.

A second report detailed all combat explosion injuries in a US Army Brigade Combat Team (n = 4,122) deployed during the 2007 troop surge in Iraq.[6] The cohort was followed for 6 months following the 15-month deployment. The incidence of explosion injuries was 83 per 1,000 deployed soldiers.

**Table 1. Incidence Data**

| Outcome | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|
| **Explosion injuries (*any*) per 1,000 deployed[6]** | | | 83[a] | | | |
| **Explosion injuries (*any*) per 1,000 deployed[8]** | 4.5 | 3.5 | 4.0 | 1.7 | 1.7 | |
| **Explosion-related *musculoskeletal injuries* per 1,000 deployed[7]** | 3.5[b] | 2.7[b] | 3.1[b] | 1.3[b] | 1.3[b] | |
| **Explosion-related *spinal injuries* per 1,000 deployed[9]** | 0.4[b] | 0.4[b] | 0.4[b] | 0.2[b] | 0.3[b] | |
| **Blast-related *thoracolumbar burst* fractures per 10,000 soldier years[10]** | | | | 0.45[c] | 0.60[c] | 2.08[c] |

[a] All explosion injuries for a US Army Brigade Combat Team (n = 4,122) deployed during the 2007 troop surge
[b] Additional analysis of cohort described by in Belmont 2012
[c] Data from August of preceding year to August of specified year

## Key Question #1a

No study reported incidence by blast characteristics (*ie*, primary, secondary, etc.) or injury outcomes (*eg*, pain, amputations, vision loss, cognitive function, functional status, quality of life). Three reported incidence by injury site (*ie*, body location or system injured) (Table 1).[7,9,10]

Two of the studies provided information about specific injury types for the service members deployed to Afghanistan or Iraq included in the cohort described by Belmont 2012.[8] One study identified explosion-related musculoskeletal injuries (upper and lower extremity, spine, and pelvis wounds including fractures, soft tissue injuries, joint dislocations, neurologic injuries, and traumatic amputations) during a 5 year period.[7] The incidence values (per 1,000 deployed soldiers) were 3.5 in 2005, 2.7 in 2006, 3.1 in 2007, 1.3 in 2008, and 1.3 in 2009. The other study reported on explosion-related spinal injuries finding 0.4 per 1,000 deployed soldiers in 2005, 2006, and 2007; 0.2 per 1,000 soldiers in 2008; and 0.3 per 1,000 soldiers in 2009.[9] The injuries included fractures, dislocations, disk displacements, nerve root injuries, and spinal cord injuries.

Another study looked specifically at combat thoracolumbar burst fractures, a pattern of injury that occurs as a result of vertical forces imparted by an explosion beneath an armored vehicle.[10] All soldiers who sustained this type of injury while deployed to Iraq or Afghanistan in 2007 to 2010 were identified through the JTTR and medical records from Landstuhl Regional Medical Center. The incidence increased from 0.45 per 10,000 soldier-years in the one-year period August 2007-2008, to 0.60 per 10,000 soldier-years in August 2008-2009, and 2.08 per 10,000 soldier-years in August 2009-2010. The increase in 2009-2010 was largely among soldiers serving in Afghanistan and the authors attributed to increased use of powerful improvised explosive devices against newer, up-armored vehicles. The authors speculated that with the newer military vehicles, explosives that might have caused deaths in the past were now associated with non-fatal burst fracture injuries.

### Key Question #2. Prevalence

The National Institute of Mental Health has defined prevalence as the proportion of a population who have (or had) a specific condition in a given time period regardless of when they first acquired the condition.[12] For this review, we report cumulative data as prevalence. (Table 2)

Explosion-related injuries over a 5-year period (2005-2009) were reported for the Belmont et al cohort.[8] Among 1,992,232 soldiers deployed to Afghanistan or Iraq during that time period, there were 5,862 explosion injuries, or 0.29% of deployed soldiers experienced an explosion-related injury. Explosion injuries accounted for 74% of injuries.

### Key Question #2a

No studies reported prevalence by blast characteristics (*ie,* primary, secondary, *etc*) or injury outcomes (*eg*, pain, amputations, vision loss, cognitive function, functional status, quality of life).

Four studies reported injuries to specific body sites or systems (Table 2). Two studies were additional analyses of the cohort reported by Belmont et al.[8] The study of musculoskeletal injuries reported 4,563 soldiers deployed to Afghanistan or Iraq with explosion-related injuries (0.23% of deployed soldiers).[7] Of all musculoskeletal injuries, 82% were explosion-related. By type of injury, 74% of axial skeleton fractures, 78% of upper extremity fractures, 84% of lower extremity fractures, 94% of amputations, 64% of neurologic injuries, 84% of joint dislocations, and 85% of soft tissue injuries were blast-related. Another analysis reported there were 650 soldiers with explosion-related spinal injuries (0.03% of deployed soldiers).[9] Of all spinal injuries, 75% were explosion-related. Among the 650 with explosion-related spinal injuries, 31% (n = 204) had injuries to more than one spinal region. Associated head and neck injuries were noted in 57% (n = 132) of soldiers with an explosion-related cervical spine injury.

The study of thoracolumbar burst fractures in Afghanistan or Iraq reported that over the period 2007-2010, the rate of blast-related fractures was 2.02 per 10,000 soldier years.[10] A Congressional Budget Office Working Paper reported major amputations (loss of a limb proximal to the wrist or ankle).[11] The prevalence was 38 per 100,000 troop years in OEF and OND and 88 per 100,000 troop years in OEF.

**Table 2. Prevalence Data**

| Outcome | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Explosion-related injuries *(any)*[8]** | | | | | 74% of injuries<br>0.29% of 1,992,232 deployed<br>(30.5 per 10,000 deployed) | | | | | | |
| **Blast-related *thoraco-lumbar burst fractures*[10]** | | | | | | | 2.02 per 10,000 soldier-years | | | | |
| **Explosion-related *musculo-skeletal injuries*[7]** | | | | | 82% of musculoskeletal wounds<br>(14,158 wounds)<br>0.23% of 1,992,232 deployed<br>(22.9 per 10,000 deployed) | | | | | | |
| **Explosion-related *spinal injuries*[9]** | | | | | 75% of spinal casualties<br>0.03% of 1,992,236 deployed<br>(3.3 per 10,000) | | | | | | |
| **Improvised explosive device *major amputations*[11]** | Iraq (OEF, OND): 38.3/100,000 troop-years<br>Afghanistan (OEF): 87.8/100,000 troop-years | | | | | | | | | | |

## Summary of Findings for Key Questions #1 and #2

One study reported explosion injury incidence from Afghanistan and Iraq, finding values ranging from 4.5/1,000 deployed in 2005 to 1.7/1,000 deployed in 2009. Another study reported data from the Iraq troop surge (2007), finding a high incidence of explosion injury (83/1,000 deployed in a US Army Brigade Combat Team). Three studies reported blast injury incidence by body location (musculoskeletal injuries, spinal injuries, or thoracolumbar burst fractures). No study reported incidence by blast characteristics.

Seventy-four percent of all combat injuries over the period from 2001 to 2011 were due to explosions. The prevalence was 30.5 per 10,000 deployed. The prevalence of explosion-related musculoskeletal injuries was 23 per 10,000 deployed; the prevalence of explosion-related spinal injuries was 3 per 10,000 deployed, the prevalence of blast-related thoracolumbar burst fractures was 2 per 10,000 soldier-years, and the prevalence of explosion-related major amputations ranged from 4 per 10,000 troop-years in Iraq to 9 per 10,000 troop-years in Afghanistan. No study reported prevalence by blast characteristics.

## KEY QUESTION #3: What are the short-term (up to 30 days), mid-term (30 days to one year) and long-term (greater than one year) injury outcomes (*ie*, pain, burns, limb loss, vision loss, hearing loss, vestibular dysfunction, PTSD, cognitive function, quality of life, functional status/employment, other) among US military personnel (2001-2014) who have sustained a blast-related TBI versus a non-blast TBI or a combined blast/non-blast TBI?

