Hospitalization associated with traumatic brain injury in the active duty US Army: 2000–2006[1]

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Abstract. *Objective*: to determine the potential impacts of Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) on the incidence of TBI-related hospitalization in the active duty US Army.
Methods: All active duty Army personnel hospitalized with a TBI diagnosis during fiscal years 2000 through 2006 were identified in an administrative database. Annual crude incidence rates were calculated. Two-year adjusted incidence rates were calculated to compare TBI-related hospitalization rates in the Army to rates in the age-comparable segment of the US civilian population.
Results: The overall incidence of TBI-related hospitalization in the active duty Army increased 105% from FY2000 to FY2006. There was a 60-fold increase in the hospitalization rate for TBIs attributed to weapons. The increases in TBI hospitalizations coincided with the occurrence of OEF/OIF. During OEF/OIF, the Army's hospitalization rates for moderate and severe TBIs were lower than civilian rates; however, the Army's hospitalization rate for mild TBIs was higher than civilian rates.
Conclusion: OEF/OIF appear to have had a substantial impact on TBI-related hospitalization rates in the active duty US Army but differences between Army and civilian rates were not as excessive as expected.

Keywords: Traumatic brain injury, incidence rates, US Army, blasts, war-related

1. Introduction

The annual incidence of hospitalization associated with traumatic brain injury (TBI) in the active duty US Army decreased substantially in the 1990's [22]. Changes in hospital admission practices for mild TBI, an increased emphasis on injury prevention, and changes in the Army population likely contributed to the decrease [22]. Furthermore, the United States did not participate in any prolonged large-scale military conflicts during the 1990s and the resulting lack of battle injuries helped facilitate the decrease. However, for most of the current decade, the United States has been involved in two large-scale protracted military conflicts

in Afghanistan and Iraq that have likely increased the annual incidence of TBI-related hospitalizations in the active duty Army.

The war in Afghanistan, which was designated Operation Enduring Freedom (OEF) by the US military, began in October 2001 and is the smaller of the two conflicts. The war in Iraq, which was designated Operation Iraqi Freedom (OIF), began in March 2003 and is considerably larger in scale than OEF. Both conflicts are still ongoing and, because of their simultaneous occurrence, are treated in this paper as one entity, OEF/OIF, for ease of analysis and discussion.

TBI is one of the more common types of battle injury. This is because "the head is preferentially exposed in combat as the soldier constantly monitors his environment by means of exteroceptive neurosensory structures (eyes, ears, and nose) in order to enhance his own survival" [8]. It is estimated that the head and neck together comprise 12% of the total body area that is ex-

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[1] The views expressed in this article are those of the author and do not reflect the official policy of the Department of Army, Department of Defense, or U.S. Government.

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14. ABSTRACT

Objective: to determine the potential impacts of Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) on the incidence of TBI-related hospitalization in the active duty US Army. Methods: All active duty Army personnel hospitalized with a TBI diagnosis during fiscal years 2000 through 2006 were identified in an administrative database. Annual crude incidence rates were calculated. Two-year adjusted incidence rates were calculated to compare TBI-related hospitalization rates in the Army to rates in the age-comparable segment of the US civilian population. Results: The overall incidence of TBI-related hospitalization in the active duty Army increased 105% from FY2000 to FY2006. There was a 60-fold increase in the hospitalization rate for TBIs attributed to weapons. The increases in TBI hospitalizations coincided with the occurrence of OEF/OIF. During OEF/OIF, the Army?s hospitalization rates for moderate and severe TBIs were lower than civilian rates; however, the Army?s hospitalization rate for mild TBIs was higher than civilian rates. Conclusion: OEF/OIF appear to have had a substantial impact on TBI-related hospitalization rates in the active duty US Army but differences between Army and civilian rates were not as excessive as expected.

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posed during combat but in World War II and the Korean and Vietnam Wars, 15% to 25% of combat wounds were to the head/neck region [8]. However, in OEF/OIF the proportion may be higher. A recent study that examined 6,609 combat wounds sustained by US military personnel in these conflicts found that 30% were to the head/neck region [37].

TBI has often been described in the news media as the "signature" injury of OEF/OIF but the incidence of TBI in these conflicts is not known and without such data this type of description can lead to misperceptions about the magnitude of the public health problem TBI currently poses to the US Army. So far, the TBI-focused epidemiologic studies that have been published obtained their data from non-clinical samples of soldiers who were screened for TBI after they returned from OEF/OIF [16,43,44,49]. Although these studies were useful for demonstrating the feasibility and potential utility of population-based TBI screening, they cannot be used estimate the incidence of TBI in the Army resulting from OEF/OIF. Consequently, there is an insufficient amount of data available in the research literature at the present time to assess the impact of OEF/OIF on TBI in the Army.

To measure the impact of these conflicts on TBI in the Army, studies including a broader spectrum of soldiers are needed. They need to include data from soldiers who were medically evacuated from OEF/OIF and still hospitalized as well as those convalescing after being discharged from the hospital. They also need to include data from soldiers who were not deployed to OEF/OIF. In addition, data about the pre-war incidence of TBI in the Army need to be provided to serve as a benchmark. TBI incidence data from the civilian population could also be added to serve as another benchmark.