### Overview of Studies

We identified 34 studies (36 articles) reporting on outcomes associated with blast versus non-blast related TBI (Table 3). Six studies included data from registries or databases with sample sizes ranging from 604[13] to 12,521.[14] The remaining studies were clinical cohort studies with sample sizes ranging from 18[15] to 727.[16]

In 26 studies, patients were assessed at a medical facility (typically a DoD or VA hospital). Three studies assessed patients in combat zone facilities,[17-19] 2 included post-deployment assessment data,[20,21] one included both combat zone and post-deployment data,[22] one used a mailed questionnaire,[23] and location could not be determined for one study.[13]

The time from exposure to outcome assessment was less than 30 days for 3 studies[17,19,24] with another study including both an immediate assessment and a follow-up at 6 to 12 months.[18] One study assessed patients within 12 months of injury (50% within the first month).[25] Ten studies assessed outcomes between 30 days and one year from exposure and 5 at greater than one year. Fourteen studies included any time post-exposure or did not specify a time.

Eighteen studies included only patients with mild TBI (mTBI), one study included only patients with moderate or severe TBI,[13] 2 studies included patients with mild or moderate/severe TBI and reported results separately, 12 studies included any TBI (and did not report results by TBI severity), and one study reported some outcomes by TBI severity and some outcomes for the total sample.[20] Additional study characteristics are presented in Appendix C, Table 3.

Table 4 provides an overview of outcomes reported in these studies. The most frequently reported outcomes were PTSD, cognitive function, hearing impairment, and vision impairment. Few studies reported mortality, quality of life, limb loss, pain, or burn injuries. Findings for each outcome are reported below. More detailed outcome data are presented in Appendix C, Tables 4a to 4l.

**Table 3. KQ3 Overview: Blast versus Non-blast TBI – Population and Study Characteristics**

| Author, year | Data Source | | Sample Size | Characteristics | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Location of Assessment | | | Time Since Exposure | | | | TBI Severity | | |
| | Registry/ Database | Clinical Cohort | | Combat Zone | After Deployment | DoD, VA, or Other Medical Facility | < 30 days | 30 days to 1 year | > 1 year | Any or Unclear | Mild | Moderate/ Severe | Mixed (results not reported separately) |
| Akin, 2011[15] | | ü | 18 | | | ü | | | | ü | ü | | |
| Belanger, 2009[26] | | ü | 102 | | | ü | | | ü | | ü | ü | |
| Belanger, 2011[27] | | ü | 390 | | | ü | | | | ü | ü | | |
| Brahm, 2009[28] | | ü | 192 | | | ü | | | | ü | ü | ü | |
| Clark, 2009[29] | | ü | 85 | | | ü | | | | ü | | | ü |
| Cockerham, 2013[30] | | ü | 53 | | | ü | | ü | | | | | ü |
| Collen, 2012[31] | | ü | 116 | | | ü | | | ü | | | | ü |
| Cooper, 2012[32] | | ü | 60 | | | ü | | ü | | | ü | | |
| DuBose, 2011[13] | ü | | 604 | ? | ? | | | | | ü | | ü | |
| Fortier, 2014[33] | | ü | 56 | | | ü | | | ü | | ü | | |
| French, 2014[25] | | ü | 579 | | | ü | | ü | | | ü | | |
| Goodrich, 2013[34] Goodrich, 2014[35] | | ü | 100 | | | ü | | ü | | | | | ü |
| Hoffer, 2009[36] | | ü | 127 | | | ü | | | | ü | ü | | |
| Kennedy, 2010[16] | | ü | 724 | | | ü | | ü | | | ü | | |
| Kontos, 2013[22] | ü | | 2,813 | ü | ü | | | | | ü | ü | | |
| Lange, 2012[37] | | ü | 56 | | | ü | | ü | | | ü | | |
| Lew, 2011[14] | ü | | 12,521 | | | ü | | | | ü | | | ü |
| Lew, 2007[38] | | ü | 150 | | | ü | | | | ü | | | ü |
| Lippa, 2010[39] | | ü | 194 | | | ü | | | ü | | ü | | |
| Luethcke, 2011[17] Blast is primary blast; non-blast includes secondary, tertiary, quaternary, and non-blast | | ü | 82 | ü | | | ü | | | | ü | | |

| Author, year | Data Source | | Sample Size | Characteristics | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Location of Assessment | | | Time Since Exposure | | | | TBI Severity | | |
| | Registry/ Database | Clinical Cohort | | Combat Zone | After Deployment | DoD, VA, or Other Medical Facility | < 30 days | 30 days to 1 year | > 1 year | Any or Unclear | Mild | Moderate/ Severe | Mixed (results not reported separately) |
| Mac Donald, 2014[18] Blast is blast plus other mechanism of head injury | | ü | 82[c] | ü[c] | | | ü[c] | ü[c] | | | | | ü |
| MacGregor, 2011[20] | ü | | 2,074 | | ü | | | ü | | | ü | ü | ü |
| Maguen, 2012[40] | | ü | 1,082 (968 for PTSD) | | | ü | | | | ü | | | ü |
| Mendez, 2013[41] Mendez, 2013[42] Blast is primary blast only; non-blast is blunt injury | | ü | 24 | | | ü | | | ü | | ü | | |
| Mora, 2009[43] Blast is IED exposure with primary blast injury; non-blast is IED exposure without primary blast injury | | ü | 19 | | | ü | | ü | | | ü | | |
| Nakase-Richardson, 2013[44] | | ü | 106[b] | | | ü | | ü | | | | | ü |
| Oleksiak, 2012[45] | | ü | 189 | | | ü | | | | ü | ü | | |
| Pogoda, 2012[46] | ü | | 9,998 | | | ü | | | | ü | ü | | |
| Reid, 2014[47] | | ü | 573 | | | ü | | | | ü | ü | | |
| Sayer, 2008[48] | | ü | 188 | | | ü | | ü | | | | | ü |
| Schneiderman, 2008[23] | | ü | 275[e] | | | | | ü | ü | | ü | | |
| Wilk, 2010[21] | | ü | 574 | | ü | | | ü | | | ü | | |
| Wojcik 2010[19] | ü | | 1,388[d] | ü | | | ü | | | | | | ü |

| Author, year | Data Source | | Sample Size | Characteristics | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Location of Assessment | | | Time Since Exposure | | | | TBI Severity | | |
| | Registry/ Database | Clinical Cohort | | Combat Zone | After Deployment | DoD, VA, or Other Medical Facility | < 30 days | 30 days to 1 year | > 1 year | Any or Unclear | Mild | Moderate/ Severe | Mixed (results not reported separately) |
| Xydakis, 2012[24] | | ü | 256 | | | ü | ü | | | | | | ü |

[a] Patients admitted to US Army Institute of Surgical Research burn center
[b] Patients admitted to Polytrauma Rehabilitation System of Care with a disorder of consciousness (DOC)
[c] Initial assessment in Germany (n = 123 with TBI); followed 6-12 months post-injury at Washington University (US) (n = 82)
[d] Episodes (TBI hospitalizations with mechanism of injury data)
[e] Responded to self-administered mail questionnaire
**?** = unclear

Table 4. KQ3 Overview: Blast versus Non-blast TBI – Summary of Outcomes

| **Author, year** | **Data Source** | | **Sample Size** | **Outcomes Reported** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Registry/ Database** | **Clinical Cohort** | | **Mortality** | **PTSD** | **Pain** | **Burn** | **Limb Loss** | **Vision Impairment** | **Hearing Impairment** | **Vestibular Dysfunction** | **Cognitive Function Loss** | **Quality of Life** | **Functional Status/ Employment** | **Other** |
| Akin, 2011[15] | | ü | 18 | | | | | | | | ↔ | | | | |
| Belanger, 2009[26] | | ü | 102 | | ↔ | | | | | | | ↔ | | | |
| Belanger, 2011[27] | | ü | 390 | | - | | | | | | | | | | ↔Post-concussive symptoms |
| Brahm, 2009[28] | | ü | 192 | | | | | | ↔ | | | | | | |
| Clark, 2009[29] | | ü | 85 | | - | ↔ | ↔ | - | ↔ | ↔ | | ↔ | | ↔ | ↔Depression<br>- Any psychiatric diagnosis |
| Cockerham, 2013[30] | | ü | 53 | | | | | | ↔ | | | | | | |
| Collen, 2012[31] | | ü | 116 | | ↔ | | | | | | | | | | ↔Depression<br>**-** Anxiety<br>**MIXED** Sleep disorders |
| Cooper, 2012[32] | | ü | 60 | | ↔ | | | | | | | | | | ↔Headache |
| DuBose, 2011[13] | ü | | 604 | ↔ | | | | | | | | | | | |
| Fortier, 2014[33] | | ü | 56 | | | | | | | | | | | | ↔TBI severity |
| French, 2014[25] | | ü | 579 | | | | | | | | | | | | ↔Injury severity |
| Goodrich, 2013[34]<br>Goodrich, 2014[35] | | ü | 100 | | - | | | | ↔ | | | | | | |
| Hoffer, 2009[36] | | ü | 127 | | | | | | | | ↔<br>**VOR**<br>**MIXED**<br>**VSR** | | | | |
| Kennedy, 2010[16] | | ü | 724 | | ↔ | | | | | | | | | | |
| Kontos, 2013[22] | ü | | 2,813 | | - | | | | | | | - | | | |
| Lange, 2012[37] | | ü | 56 | | | | | | | | | ↔ | | | ↔Personality |
| Lew, 2011[14] | ü | | 12,521 | | | | | | – | - | | | | | |
| Lew, 2007[38] | | ü | 150 | | | | | | | - | | | | | |

| **Author, year** | **Data Source** | | **Sample Size** | **Outcomes Reported** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Registry/ Database** | **Clinical Cohort** | | **Mortality** | **PTSD** | **Pain** | **Burn** | **Limb Loss** | **Vision Impairment** | **Hearing Impairment** | **Vestibular Dysfunction** | **Cognitive Function Loss** | **Quality of Life** | **Functional Status/ Employment** | **Other** |
| Lippa, 2010[39] | | ü | 194 | | **MIXED** | | | | | | | | | | ↔Post-concussive symptoms |
| Luethcke, 2011[17] Blast is primary blast; non-blast includes secondary, tertiary, quaternary, and non-blast | | ü | 82 | | ↔ | | | | ↔ | - Immediate ↔ Current | ↔ | ↔ | | | ↔Global mental health ↔Insomnia ↔Immediate headache ¯Current headache |
| Mac Donald, 2014[18] Blast is blast plus other mechanism of head injury | | ü | 82[c] | | ↔ | | | | | ↔ | | | | ↔ | ↔Neuro-behavioral & neuro-psychological assessments ↔Depression severity ↔Headache ¯Smell ↔Alcohol misuse |
| MacGregor, 2011[20] | ü | | 2,074 | | | | | | | | | | | | - HNF injuries ↔Extremity injuries - Spine/back injuries ¯mTBI - Moderate & severe TBI |
| Maguen, 2012[40] | | ü | 1,082 (968 for PTSD) | | - | | | | | | | | | | ↔Depression ↔Alcohol misuse |

| Author, year | Data Source | | Sample Size | Outcomes Reported | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Registry/ Database | Clinical Cohort | | Mortality | PTSD | Pain | Burn | Limb Loss | Vision Impairment | Hearing Impairment | Vestibular Dysfunction | Cognitive Function Loss | Quality of Life | Functional Status/ Employment | Other |
| Mendez, 2013[41] Mendez, 2013[42] Blast is primary blast only; non-blast is blunt injury | | ü | 24 | | | | | | | | | **MIXED** | ↔ | | ↔Post-concussive symptoms **-** Psychopathy ↔Behavior |
| Mora, 2009[43] Blast is IED exposure with primary blast injury; non-blast is IED exposure without primary blast injury | | ü | 19[a] | | ↔ | | **?** | | | | | | | | **?**Injury Severity Score |
| Nakase-Richardson, 2013[44] | | ü | 106[b] | | | | | | | | | **MIXED** | | – | ¯Recovery of consciousness (vs other trauma) |
| Oleksiak, 2012[45] | | ü | 189 | | | | | | | ↔ | | | | | |
| Pogoda, 2012[46] | ü | | 9,998 | | | | | | | | | | | | ↔Multi-sensory |
| Reid, 2014[47] | | ü | 573 | | **-** | | | | **-** | **-** | **-** | **-** | | | **-** Post-concussive symptoms **-** Sleep ↔Depression |
| Sayer, 2008[48] | | ü | 188 | ↔ | **-** | ↔ | **-** | ↔ | ↔ **-** Injury | **-** | ↔ | ↔ | | ↔ | ↔Sleep ↔Depression |
| Schneiderman, 2008[23] | | ü | 275[e] | | | | | | | | | | | | ↔Post-concussive symptoms |
| Wilk, 2010[21] | | ü | 574 | | ↔ | ↔ | | | | **MIXED** | ↔ | **MIXED** | | ↔ | ↔Depression **MIXED** Headache ↔Sleep ↔Alcohol misuse |
| Wojcik 2010[19] | ü | | 1,388[d] | | | | | | | | | | | | **?**Severity of TBI |
| Xydakis, 2012[24] | | ü | 256 | | | | | | | | | | | | **?**Severity of TBI |

VOR = vestibular-ocular reflex; VSR = vestibular-spinal reflex
[a] Patients admitted to US Army Institute of Surgical Research burn center
[b] Patients admitted to Polytrauma Rehabilitation System of Care with a disorder of consciousness (DOC)
[c] Episodes (TBI hospitalizations with mechanism of injury data)
[d] Initial assessment in Germany (n = 123 with TBI); followed 6-12 months post –injury at Washington University (US) (n = 82)
[e] Responded to self-administered mail questionnaire
[f] Significance of findings is across blast exposure groups: 0 blasts, 1 blast, 2 blasts, 3 blasts, 4-10 blasts
**-** Higher prevalence or more severe in blast TBI group; ¯ Higher prevalence or more severe in non-blast TBI group; **↔** Blast and non-blast groups similar; **?** P value not reported; **MIXED** Multiple tests with mixed results

### Mortality (k = 2) (Appendix C, Table 4a)

*< 30 days post-exposure*

One study included service members receiving polytrauma/TBI inpatient rehabilitation at a VA polytrauma rehabilitation center (PRC).[48] Of 188 patients studied, 106 had a blast exposure and 82 did not; 97% had a TBI. Mortality was 3% in the blast group and 1% in the non-blast group. Mortality was similar between the groups (P = .63).

*Other*

A second study was based on data from the JTTR.[13] Time from exposure to evaluation was not specified. The 604 patients included in the study had an isolated TBI: 374 were associated with a blast exposure, 118 from gunshot, and 112 following blunt trauma. Mortality was 9% in the blast group, 7% in the gunshot group, and 10% in the blunt trauma group. Relative to the blunt trauma group, the odds ratios for mortality in the blast and gunshot groups, respectively, were 0.66 (95% CI 0.31, 1.41) and 0.60 (95% CI 0.19, 1.89), respectively.

### Posttraumatic Stress Disorder (PTSD) (k = 16) (Appendix C, Table 4b)

*< 30 days post-exposure*

One study reported short-term results.[17] Eighty-two military and civilian contractors were evaluated within 72 hours of injury in an outpatient TBI clinic at a forward-deployed combat support hospital (CSH). The blast and comparator groups had similar Posttraumatic Stress Disorder Checklist (PCL) scores. The blast group included only those with primary blast exposure while the comparator group included secondary, tertiary, quaternary, and non-blast exposures.