Administrative databases can be useful for these types of studies because they often contain data about an entire segment of a patient population. This paper examines the annual incidence of TBI-related hospitalization in the active duty Army from fiscal year (FY) 2000 through FY2006 using data from the military's Standard Inpatient Data Record (SIDR) database. The SIDR contains data about all military personnel who are hospitalized in military medical facilities as well as those who are treated in civilian hospitals [3]. In addition, this paper will compare the incidence of TBI-related hospitalizations in the Army to that of the age-comparable segment of the US civilian population using data from the National Hospital Discharge Survey (NHDS), which is based on a large annual probability sample of discharges from short stay hospitals with

more than six beds located in all 50 states and the District of Columbia [10]. The paper will infer from these data the likely impact of OEF/OIF on TBIs in the Army and illustrate how a better understanding of the epidemiology of military TBI can provide some insights about the nature of these conflicts as well as our current understanding of TBI.

2. Methods

Deidentified data for all active duty U.S. Army personnel with a TBI diagnosis in SIDR from FY2000 through FY2006 were analyzed. These data were obtained from the U.S. Army's Patient Administration Systems and Biostatistics Activity. Data for US civilians 17 to 49 years of age who were hospitalized with a TBI diagnosis in 2000, 2001, 2005 and 2006 were also analyzed. This is the age range of approximately 98% of the active duty Army population. The number of civilian hospitalizations was estimated from NHDS public-use data files for those years [11]. To avoid over counting Army personnel hospitalized multiple times for the same injury event, only data from the initial hospitalization were used.

A patient was considered to have had a TBI if at least one code from any of the following categories in the *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9 CM) was listed in any of the available diagnosis fields in the SIDR and NHDS: 800.00 to 801.99, 803.00 to 804.99, and 850.0 to 854.19. These diagnosis codes have been used in numerous studies to identify TBIs [18]. Patients who had any ICD-9 CM codes in the 800–959 range other than those used to indicate TBI were considered to have associated extra-cranial injuries.

TBI severity was estimated by mapping ICD-9 CM diagnoses to the Abbreviated Injury Scale (AIS) 1990 Revision by using a computer algorithm called ICDMap-90 [4,50]. 1990 was the year of that last major AIS revision prior to the recent 2005 revision. The AIS uses the following six-category score to indicate the severity of each diagnosis: 1 (minor), 2 (moderate), 3 (serious), 4 (severe), 5 (critical), and 6 (maximal). The AIS severity scores for TBI diagnoses were subsequently converted into the three categories that are generally used to categorize TBI severity. Diagnoses with a severity score $\leqslant 2$ were classified as mild, those with a score of 3 were classified as moderate, and those with a score of 4, 5, or 6 were classified as severe. For patients with multiple TBI diagnoses, the injury with

the highest severity score was used to indicate overall severity.

TBI diagnoses with a severity score of 2 were considered mild because the most common TBI diagnoses in this analysis, concussions (ICD-9 category 850), were almost always mapped to AIS diagnoses with a severity score of 2. This was the case for concussions with brief loss of consciousness (LOC) (ICD-9 code 850.1), LOC of unspecified duration (ICD-9 code 850.5), or if the diagnosis was "Concussion, unspecified" (ICD-9 code 850.9). Only 27 of the 2,959 Army TBI cases included in this analysis had TBIs that mapped to AIS diagnoses with a severity score of 1. These were concussions that did not result in LOC (ICD-9 code 850.0). Since TBIs resulting in LOC lasting up to 30 minutes are considered mild, defining mild TBIs only as those with an AIS severity score of 1 would have grossly underestimated the number of mild TBIs [2]. Other studies have used the same methodology to convert AIS severity scores to traditional TBI severity indicators [12,22,36,45,51].

Cause of injury was determined from the North Atlantic Treaty Organization (NATO) Standardized Agreement (STANAG) 2050 code reported in the SIDR [31]. STANAG cause of injury codes were developed by NATO to serve as an alternative to ICD-9 E-codes in order to provide more militarily relevant information about cause of injury. In this paper, all cases with STANAG codes indicating a weapon as the cause of injury were classified as having a weapon-related injury. Cases with any other STANAG codes were classified as having injuries attributed to non-weapon causes.

Crude incidence rates for Army TBI hospitalizations were calculated for each fiscal year using the year-end active duty Army population as the denominator. Army population data were obtained from the Defense Manpower Data Center in Monterey, California. Crude rates were calculated for the following categories: all TBIs, each TBI severity level, outcome, cause of injury, patients with and without associated extra-cranial injuries, gender, and age. No inferential statistics were used to compare the changes in the Army's rates over time because all hospitalizations were included in the SIDR.