*30 to 365 days post-exposure*

Seven studies evaluated patients 30 days to one year after exposure with 5 including only patients with mTBI[16,21,32,43,48] and 2 including any TBI severity.[18,34,35] Studies used variable definitions of non-blast injury (*eg,* some studies included secondary blast injuries as non-blast injuries) which could affect the prevalence and outcomes of estimates. Five studies reported the percentage of patients with a PTSD diagnosis. In 4 of the 5 studies, the blast and non-blast groups were similar.[16,18,21,43] One was a study of 724 patients screened and identified with mTBI at a military medical center.[16] Another was a small study (n = 19) of mTBI patients treated at a military burn center. Blast cases had experienced an improvised explosive device (IED) primary blast while non-blast cases had IED exposure without primary blast injury.[43] The third was a study of 82 patients, 52 with blast exposure. Blast cases in this study had experienced a blast explosion plus another mechanism of head injury.[18] The fourth study included 574 patients who reported concussion. The patients were further categorized as having experienced a loss of consciousness or a change in consciousness. Prevalence of PTSD was similar for blast and non-blast groups in both subgroups.[21] The study finding higher prevalence of PTSD in the blast TBI group was designed to assess vision outcomes but also reported PTSD prevalence in the 100 patients. The prevalence of PTSD was 62% in the blast group and 20% in the non-blast group (P<.001).[35]

Two studies reported PCL scores finding similar scores for blast and non-blast TBI groups.[16,32] One was a study of 60 patients referred to a TBI clinic at an Army medical center for neuropsychological testing[32] and the other was a study of 724 patients described above.[16] A third study with 188 patients (described in the Mortality outcomes section) reported the prevalence of PTSD symptoms was higher in the blast TBI group (42% vs 24%, P<.01).[48]

In another study, the blast TBI patients (n = 298) were evaluated less than 365 days after exposure and the non-blast TBI patients (n = 92) were evaluated more than 365 days after exposure.[27] PCL scores were significantly higher in the blast TBI group (42 vs 37, P = .047).

### *> 365 days post-exposure*

Two studies reported PTSD findings at more than 365 days after exposure. Among 116 soldiers with combat-related TBI (85% mTBI) receiving care at an Army medical center, the percentage of patients with a comorbid diagnosis of PTSD was similar for the blast and non-blast groups.[31] A study of 339 patients referred for TBI screening in the VA system reported that PCL total scores were similar for the blast and non-blast groups but a higher percentage of patients with blast-related mTBI had a PCL score of 50 or higher (65% vs 45%, P<.05).[39]

### *Other*

Five studies reported PTSD findings at any time post-exposure or did not specify the time.[22,26,29,40,47] One study of 128 active duty personnel and Veterans admitted to a PRC (80% with TBI) found a higher prevalence of PTSD in the blast group (45% vs 12%, P<.05).[29] A registry study of 2,813 US Army Special Operations Command (USASOC) personnel who completed Web-based evaluations in both deployed and non-deployed settings found significantly higher odds of clinical levels of PTSD symptoms in the blast mTBI group compared to the blunt mTBI group (OR 2.12 [95% CI 1.68, 2.66]).[22] A study of 968 Veterans reported a higher odds of a positive PTSD screen in Veterans with a blast-only head injury compared to TBI with no head injury (OR 4.7 [95% CI 2.9, 7.7]) or a blast plus other mechanism of injury compared to TBI with no head injury (OR 6.5 [95% CI 4.6, 9.3]).[40] A study of 102 VA patients reported similar PCL scores between blast and non-blast groups.[26]

A study of 573 male service members with combat-related mTBI evaluated one to 24 months post-injury reported a significant difference in PCL scores across self-reported blast exposure groups (0 blasts, 1 blast, 2 blasts, 3 blasts, or 4 to 10 blasts).[47] Subsequent analyses showed only that the PCL score for the group exposed to 4 to 10 blasts was significantly higher than the score for the group exposed to one blast. The study of USASOC personnel also reported that PTSD symptom scores increased significantly with an increased number of diagnosed blast-related mTBIs.[22] The odds ratio for clinical levels of PTSD symptoms associated with 3 or more blast-related mTBIs compared to one blast mTBI was 1.74 (95% CI 1.19, 2.54). The odds ratio for 3 or more blast-related mTBIs compared to 2 blast-related mTBIs was not significant (OR 1.32 [95% CI 0.82, 2.14]).

### Pain (k = 3) (Appendix C, Table 4c)

*30 to 365 days post-exposure*

Impairment associated with pain was similar for blast and non-blast mTBI groups in a study of 188 Veterans.[48] The percentage of US soldiers reporting back pain or arm, leg, or joint pain was similar between blast and non-blast mTBI groups and subgroups experiencing either loss of or change in consciousness.[21] The percentage of soldiers with stomach pain was significantly higher for the non-blast mTBI group among those with a change in consciousness (15% vs 6%, P = .01) but not those with a loss of consciousness.

*Other*

A third study of 128 patients admitted to a PRC (80% with TBI) did not specify the time post-exposure. Pain intensity scores and the number of pain sites were similar for blast and non-blast TBI patients.[29]

### Burns (k = 3) (Appendix C, Table 4d)

*30 to 365 days post-exposure*

The study of 188 Veterans assessed 30 days to one year post-exposure reported a higher percentage of patients with skin or soft tissue burn injury in the blast-related mTBI group compared to the non-blast group (13% vs 4%, P<.05).[48] The small study (n = 19) of mTBI patients treated at a military burn center reported the percentage of total body surface area (TBSA) burned. The mean TBSA for the blast cases (IED primary blast) was 8.1% compared to 17.0% for the non-blast cases (IED without primary blast injury).[43]

*Other*

The study of 128 patients admitted to a PRC (described above) reported a similar percentage of patients with a burn diagnosis in the blast and non-blast groups.[29]

### Limb Loss (k = 2) (Appendix C, Table 4e)

*30 to 365 days post-exposure*

In the study of outcomes at 30 days to one year post-exposure (n = 188), the percentage of Veterans with an amputation was similar between blast and non-blast exposures (9% vs 6%) with 10 amputations in the blast group and 2 in the non-blast group.[48]

*Other*

The second study reported a significantly higher percentage of amputations in the blast group (16% vs 3%, P<.05).[29]

### Vision Impairment (k = 8) (Appendix C, Table 4f)

*< 30 days post-exposure*

The study of patients assessed at a forward-deployed CSH reported blast and comparator groups experienced a similar incidence of vision loss symptoms both immediately after the injury and when assessed within 72 hours of the exposure.[17] Blast was defined as primary blast exposure in this study; the comparator group included other blast exposures and non-blast injuries.

### *30 to 365 days post-exposure*

The study of 188 Veterans (described above) reported a significantly higher incidence of eye injuries in the blast-related mTBI group (47% vs 26%, P<.01) but the groups were similar in incidence of vision impairment (58% vs 46%, P not significant).[48] The study of 100 Veterans admitted to a PRC and undergoing eye examinations reported the blast and non-blast groups were similar in percentage with ocular injury, monocular vision, vision complaints, reading complaints, and poor visual acuity (in the worse eye). More patients in the blast group reported light sensitivity (67% vs 33%, P = .002).[34,35] Another study of 53 Veterans reported a similar incidence of dry eye disease between blast and non-blast TBI patients. Measures of tear production and tear osmolarity were also similar.[30]

### *Other*

Four studies did not specify the time post-exposure or included any time post-injury. A study of polytrauma inpatients (n = 68) and outpatients (n = 124) reported similar vision outcomes (subjective visual complaint, ocular injury, legally blind status) between blast and non-blast groups for the outpatients while for the inpatients one of the outcomes, ocular injury, was significantly higher for the blast group (44% vs 9%, P = .04).[28] The study of 573 male service members evaluated at one to 24 months post-injury reported a significant difference across blast exposure groups for scores on the "vision problems, blurring, trouble seeing" component of the Neurobehavioral Symptom Inventory (NSI).[47] The highest score was observed in the group with 4 to 10 blast exposures. The study of 128 patients admitted to a PRC (described above) reported similar percentages with eye injury in the blast and non-blast groups.[29] A database study of 12,521 patients with deployment-related TBI reported a higher percentage of patients with visual impairment only in the non-blast group (16% vs 9%, P<.001).[14]

## **Hearing Impairment (k = 9) (Appendix C, Table 4g)**

### *< 30 days post-exposure*

The study of patients assessed at a forward-deployed CSH reported that a higher percentage of blast-exposed patients experienced hearing loss symptoms immediately after the injury (53% vs 17%, P = .001) but the groups were similar when assessed within 72 hours of the exposure.[17] The blast group included only primary blast-exposed patients.

### *30 to 365 days post-exposure*

The study of 188 Veterans (described above) reported a higher percentage of patients in the blast group with otologic injury (46% vs 23%, P<.01), hearing loss (48% vs 33%, P<.05), and tinnitus (26% vs 12%, P<.05).[48] The study of soldiers with concussion reported a higher percentage reporting ringing in ears in the blast group among those who experienced loss of consciousness (34% vs 15%, P = .02) but not among those who experienced change in consciousness (22% vs 17%, P = .32).[21] In the study of 82 patients where blast was defined as blast plus another mechanism of head injury, the percentage of patients reporting hearing deficit was similar for the blast and non-blast groups.[18]

### *Other*

Among the studies that did not specify a time post-exposure, the study of 128 patients admitted to a PRC found the percentage with "hearing problems" was similar for blast and non-blast groups.[29] The database study with 12,521 patients reported greater auditory impairment only in the blast group compared to the non-blast group (33% vs 23%, P<.001). The percentages of patients with dual sensory impairment were similar between groups (35% vs 30%).[14] An earlier, smaller study from this group (150 Veterans admitted for inpatient rehabilitation) found a greater percentage of patients in the blast group with hearing loss (62% vs 44%, P = .04) and tinnitus (38% vs 18%, P = .007).[38] The study of 573 male service members evaluated at one to 24 months post-injury reported a significant difference across blast exposure groups for scores on the "hearing difficulty" component of the NSI.[47] The highest score was observed in the group with 4 to 10 blast exposures. In a study of 198 Veterans with confirmed mTBI, "hearing difficulty" (from the NSI) was similar for blast and non-blast groups.[45]

## Vestibular Dysfunction (k = 6) (Appendix C, Table 4h)

### *< 30 days post-exposure*

The study that evaluated 82 patients at a forward-deployed CSH reported that blast (primary blast only) and comparator (other blast and non-blast exposure) groups were similar in balance and dizziness symptoms both immediately following the injury and at the time of assessment (72 hours or less post-exposure).[17]

### *30 to 365 days post-exposure*

The studies evaluating 188 Veterans[48] or 574 soldiers with concussion[21] at 30 days to one year post-exposure reported blast and non-blast groups were similar in balance/equilibrium impairment[48] and dizziness or balance problems.[21] In the latter study, the groups were similar whether the patients had experienced loss of or change in consciousness.[21]

### *Other*

Two studies did not report time since exposure and one included assessments at one to 24 months post-exposure. In one, a study of 18 Veterans referred to a VA Vestibular/Balance Laboratory for complaints of dizziness and/or imbalance, the mean Dizziness Handicap Inventory score for the blast-related mTBI group was in the "severe" range while the mean for the non-blast group was in the "moderate" range.[15] No statistical significance was reported. The percentage of patients with abnormal results for the Sensory Organization Test was similar between groups. Another study, conducted at a Naval medical center, included tests for vestibular-ocular reflex (VOR, n = 55) and vestibular-spinal reflex (VSR, n = 72).[36] Some "descriptive differences" were noted between blast and blunt force groups in the VOR study. In the VSR study, there was a trend toward better scores on the Sensory Organization Test in the blunt exposure group while significantly more patients in the blast exposure group had abnormal latency times on a Motor Control Test. The study of 573 male service members evaluated at one to 24 months post-injury reported a significant difference across blast exposure groups for scores on the "loss of balance" component of the NSI.[47] The highest score was observed in the group with 4 to 10 blast exposures.

### Cognitive Function Loss (k = 10) (Appendix C, Table 4i)

*< 30 days post-exposure*

The study from the forward-deployed CSH reported that blast (primary blast only) and comparator (other blast and non-blast exposures) groups had similar cognitive function scores when assessed at 72 hours or less post-exposure.[17]

*30 to 365 days post-exposure*

In a study of 60 service members referred to an Army medical center for neuropsychological testing, the cognitive functioning assessment yielded similar results for the blast and non-blast groups.[32] Another study of patients evaluated at an Army medical center following medical evacuation from the OEF/OIF combat theater found significant between-group (blast/non-blast) differences for 2 of 12 measures in a neurocognitive test battery with poorer performance by the non-blast group.[37] A study of 106 patients admitted to a polytrauma rehabilitation clinic with a disorder of consciousness found blast and non-blast groups had similar changes in cognitive scores from admission to discharge. The blast group improved by one point on an 8-point scale while the non-blast group with penetrating trauma improved by 2 points and the non-blast group with other trauma improved by 3 points. Similar results were observed for the cognitive component of the Functional Independence Measure (FIM).[44] The study of 188 Veterans receiving inpatient VA polytrauma/TBI inpatient rehabilitation services (described previously) reported that blast and non-blast groups were similar in the percent reporting cognitive impairment (88% vs 93%).[48] The study of 574 soldiers with concussions reported that similar percentages of the blast and non-blast groups that experienced loss of consciousness had memory problems (31% vs 30%, P = 1.0) or concentration problems (32% vs 34%, P = .85). In the blast and non-blast groups that experienced a change in consciousness, there was a higher percentage that experienced memory problems in the non-blast group (31% vs 18%, P = .01) while the percentage with concentration problems was similar (35% vs 24%, P = .05).[21]

*> 365 days post-exposure*

One study assessed cognitive function at more than 365 days post-exposure.[42] Three instruments were used and results were mixed. The blast group (defined for this study as primary blast force only) performed worse than the non-blast (blunt force) group on a serial addition test but the groups were similar on tests of "executive operations" and mental flexibility/decision-making.

*Other*

In 2 of the 4 studies reporting cognitive function outcomes but not specifying a time post-exposure, blast and non-blast groups had similar outcomes. One study enrolled 102 Veterans and reported similar scores on 4 neuropsychological tests.[26] The other enrolled 128 active duty personnel and Veterans and reported similar scores on a test of cognitive deficits associated with recovery from brain injury.[29] The third study, a database study of 2,813 USASOC personnel (described above), reported poorer performance in the blast mTBI group on tests of visual memory, visual processing speed, and reaction time. The groups were similar on the verbal memory test.[22] The fourth study, with 573 male service members evaluated at one to 24 months post-injury, reported a significant difference across blast exposure groups for scores on the cognitive element of the NSI.[47] The highest score was observed in the group with 4 to 10 blast exposures.

### Quality of Life (k = 1) (Appendix C, Table 4j)

#### *> 365 days post-exposure*

One study reported quality of life based on responses to the Health-Related Quality of Life 36-item Short Form (SF-36).[42] Participants were 24 Veterans undergoing a Second Level TBI evaluation at a VA medical center and mean time from exposure was over 4 years. Blast-related injury was defined as injury due to primary blast force. SF-36 scores (Physical Composite, Mental Composite, and all sub-scales) were similar for the blast and non-blast (blunt) groups.

### Functional Status/Employment (k = 5) (Appendix C, Table 4k)

#### *30 to 365 days post-exposure*

One study of 82 active duty US military evacuated from Iraq and Afghanistan and followed up in the US 6 to 12 months later found that blast and non-blast TBI groups were similar on a global outcome measure of disability.[18] The percentages of patients categorized as having moderate to severe disability were also similar (77% blast, 79% non-blast, P = .84). In this study, participants with a blast injury also had some other mechanism of head injury.

A study of 122 patients admitted to VA polytrauma care with a disorder of consciousness assessed functional independence at admission and discharge.[44] There was no change over time for the blast TBI group or for the non-blast TBI group that had experienced penetrating trauma. There was a significant change over time for the non-blast TBI group that had experienced "other trauma" relative to both the blast injury and penetrating trauma groups. In a similar population of 188 service members, 62% of the blast injury group and 65% of the non-blast injury group reported motor functioning impairment (P not significant).[48]

The study of 574 soldiers with concussion data reported on workdays missed.[21] The percentages reporting 2 or more missed workdays due to illness were similar in the blast and non-blast mTBI groups for the subgroups reporting loss of consciousness (21% vs 23%, P = .83) or change in consciousness (17% vs 10%, P = .11).

#### *Other*

One study that did not specify the time since exposure reported functional independence scores.[29] The scores for the blast and non-blast groups were similar.