Two-year age- and gender-adjusted rates were used to compare the incidence of TBI-related hospitalizations in the Army to those among 17 to 49 year-old US civilians in 2000–2001 and 2005–2006. Aggregating data from multiple years increases the stability of adjusted incidence rates because small numbers of patients in some age and gender categories can result in large variations in rates from year to year. In the Army, rates for females and those ages 35 and older are prone to this because these groups are small segments of the population with few TBI hospitalizations each year. Civilian hospitalization rates are also prone to this because relatively small differences in the sample size of each year's NHDS can result in substantial fluctuations in the estimated number of hospitalizations for any given patient category [42]. As an additional safeguard against instability in civilian rates, the Army's rates from 2005–2006 were also compared to civilian rates from 2000–2001, which was tantamount to having constant civilian hospitalization rates throughout the study period.

Civilian incidence rates were calculated using the Census Bureau's mid-year population estimates that were included in the NHDS documentation. Comparisons were made in the following categories: all TBIs, each TBI severity level, outcome, patients with and without associated extra-cranial injuries, gender, and age. The Army and civilian incidence rates in most categories were adjusted for age and gender. The rates for gender were adjusted only for age and the rates for age were only adjusted for gender. The rates were adjusted by the direct method using the 2000 US civilian population as the standard. Rate differences (RD) were calculated by subtracting each adjusted civilian rate from the appropriate adjusted Army rate. 95% confidence intervals were used to determine if rate differences were statically significant. Confidence intervals that exclude the value zero indicate that a rate difference is significant at the 0.05 level. The variance of the differences between the adjusted Army and civilian rates were calculated using methods described by Kahn and Sempos [24].

3. Results

A total of 2,959 hospitalized active duty Army personnel met the TBI case definition from FY2000 through FY2006. The hospitalization rate for all TBIs in the active duty US Army increased from 60.7 to 125.0 per 100,000 (105.7%) from FY2000 to FY2006 (Table 1). The rates for mild, moderate, and severe TBIs each more than doubled during that period (Table 1). The incidence of TBIs with associated extra-cranial injuries increased 135.1% from FY2000 through FY2006 and the incidence of TBIs without associated extra-cranial injuries increased 75.3% (Table 1). The hospitalization rate for TBIs attributed to weapons increased

Table 1
Crude incidence rates of TBI-related hospitalizations in the active duty US Army
by injury and demographic characteristics, FY2000 vs. FY2006

Characteristic	FY2000 Rate/100,000 Soldiers	FY2006 Rate/100,000 Soldiers	% Change
All TBIs	60.7	125.0	105.7
TBI severity			
Mild	33.6	69.8	107.8
Moderate	5.5	12.5	130.9
Severe	15.0	33.8	125.0
Unknown	6.7	8.8	31.1
Associated extra-cranial injuries			
Yes	30.9	72.6	135.1
No	29.9	52.3	75.3
Cause of injury			
Weapon-related	0.8	50.3	6,187.5
Other causes	59.9	74.6	24.5
Outcome			
Died in hospital	2.1	5.0	138.3
Gender			
Male	65.1	139.4	114.1
Female	36.8	36.8	0.0
Age			
17–24	93.9	180.0	91.6
25–34	47.4	102.0	115.0
>= 35	21.0	64.9	209.5

more than 6,000% from just 0.8 per 100,000 in FY2000 to 50.3 per 100,000 by FY2006 while the rate for TBIs attributed to non-weapon causes increased only 24.5% during that period (Table 1). The incidence of in-hospital deaths among TBI patients increased 138.3% from FY2000 to FY2006. However, only a small proportion (4%) of hospitalized TBI patients died in FY2006. The Army's TBI-related hospitalization rates also substantially increased in all age categories and for males but the rate for females remained unchanged.

The largest annual increases in the incidence of TBI-related hospitalizations in the active duty Army generally occurred from FY2003 to FY2005 (Figs 1–4). The largest increases in hospitalization rates for TBIs with associated extra-cranial injuries occurred from FY2003 to FY2004 (18.3 per 100,000) and FY2004 to FY2005 (21.1 per 100,000) (Fig. 3). The annual incidence of hospitalization for TBIs without associated extra-cranial injuries increased from FY2002 through FY2006 but in smaller and more consistent increments (Fig. 3). Consequently, in FY2006, the incidence of TBIs with associated extra-cranial injuries was 39% higher than the incidence of TBIs without associated extra-cranial injuries (72.6 versus 52.3 per 100,000), whereas in FY2000, the incidence rates for these two categories were about equal (30.9 versus 29.9 per 100,000) (Table 1). The Army's hospitaliza-

tion rates for TBIs attributed to weapons increased each year from FY2002 through FY2006, with the largest increases occurring from FY2003 to FY2004 (15.4 per 100,000) and FY2004 to FY2005 (16.8 per 100,000) (Fig. 4). The Army's hospitalization rates for TBIs attributed to non-weapon causes also increased by their largest amounts from FY2003 to FY2005 (6.6 and 9.2 per 100,000, respectively) (Fig. 4). However, in FY2006, the incidence of TBIs attributed to non-weapon causes was still 48% higher than the incidence of TBIs attributed to weapons (74.6 versus 50.3 per 100,000) (Table 1).