### Other Outcomes (Appendix C, Table 4l)

#### *Depression (k = 7)*

Seven studies reported on either depression diagnosis[21,29,31,40] or depression symptoms/severity.[18,47,48] All studies found blast and non-blast TBI groups to be similar. Three studies assessed outcomes 30 to 365 days post-exposure,[18,21,48] one at more than 365 days,[31] and 3 at unspecified or any time post-exposure.[29,40,47]

#### *Insomnia (k = 5)*

In 3 studies, blast and comparator groups had similar scores for insomnia severity (assessed less than 30 days post-exposure),[17] sleep impairment (assessed 30 to 365 days post-exposure),[48] and sleep problems (also at 30 to 365 days post-exposure).[21] A study of 573 male service members evaluated at one to 24 months post-injury reported a significant difference across blast exposure groups for scores on the "difficulty falling or staying asleep" component of the NSI with the highest score in the group with 4 to 10 blast exposures.[47] One study of 116 soldiers receiving care at an Army medical center and assessed more than 365 days post-exposure reported higher levels of insomnia in the blast injury group (63% vs 40%, P = .02) but fewer with a diagnosis of obstructive sleep apnea syndrome (26% vs 54%, P = .003) and lower mean scores on the Epworth Sleepiness Scale (9 vs 11, P = .04).[31]

### *Headache (k = 4)*

Two studies, both assessing outcomes at 30 to 365 days post-exposure, reported that blast and non-blast TBI group were similar on measures of headache impact[32] or migraine disability.[18] Another study found similar percentages of patients in the blast (primary blast only) and non-blast groups with headache symptoms immediately post-injury (70% vs 81%, P = .25) but within 72 hours, there was a higher percentage with headache symptoms in the comparator (other blast and non-blast exposure) group (53% vs 83%, P = .003).[17] A fourth study reported a higher percentage of patients with headache in the blast with loss of consciousness group than the non-blast loss of consciousness group (40% vs 23%, P = .04) while the percentages of patients with headache in the blast and non-blast change in consciousness groups were similar (21% vs 18%, P = .57). Outcomes were assessed 30 to 365 days post-exposure.[21]

### *Severity of TBI (k = 4)*

Four studies provided a measure of whether TBI severity differed between blast and non-blast exposures. A database study of 1,388 soldiers hospitalized with a TBI and a known associated mechanism of injury, found that 55% of explosion-related TBIs were Type 1 (most severe), 39% were Type 2, and 6% were Type 3 (least severe).[19] For non-blast TBIs the corresponding percentages were 43%, 50%, and 6%. Alternatively, 68% of the Type 1 (most severe) TBIs, 56% of the Type 2, and 63% of the Type 3 (least severe) were explosion-related. Statistical significance was not reported.

A study of polytrauma patients with combat-related closed head injuries (blunt or blast mechanism) requiring immediate evaluation at an Army medical center in the US reported that the percentages of patients with mTBI (68% of blast mechanism injuries, 58% of blunt mechanism injuries, P = .21), moderate TBI (28% vs 33%, P = .51), or severe TBI (5% vs 9%, P = .32) were similar for the blast mechanism and blunt mechanism groups.[24]

In a larger, database study (n = 2,074) of injured personnel who completed post-deployment health assessments within 365 days of injury, there were significant differences between the blast and non-blast groups.[20] Of 1,852 with mTBI, 98% had a blast injury and 2% had a non-blast injury. Of 90 with moderate TBI, 84% had a blast injury and 16% had a non-blast injury. Of 143 with severe TBI, 67% had a blast injury and 33% had a non-blast injury. Alternatively, of 1,987 with a blast injury, 92% had mTBI (vs 34% of the 87 with a non-blast injury), 4% had moderate TBI (vs 16% of the non-blast group), and 4% had severe TBI (vs 50% of the non-blast group).

In one study of 56 Veterans with military TBI assessed more than 365 days post-exposure, the percentages of patients in the blast and non-blast groups with Type 1 TBI (most severe), Type 2 TBI, or Type 3 TBI (least severe) were similar.[33]

### *Alcohol Misuse (k = 3)*

Blast and non-blast groups were similar regarding alcohol misuse in 3 studies that reported this outcome. One was a study of 82 active duty US military evacuated from Iraq or Afghanistan with follow-up assessment 6 to 12 months later.[18] Blast-exposed service members had also experienced another mechanism of head injury. Another was a study of Veterans (n = 968 completing the alcohol misuse evaluation) that did not specify the time from blast exposure to assessment.[40] The third was the study of 574 with concussion (either loss of consciousness or change in consciousness) and outcomes assessed 30 to 365 days post-exposure.[21]

### *Post-concussive Symptoms (k = 5)*

Five studies reported that blast and non-blast groups were similar on measures of post-concussive symptoms including a study of 339 Veterans with mTBI,[39] a study of 390 Veterans with mTBI,[27] a study of 24 Veterans that defined blast injury as primary blast only and non-blast as blunt force injury,[42] and a survey study with 275 reporting mTBI.[23] Two of the studies assessed outcomes more than 365 days post-exposure;[39,42] in the survey study, participants were more than 30 days post-exposure.[23] In the other study, the blast TBI patients (n = 298) were evaluated less than 365 days after exposure and the non-blast TBI patients (n = 92) were evaluated more than 365 days after exposure.[27] A fifth study, with 573 male service members evaluated at one to 24 months post-injury, reported a significant difference across blast exposure groups for scores on the NSI.[47] The highest score was observed in the group with 4 to 10 blast exposures and scores in that group were significantly different from the groups with no blast exposure or exposure to one or 2 blasts.

### *Injury Severity (k = 1)*

A study of 579 male service members evaluated within 12 months of injury categorized severity of bodily injuries (excluding injury to the brain) as minor, moderate, serious, or severe/critical.[25] Severity of injury was not related to mechanism (blast versus non-blast) of injury.

### *Multisensory Impairment (k = 1)*

A study of 9,998 Veterans (95% male) completing the VA comprehensive TBI evaluation (CTBIE) assessed multisensory impairment – the co-occurrence of self-reported auditory, visual, and vestibular impairment.[46] Relative to those with no reported etiology of injury, the odds ratios for predicting multisensory impairment were 1.00 (95% CI 0.80, 1.25) for those with one or more non-blast injuries and 1.03 (95% CI 0.84, 1.25) for those with one or more blast injuries.

## KEY QUESTION #3A: What are the short-term (up to 30 days), mid-term (30 days to one year) and long-term (greater than one year) injury outcomes among US military personnel (2001-2014) who have sustained a blast-related TBI according to blast characteristics?

Few studies reported outcomes according to blast characteristics. One study of hearing outcomes in Veterans with confirmed mTBI reported findings for subgroups based on the type of blast injury (primary [n = 62] or secondary [n = 11]). Time since exposure was not reported. Hearing difficulty scores were similar for the 2 subgroups (2.1 for the primary blast group, 1.8 for the secondary blast group). A score of one represented mild and a score of 2 moderate hearing difficulty. The percentage of patients with a score of greater than one was also similar (94% primary, 100% secondary).[45]

Three studies defined blast injury as primary blast force only.[17,41-43] In one of these studies, mTBI patients were evaluated at a forward-deployed CSH within 72 hours of injury.[17] The comparator group included patients experiencing secondary, tertiary, and quaternary blast injuries along with injuries not involving blasts. The blast group was similar to the comparator group for most outcomes (PTSD symptoms, vision symptoms, hearing symptoms at the time of assessment, vestibular dysfunction symptoms, cognitive function, insomnia, global mental health, and headache immediately following injury). The blast group reported more or more-severe hearing symptoms and lesser headache symptoms at the time of assessment.

The second study reported outcomes for 24 Veterans assessed at a mean of 4 years post-exposure.[41,42] Of the 12 "blast-injury" (primary blast) subjects, 10 reported the blast was less than 10 feet from their location at the time of the blast, one reported less than 30 feet, and one reported less than 50 feet. The blast group was similar to the non-blast (blunt force) group on measures of quality of life, post-concussive symptoms, personality, and behavior. Scores on a measure of interpersonal behaviors associated with psychopathy were higher for the blast group. Results were mixed for cognitive outcomes with the blast group scoring poorer on one measure and blast and non-blast groups being similar on 2 measures.

The third study evaluated 19 mTBI patients treated at a military burn center 30 to 365 days post-exposure.[43] Six had primary blast injury associated with an IED and 13 had been wounded in an IED explosion but had not sustained a primary blast injury. The prevalence of PTSD was similar for the blast and non-blast groups. The mean injury severity score was lower in the blast group (7.8 vs 15.0) as was the measure of burn severity (TBSA, 8.1% vs 17.0%) but it was not reported if the differences were significant.

### Summary of Findings for Key Question #3

In 34 studies of injury outcomes among military personnel sustaining a blast or non-blast TBI, we found blast and non-blast groups to be similar in terms of mortality, pain, vision loss, vestibular dysfunction, functional ability, depression, sleep disorders, alcohol misuse, and post-concussive symptoms. The results were consistent across studies despite the fact that these studies varied in sample size, location of assessment, time from exposure to assessment, and level of TBI severity.

There were less consistent findings for some outcomes. A diagnosis of PTSD or PTSD symptom severity was higher in the blast groups in 7 studies. An additional 8 studies found the blast and non-blast groups to be similar and one reported mixed results for different ways of reporting PTSD. Four studies reported greater hearing loss in the blast injury group while 3 other studies reported the blast and non-blast groups were similar. Two reported mixed results; one of these studies looked at immediate post-injury hearing loss and current hearing loss (with current defined as within 72 hours of injury) and reported greater hearing loss in the blast group early post-injury but no difference at the later assessment. Cognitive outcomes also were less consistent. Five studies reported that blast and non-blast groups were similar, 2 reported greater cognitive impairment in the blast group, and 3 reported mixed results across different measures or across subgroups within the study. For the headache outcome, 2 studies reported that the blast and non-blast groups were similar and 2 reported mixed results depending on time of assessment or state of consciousness following the exposure.

Other outcomes were rarely reported making conclusions difficult. Three studies reported burn and 2 reported limb loss. One study reported an increased percentage of patients with burn injuries in the blast group compared to the non-blast group while another reported the percentages with a burn diagnosis were similar in the 2 groups. The third reported that the total body surface area effected was similar in blast and non-blast TBI groups admitted to a burn center. One study reported an increased number of amputations in the blast group while the other reported that the groups were similar. Level of quality of life was reported in just one study with blast and non-blast groups similar.

There is little data on outcomes according to blast characteristics. One study reported similar hearing outcomes for groups who experienced either primary or secondary. Three studies that defined blast injury as due to primary blast force reported few differences between their blast injury group and comparator groups.

# SUMMARY AND DISCUSSION

## SUMMARY OF EVIDENCE BY KEY QUESTION

### Key Questions 1 and 1a – Incidence

- The published literature provides limited information about the true incidence and prevalence of blast-related injuries experienced by US military personnel. Findings are likely influenced by assessment and reporting methods.
- The reported explosion injury incidence ranged from 4.5/1,000 deployed in 2005 to 1.7/1,000 deployed in 2009.
- During the Iraq troop surge (2007) explosion injury incidence was particularly high (83/1,000 deployed in a US Army Brigade Combat Team).
- Musculoskeletal explosion injury incidence (fractures, amputations, neurological injuries, joint dislocations, and soft tissue injuries) ranged from 3.5/1,000 deployed in 2005 to 1.3/1,000 deployed in 2009.
- Spinal injury incidence (fractures, dislocations, nerve root injuries, spinal cord injuries) ranged from 0.18/1,000 deployed in 2008 to 0.40/1,000 deployed in 2005.
- Thoracolumbar burst fracture incidence was low (0.45 to 2.1 per 10,000 soldier years between 2008 and 2010) but higher in Afghanistan than Iraq and increased over the study period.
- No study reported incidence by blast characteristics.

### Key Question 2 and 2a – Prevalence

- Nearly three-quarters of all combat injuries over the period from 2005 to 2009 (31 per 10,000 deployed) were due to explosions.
- A high proportion of musculoskeletal injuries (82%; 23 per 10,000 deployed) and spinal injuries (75%; 3 per 10,000 deployed) between 2005 and 2009 were due to explosions. Of the musculoskeletal injuries, 80% of axial skeletal and extremity fractures, 94% of amputations, and 85% of soft tissue injuries were explosion-related. Another study reported explosion-related amputations in 4 per 10,000 troop-years (Iraq) and 9 per 10,000 troop-years (Afghanistan) over the period from 2001 to 2011.
- No study reported prevalence by blast characteristics.

### Key Question 3

- The published literature provides limited information on outcomes associated with blast versus non-blast TBI experienced by US military personnel. Definitions of blast/non-blast injury, assessment of outcomes, and reporting methods vary and often are based on small selected groups.

- Blast and non-blast TBI groups had similar rates of pain, vision loss, vestibular dysfunction, functional ability, depression, sleep disorders, alcohol misuse, and post-concussive symptoms.
- Comparative outcomes in individuals with blast versus non-blast TBI were inconsistent across studies with regard to PTSD diagnosis or symptom severity, hearing loss, cognitive function, and headache in blast and non-blast TBI groups.
- Mortality, burn injuries, limb loss, and quality of life were infrequently reported in studies comparing blast versus non-blast TBI.
- Results were consistent across studies that varied by location of assessment (combat zone, medical facility), time from exposure to assessment (< 30 days, 30 days to one year, or > one year), and level of TBI severity, although the most studies were small, clinical cohort studies, with mTBI patients evaluated at a DoD or VA medical facility.
- There is little data on outcomes among those with TBI according to blast characteristics.

## DISCUSSION

Numerous studies have reported combat casualties but do not provide a denominator to allow for determination of true incidence or prevalence in the deployed population at risk.[49] For example, Ivey et al reported that 2,049 of 23,797 wounded US military personnel documented in the JTTR from January 2003 to May 2011 sustained thoracic injuries, a "prevalence" of 8.6%.[50] They further note that an explosive device was the source of injury for 62% of the thoracic injuries. However, these data do not allow a true determination of prevalence of thoracic injuries associated with explosive devices among deployed service members. Our literature search identified studies like the Ivey et al study for deaths (Eastridge 2012) and other types of injuries including spinal column, craniomaxillofacial, colorectal, ocular, otologic, and extremity.[51-56]

Similarly, we identified a recent systematic review and meta-analysis reporting the "prevalence" and characteristics of battle casualties in Iraq and Afghanistan.[57] The review included 8 studies spanning 2001 to 2013. Four of the studies are included in our review; the remaining 4 studies would not have been eligible for our review because they were either single facility or short-term studies, not published in English, and/or not predominantly US soldiers. Different studies addressed the casualty classifications (died of wounds, killed in action [KIA], wounded in action, and returned to duty) differently (*eg,* one study included only KIA; 2 other studies excluded KIA) but the results of all 8 studies were combined. Of 19,671 battle casualties, 14,056 (72%) were caused by blasts but, again, no denominator of deployed service members was provided.

The DoDTR (formerly the JTTR) is recognized as the best available source of data for the study of US military combat injuries, but it is not without limitations.[7] The DoDTR provides data on all combat casualty cases initially entering the Joint Theater Trauma System at Level III medical facilities (combat zone). Information is added to the DoDTR as the service member moves to an out-of-theater facility and ultimately to a facility in the United States (if required for their care). Disadvantages of the DoDTR include variations in the reliability of the data entered by non-researchers involved in the delivery of care, absence of data on service members killed in action or returned to duty (*ie,* not medically evacuated), and absence of data on US troops treated at

North Atlantic Treaty Organization Facilities prior to late 2008.[7,50] Furthermore, in 2007, the system for classifying mechanism of injury used in the JTTR was changed and injuries are now classified as primarily blunt or penetrating. As a result, blast injury is now less frequently reported.[50]

Few studies of blast incidence or blast-related TBI outcomes report any of the important characteristics of a blast injury: how far the individual was from the blast, whether they experienced a blast wave, whether there was loss of consciousness or altered consciousness, whether there was amnesia (and length of time), and whether there was additional trauma.[58] There have been attempts to document this information, however. Data from 367,555 service members who completed a Post-Deployment Health Assessment (PDHA) that included questions about possible TBI events experienced during deployments from 2012 to 2015 showed that 45.7% with a positive TBI screen experienced a blast or explosion.[59] Among those who reported the distance from the blast, the majority were less than 25 meters away. Over 30% reported receiving more than one concussive event during the deployment. Among those with a positive TBI screen, 11.5% reported 3 or more events.