The 2-year adjusted incidence rate of all TBI-related hospitalization in the active duty Army in 2000–2001 (40.1 per 100,000) was significantly lower than it was among age-comparable US civilians during 2000–2001 ($RD = -21.9, 95\%$ CI $= -28.7, -15.1$) (Table 2). The Army's adjusted rates for mild, moderate, and severe TBIs and for TBIs with associated extra-cranial injuries were also significantly lower than rates for civilians in 2000–2001 (Table 2). Additionally, the Army's adjusted rates for males and for personnel 25 years of age and older were significantly lower than civilian rates but the rate for females in the Army was not significantly different from the rate for civilian females (Table 2).

However, in 2005–2006, the Army's adjusted overall incidence of TBI-related hospitalization (71.9 per 100,000) was significantly higher than the incidence
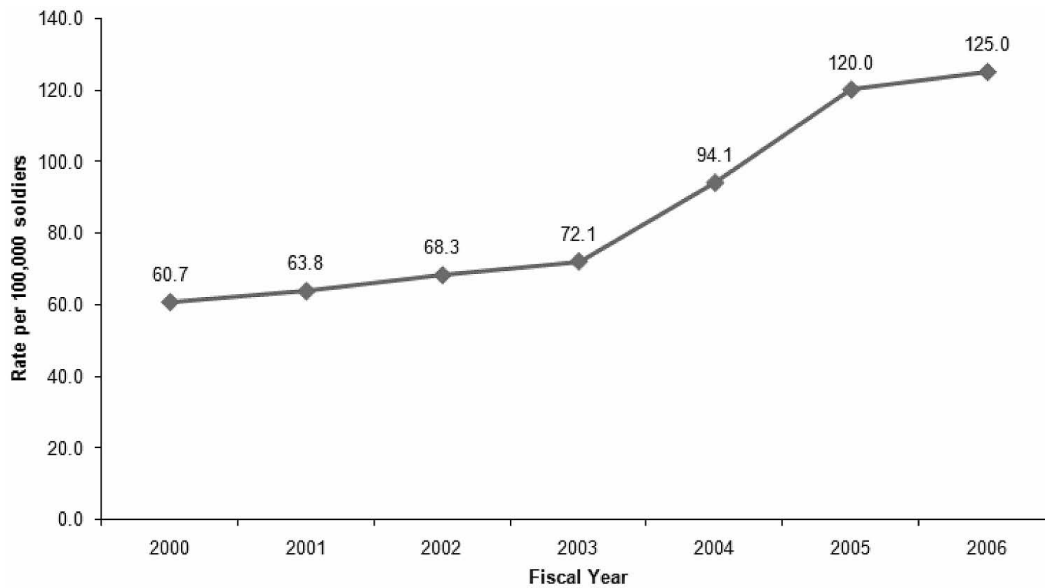
Fig. 1. Annual crude incidence rate of all TBI-related Hospitalizations in the active duty US Army, FY2000-FY2006.
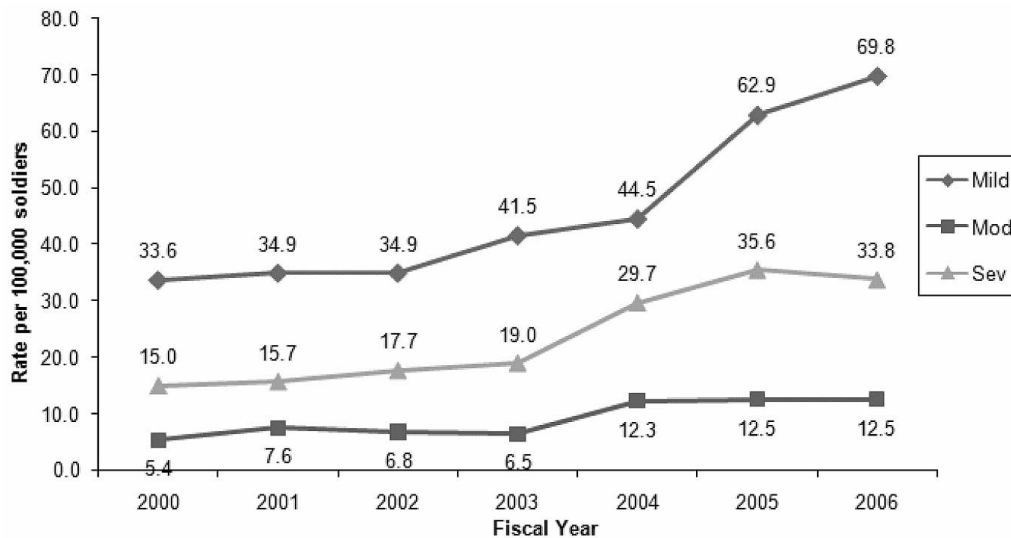

Fig. 2. Annual crude incidence rates of TBI-related hospitalizations In the active duty US Army by TBI severity, FY2000-FY2006.

among civilians 17 to 49 years of age (RD = 13.9, 95% CI = 7.2, 20.6) (Table 2). The Army's adjusted rates for mild TBI and for TBIs with associated extra-cranial injuries were also significantly higher than civilian rates in 2005–2006 (RD = 26.9, 95% CI = 24.0, 29.7 for mild TBI and RD = 12.3, 95% CI = 7.7, 16.9 for TBIs with associated extra-cranial injuries). But, the Army's hospitalization rates for moderate and severe TBIs were significantly lower than the rates among age-comparable US civilians in 2005–