We found no reports of blast injuries associated with different combat roles. One combat role considered to place soldiers at higher risk of injury due to repeated low-level primary blast exposure is that of breacher. Breachers place explosives on structures where access is needed and then stand at a “safe” distance away during the explosion. A study of US Marines enrolled in a 2-week Breacher Training Course focused on auditory and vestibular effects.[60] Clinically significant hearing loss was noted while the vestibular effects were “unremarkable.” A similar study enrolling US Marine instructors measured effects on vision.[61] The analysis included 9 breacher instructors (estimated to be exposed to 500 to 600 “low-level” blasts each year of a 2-to-3-year assignment) and a control group of 4 breacher engineers (not exposed to blasts) with repeat testing of both groups over a 2-year period. Vision test results for the blast-exposed group were within or slightly lower (worse) than normal ranges and symptom scores did not differ between blast-exposed and control. A study of 21 participants in a 2-week New Zealand military breacher training course where blast exposures occurred one to 20 times per day on 5 of the training days observed changes in neurocognitive performance and self-reported symptom scores warranting further investigation.[62] A report of neuropsychological and neurocognitive outcomes following a Canadian Explosives Forced Entry course (10 days of lectures and training on use of explosives to gain entry into building walls, doors, and windows) for police (4 instructors and 10 students) found no significant changes from baseline to the end of the course.[63]

## LIMITATIONS

The limitations of this review relate to little published information on blast injuries and variations in reporting across studies. There is no information on incidence and prevalence of blast injuries by blast mechanism (*eg*, primary, secondary, tertiary, quaternary, quinary) and limited reporting in studies comparing blast and non-blast TBI. For determination of incidence and prevalence, there are also limited published data on numbers of soldiers deployed that accurately take into account factors such as true deployment length, combat intensity, and type of unit.[7] Clear and consistent definitions for injuries (*eg*, casualties, battle injuries, wounded in action, *etc*) and consistent standards for what to include in numerators and denominators when calculating incidence is necessary for accurate interpretation of combat trauma data.[64]

In the TBI studies, diagnoses and outcomes assessment were done at different time points following the blast and using different instruments, making comparisons across studies difficult. Reporting of symptoms may change over time and persistent or late-occurring symptoms may or may not be related to an earlier TBI.[4] For example, a recent study of 119,353 active duty US service members who began their first deployment in 2011 and were followed for approximately 4 years reported 11,498 first-time TBI diagnoses in the cohort including 2,525 prior to deployment, 3,086 during deployment, and 5,897 after deployment.[65] Cause of injury data were not complete and were not fully reported. In addition, authors used varying definitions of blast/non-blast injury. It was unclear whether the increased rate of TBI diagnoses post-deployment was a result of late diagnoses of TBI that occurred during deployment, delayed diagnoses during a more complete evaluation of severe injuries obtained during deployment, or increased post-deployment injury, possibly due to increased risk-taking behaviors.

Furthermore, confounding factors in studies of blast-exposed soldiers make it difficult to isolate the effects of the blast.[63] In studies comparing individuals with blast and non-blast TBI, outcomes such as headache, sleep disturbance, memory difficulties, and depression may be attributed to factors other than blast exposure (*eg*, deployment status, chronic pain and other physical injuries, substance use disorders).[4]

## APPLICABILITY OF FINDINGS TO THE VA POPULATION

Our review was limited to studies of combat injuries associated with OEF, OIF, and OND. The findings are highly applicable to military personnel and organizations that provide direct acute or chronic health care services including rehabilitation as well as employment to those either currently serving or of recent Veteran status. Additionally, an understanding of the incidence, prevalence, outcomes, and causal factors of blast and non-blast injuries may be used to help reduce these injuries in future combat operations.

However, many studies reported findings from individuals presenting to medical facilities and undergoing treatment for a specific combat injury. Patient and injury characteristics and subsequent health outcomes from these selected patients may differ in unknown ways from the broader group of individuals who had combat injuries. We also have little information on very long-term effects (*eg*, cognitive function decline over decades).

The Analysis of VA Health Care Utilization among Operation Enduring Freedom (OEF), Operation Iraqi Freedom (OIF), and Operation New Dawn (OND) Veterans (released June 2015) reports that 1,906,754 OEF/OIF/OND Veterans have become eligible for VA health care since fiscal year 2002 (beginning October 1, 2001) and approximately 2.7 million troops (as of December 31, 2014) have served or are serving in the 2 theaters of operation since the beginning of the conflicts in Iraq and Afghanistan (http://www.publichealth.va.gov/docs/epidemiology/healthcare-utilization-report-fy2015-qtr1.pdf Accessed 10 August 2015). In 2007, the VA began a program of TBI screening and comprehensive. OEF/OIF/OND Veterans who present for care at a VA facility undergo a screen for TBI.[66] One of the screening questions addresses exposure to physical trauma. Veterans who screen positive for TBI undergo a comprehensive evaluation. An analysis of data from October 2007 to June 2010 found that 55% (30,267/55,070) of those evaluated for TBI after a positive screen were diagnosed with TBI. Of those, 36% had blast exposure and 44% had both blast and non-blast exposures.[67]

## RESEARCH GAPS/FUTURE RESEARCH

In the Institute of Medicine's "Gulf War and Health, Volume 9: Long-term Effects of Blast Exposures," recommendations for future work highlighted the need to fill the gaps in the evidence base pertaining to the health effects of blast exposure and the need for greater emphasis on identifying and treating the complex injury patterns that often follow blast exposure. Collaborative efforts between the VA, DoD, and others were encouraged including the development of more complete registries with detailed information about the blast environment, information about both blast-injured and blast-exposed service members, and measurement of long-term health outcomes.[68]

Accurately recording in a standardized fashion every injury to every individual who experiences a blast (including type of blast [*eg*, primary, secondary, *etc*], distance from the blast, *etc*), and then following those individuals to assess long-term outcomes, would be ideal insofar as possible within the combat environment. However, for those who have been determined to have received blast-related injuries, additional information on the circumstances surrounding the injury should include: type of blast, distance from the blast, history of blast exposure, injury severity, assigned and actual duties, and military member's physical and psychosocial characteristics. Additional information gathered would be useful to evaluate methods to reduce combat-related blast injuries. Comparisons versus deployed controls may facilitate our understanding of the mechanisms and severity of blast-related injuries and the long-term health and social consequences of those injuries. This includes not only the treatments and health outcomes specific to the blast injury but also the long-term psychosocial, employment, and economic impact of blast injuries and the role and capacity needs for health care systems and the work force as these individuals reintegrate into the civilian society. Existing databases may already contain some of this information and future analyses should incorporate blast data where possible.

## CONCLUSIONS

- The published literature provides limited information about the true incidence and prevalence of blast-related injuries experienced by US military personnel and the outcomes associated with blast versus non-blast TBI. We found no reports of incidence and prevalence of blast injuries associated with different combat roles.

- Few studies of incidence of blast-related injuries or outcomes associated with blast versus non-blast TBI report important characteristics of a blast injury: type of blast, how far the individual was from the blast, whether they experienced a blast wave, whether there was loss of consciousness or altered consciousness, whether there was amnesia (and length of time), and whether there was additional trauma.

- Only 6 studies, 3 of which were derived from the same data set, provide information about the incidence and prevalence of blast-related injuries in the deployed population at risk.

- Pain, vision loss, vestibular dysfunction, functional status, depression, sleep disturbance, alcohol misuse, and post-concussive symptoms were similar in groups of patients with blast and non-blast TBI. Findings were less consistent for PTSD, hearing loss, cognitive function, and headache. Few studies reported mortality, burn outcomes, limb loss, or quality of life.

- Reporting studies were often small and involved highly selected patients and thus may not be fully representative of all individuals with blast or non-blast TBI. There are little data on very long-term outcomes that may be particularly relevant to assessment of cognitive function and quality of life.

- Blast and blast injuries (including TBI) are often defined differently. Therefore, the incidence, prevalence, and patient outcomes may vary across studies in part due to differences in how blast injury is categorized.

- To more adequately address questions about consequences of blast exposure, future research efforts should focus on comprehensive and consistent documentation at the time of and following blast exposure and more complete analyses of databases that may have already captured blast exposure information.

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