2006 (RD = −4.4, 95% CI = −7.5, −1.3 for moderate TBI and RD = −12.9, 95% CI, −18.1, −7.9 for severe TBI) (Table 2). When the Army's incidence rates from 2005–2006 were compared to civilian rates from 2000–2001, it showed that the Army's rates in several categories were significantly different from civilian rates, including the overall rate and the rates for mild and severe TBIs (Table 3). This suggests that, in some categories, instability in civilian rates did not account for differences between some of the Army's and civilians'
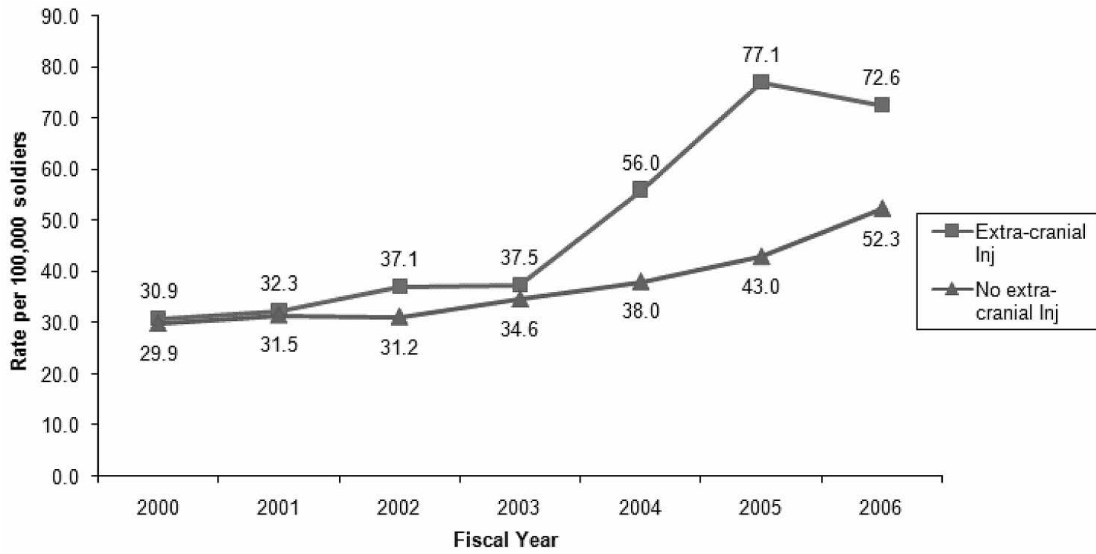
Fig. 3. Annual crude incidence rates of TBI-related hospitalizations in the active duty US Army by presence of associated extra-cranial injuries, FY2000-FY2006.
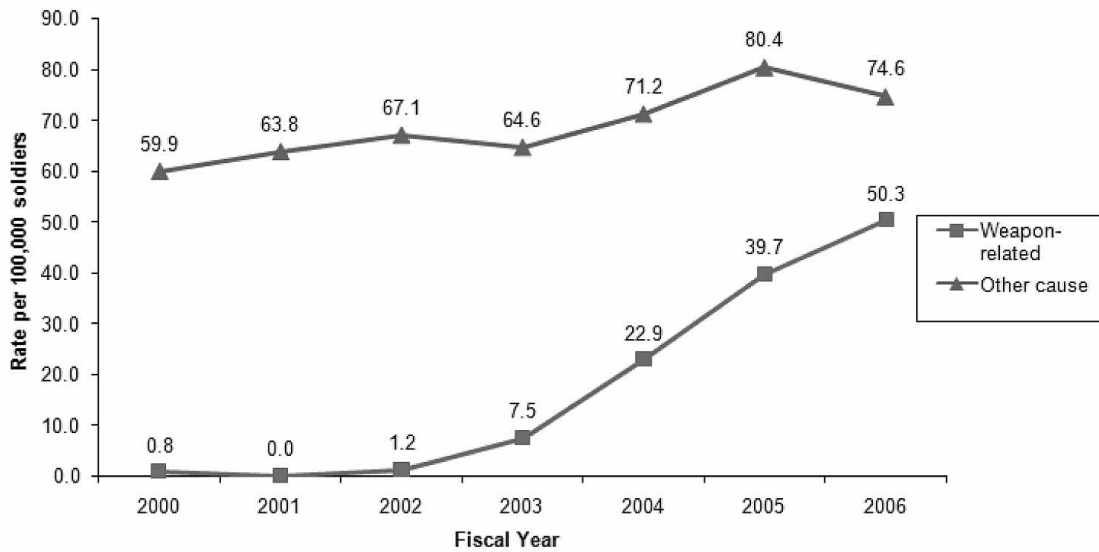

Fig. 4. Annual crude incidence rates of TBI-related hospitalizations In the active duty US Army by cause of injury, FY2000-FY2006.

TBI-related hospitalization rates.

4. Discussion

These results suggest that OEF/OIF may have had a substantial impact on the incidence of TBI-related hospitalization in the active duty US Army. This is reflected in many ways. The most obvious is that the increase in the incidence of TBI hospitalizations at-

tributed to weapons coincided with the commencement of OEF/OIF, which began in FY2002 and FY2003, respectively (Fig. 4). It is also reflected by the timing of largest annual increases in hospitalization rates for all TBIs, TBIs of every severity level, and TBIs with associated extra-cranial injuries, all of which occurred after OEF/OIF began (Figs 1–3).

The hospitalization trends that are most reflective of the impact of OEF/OIF on TBIs in the active duty Army are those for cause of injury, TBI severity, and

Table 2
Comparison of 2-year adjusted incidence rates of TBI-related hospitalization between the active duty US Army and US civilians 17–49 years of age by injury and demographic characteristics in 2000–2001 and 2005–2006

Characteristic	Incidence rates				Incidence rate differences (RD) and 95% confidence intervals (CI) of difference (AD Army-Civilian)					
	2000–2001		2005–2006		AD Army vs. Civilian in 2000–2001		AD Army vs. Civilian in 2005–2006		AD Army in 2005–2006 vs. Civilian in 2000–2001	
	AD Army	Civilian	AD Army	Civilian	RD	95% CI (RD)	RD	95% CI (RD)	RD	95% CI (RD)
Overall	40.1	62.0	71.9	58.0	−21.9	(−28.7, −15.1)*	13.9	(7.2, 20.6)*	9.9	(3.3, 16.6)*
TBI severity										
Mild	20.6	26.1	38.9	12.1	−5.5	(−9.9, −1.1)*	26.9	(24.0, 29.7)*	12.8	(8.5, 17.2)*
Moderate	4.9	8.7	8.0	12.4	−3.8	(−6.2, −1.4)*	−4.4	(−7.5, −1.3)*	−0.7	(−3.0, 1.7)
Severe	8.7	27.4	19.7	32.6	−16.8	(−21.2, −12.3)*	−12.9	(−18.1, −7.9)*	−5.7	(−10.0, −1.3)*
Unknown	5.9	1.7	5.2	0.9	4.2	(3.1, 5.3)*	4.3	(3.8, 4.9)*	3.5	(2.4, 4.5)*
Associated extra-cranial injuries										
Yes	20.7	44.3	42.1	29.8	−23.6	(−29.3, −17.8)*	12.3	(7.7, 16.9)*	−2.3	(−7.9, 3.4)
No	19.4	17.7	29.8	28.2	1.7	(−2.0, 5.4)	1.5	(−3.3, 6.4)	12.1	(8.5, 15.7)*
Outcome										
Died in hospital	0.9	2.7	2.0	3.8	−1.8	(−3.7, 0.0)	−1.8	(−3.2, −0.4)*	−0.7	(−2.5, 1.0)
Gender										
Male	49.7	90.6	109.1	88.8	−41.1	(−48.4, −33.8)*	20.3	(13.3, 27.4)*	18.4	(11.2, 25.5)*
Female	30.3	33.3	34.6	27.3	3.0	(−14.4, 8.4)	7.3	(−4.0, 18.6)	1.3	(−10.0, 12.5)
Age										
17–24	77.0	87.0	122.1	77.0	−10.0	(−20.5, 0.3)	45.1	(36.3, 53.9)*	35.1	(24.3, 45.3)*
25–34	40.5	60.2	75.7	50.5	−19.7	(−28.5, −10.9)*	25.2	(17.7, 32.6)*	15.5	(6.8, 24.3)*
>= 35	22.1	51.0	45.3	53.1	−28.9	(−40.9, −16.9)*	−7.7	(−20.1, 4.6)	−5.7	(−17.3, 6.0)

*Statistically significant at the 0.05 level.

TBIs with and without associated extra-cranial injuries. When these particular trends are examined more closely and possible explanations for them are explored, they provide insights about some important characteristics of OEF/OIF that distinguish them from other conflicts. They also provide some insights about the current state of our TBI knowledge.

The increase in the incidence of TBI hospitalizations attributed to weapons from virtually none prior to OEF/OIF to 50.3 per 100,000 in FY2006 provides the strongest evidence that OEF/OIF have affected TBI rates in the Army (Table 1, Fig. 4). Combat in OEF/OIF is the only plausible explanation for such a large increase in the incidence of weapon-related TBIs. However, in FY2006, the incidence rate of TBIs hospitalizations in the Army attributed to non-weapon causes was still 48% higher than the rate of weapon-related TBI hospitalizations (74.6/100,000 versus 50.3/100,000) (Table 1, Fig. 4). This certainly reflects a TBI characteristic and possibly a characteristic of OEF/OIF. The TBI characteristic reflected in this finding is that these injuries continue to occur in the large segment of the Army population that is not serving in OEF/OIF at any given time. Non-deployed soldiers at their home bases are sustaining TBIs from causes such as motor vehicle accidents, sports and recreation activities, and falls just as they always have. This fact needs to be emphasized because we should not lose sight of non-war TBIs in military populations during wartime.

The higher incidence of non-weapon TBI hospitalizations in the Army in FY2006 may also reflect a characteristic of OEF/OIF that is different from other prolonged large-scale conflicts the US has participated in: low intensity combat. This has resulted in relatively few battle casualties compared to other wars. The combat intensity in OEF/OIF is lower because in both Afghanistan and Iraq the US military is not fighting large, heavily armed, and well trained professional armies like those it faced in the two world wars, the Korean War, and even to some extent in the Vietnam War. Instead, it is facing much smaller insurgent and terrorist groups that lack most of the capabilities needed to wage conventional warfare on any appreciable scale. Because of the vastly superior fighting capabilities of the US military, enemy forces in Afghanistan and Iraq have been forced to wage a very limited form of war, avoiding conventional pitched battles that would result in heavy and irreplaceable losses of both personnel and weapons, and are relying instead on less costly indirect methods of engagement, such as hiding land mines

and improvised explosive devices (IEDs) in areas frequented by US forces or by conducting small-scale "hit and run" attacks on US military bases with mortars and rockets. This is reflected by findings from studies of battle injuries that occurred in OEF/OIF. Owens and colleagues found that of 81% of 1,566 US service members injured in battle in OEF/OIF were injured by blasts and only 19% were injured by gunshots [37]. Furthermore, they estimated that OEF/OIF together had the lowest proportion battle injuries from gunshots than any previous major war the US has engaged in including the Civil War of the 1860's [37]. Other studies had similar findings. Murray and colleagues reported that 88% of 269 US military personnel evaluated for battle injuries at an Army medical facility in Iraq were injured by blasts mostly from IEDs and mortars [34]. The remaining 12% of those with battle injuries sustained gunshot wounds and most of these individuals (22 out of 33) were injured in a single firefight. Gondusky and Reiter found that 97% of the 125 battle injury patent-events that occurred in a Marine Corps battalion that served in Iraq were due to blasts from IEDs or mines and only 3% from direct fire [13]. The term "improvised explosive device," which is used to describe the class of weapons accounting for most of the battle injuries in these studies, is itself indicative of the limited combat capabilities of enemy forces in Afghanistan and Iraq.

Examining the trends in the Army's hospitalization rates for each TBI severity level can also provide some insight about the nature of OEF/OIF as well as our understanding of TBI. The increase in the Army's hospitalization rate for severe TBIs was undoubtedly the result of an increase in the occurrence of severe TBIs. Indicators of severe TBI, such as prolonged LOC and post traumatic amnesia as well as positive imaging results, are generally definitive and would be difficult to miss in most cases. However, it is impossible to determine the extent to which the increase in the Army's hospitalization rate for mild TBIs reflected an actual increase in the occurrence of mild TBIs or was simply an artifact of the retrospective TBI screening initiated by the military during OEF/OIF.

The retrospective TBI screening that is now routinely performed on all service members returning from an overseas deployment is a direct result of OEF/OIF. It was initiated because of concerns that US military personnel serving in OEF/OIF may have a higher risk of sustaining a closed TBI than those who served in previous conflicts due to the overwhelming reliance on explosive weapons by the enemy and to higher survival rates among those injured in combat. The imple-

mentation of TBI screening was aided by the increased understanding of mild TBI that occurred over the last 20 years, such as the publication of the ACRM mild TBI definition, which has been described as a significant advancement in the ability to diagnose mild TBI [2,41]. It was also aided by the endorsement of the CDC and the Institute of Medicine as a useful method for identifying individuals who may have had a mild TBI [17, 35].

The ability of screening to identify TBIs that would have otherwise been undiagnosed was well illustrated by a study of patients admitted to a British trauma center [33]. TBI status was determined by a TBI specialist based on reviews of medical notes and patient interviews. Evidence of injury to the head combined with any memory gaps for events were required for a definitive TBI diagnosis by the researcher. The study found that 51% of the 47 patients who met the research criteria for TBI did not have a TBI diagnosis recorded in the medical notes. The failure to document a TBI occurred in 75% of the TBI cases with other injuries but in only 16% of those with head injury alone. Failure to document a TBI was associated with having surgery within 48 hours of the injury event. Furthermore, 83% of those with an undiagnosed TBI had a mild TBI although three individuals with moderate TBIs and one with a severe TBI also did not have a diagnosis recorded.

Concerns about undiagnosed TBIs, particularly mild ones, among service members returning from combat have existed since World War I, when many soldiers exposed to blasts but with no apparent head wounds reported to medical aid stations with symptoms similar to those who had head wounds and brain injury [23]. The term "shell shock" was developed at that time to describe this phenomenon and it was initially thought to have a neurologic origin but a debate quickly developed about whether shell shock's origin was neurologic or psychological and by World War II it was generally considered to be a psychological condition [23]. Unfortunately, however, our current understanding of this phenomenon is no better than it was more than 90 years ago and debate about its origin has erupted once again.

The current debate was triggered by the military's adoption of retrospective TBI screening. It was argued by Bryant in a recent editorial that mild TBIs identified by retrospective screenings are more likely to be misidentified stress reactions. He concluded that unnecessarily attributing persistent symptoms and health problems to a mild TBI sustained in OEF/OIF could result in the development of a new war syndrome, like

the unexplained Gulf War syndrome that emerged after the 1991 Persian Gulf war, and that it could be harmful to both the morale and future mental health of service members because of misperceptions about recovery from brain injury [7]. Bryant based his conclusion on three issues: 1) the non-specificity of persistent postconcussive symptoms to mild TBI; 2) the possibility that mild TBI increases the risk of developing PTSD, which subsequently results in symptom maintenance; and 3) the characteristics used to identify TBIs in the retrospective screening (loss of consciousness, altered consciousness- such as being dazed or confused- and not remembering events) could also result from acute stress reactions thereby rendering any differential diagnosis made long after the traumatic event problematic [7].

Although Bryant's conclusions about the possible consequences of attributing persistent symptoms and health problems to mild TBI are not based on evidence from OEF/OIF, the issues he points out are well documented. Numerous studies have shown that postconcussive symptoms are not specific to mild TBI and that perceptions about recovery may play a role in the development of persistent symptoms [14,15,19,21,30, 39,46,52–54]. A recent study by Brenner and colleagues of TBI and PTSD screening results from US soldiers who returned from Iraq supports this [6]. It found that mild TBI and PTSD were both independently associated with reports of post-concussive symptoms. Recent studies of US military personnel who served in OEF/OIF also support the possibility that mild TBI may increase the risk of developing PTSD [16,49]. Furthermore, several studies have also pointed out the difficulty of determining the causes of post traumatic amnesia and altered consciousness when psychiatric conditions, like PTSD, occur after an injury event [20,27–29]. Therefore, it is likely that the incidence of mild TBI hospitalizations in the Army in FY2004 through FY2006 is inflated to some degree by false positive screening results.

It is also likely that some of the excess incidence reflects an actual increase in the occurrence of mild TBIs in the Army population. Given the sizable proportion of Army TBI hospitalizations attributed to weapons after the commencement of OEF/OIF and the apparently overwhelming reliance on explosive weapons by enemy forces, blast exposure was likely a major contributor to the increase in hospitalizations for TBIs of all severity levels in the Army from FY2003 through FY2006. Blasts appear to be the predominant cause of battle injuries among US military personnel who participated

in major conflicts in the last 60 years [37]. Scholarly works on the history of war in the modern era point out the profound effects that the application of science to weapon development and production has had on the scope and nature of warfare especially from the late nineteenth century through the present [26,40]. In the first half of the twentieth century the mass production of powerful and sophisticated explosive weapons by the world's major military powers manifested itself in millions of battle casualties during the two world wars. In the decades following the Second World War, the combination of Cold War rivalry between the US and USSR and the collapse of European empires around the world resulted in the proliferation of modern weapons as well as the knowledge needed to use and produce them. Consequently, the widespread availability of modern explosive weapons has enabled insurgent and terrorist groups with limited budgets to wage wars and commit violent acts throughout the world and to sustain their campaigns for years and sometimes decades. Furthermore, despite their financial limitations, these groups have also acquired sufficient knowledge and experience from these long campaigns to adapt and use explosive weapons in ways that inflict maximum injury and death on their intended victims [25].

Explosive weapons have become predominant because they are more versatile than firearms. They come in all shapes and sizes and can be delivered to their targets in almost limitless ways, including indirectly, such as hiding mines or bombs where the intended victims can unknowingly trigger them. Explosive weapons have also become predominant because they provide an efficient means of injuring and killing people as well as destroying property. They are so efficient because blasts simultaneously transmit many forms of energy such as fragments and shrapnel, the blast shockwave, acoustic energy, as well as heat and electromagnetic field (EMF) energy each of which is a unique injury mechanism [32]. Consequently, blast injuries are classified into three and sometimes four categories based on injury mechanism [9,48]. Primary blast injury results from exposure to the sudden increase in atmospheric pressure, known as the blast wave, and can injure air filled organs such as the lungs, middle ear, and gastrointestinal organs. Secondary blast injury results when individuals are struck by objects set in motion by a blast. Tertiary blast injury results when individuals are displaced by the blast and subsequently strike something. Secondary and tertiary blasts injuries can be blunt or penetrating and can occur in many body regions including the head. Finally, quaternary blast

injury results from other mechanisms such as exposure to heat, radiation, or caustic chemicals.

The injury risk from blast exposure depends on many factors that can interact in very complex ways. One factor, proximity, greatly influences the risk of injury. Victims in close proximity to the detonation point are at risk for primary, secondary, tertiary, and quaternary blast injury. However, injury risk varies for each blast injury mechanism as proximity decreases. Victims have to be relatively close to the detonation point in order to sustain primary blast injury because the atmospheric overpressure resulting from the blast wave decreases exponentially as it travels away from the detonation point [47]. But fragments can travel far beyond the distance that the blast wave can cause injury [47].

Another factor that affects injury risk is the size of the explosive weapon because it influences the distance from the detonation at which the peak overpressure occurs. If the peak overpressure from one weapon occurs a certain distance from the detonation point, the same peak overpressure from a larger weapon will occur at a greater distance from the detonation point. For example, at 20 feet from the detonation point, the peak over pressure from the explosion of 8 pounds of TNT will equal the peak overpressure that occurs 10 feet from the detonation point of 1 pound of TNT [47].

The location of the blast also affects injury risk. Explosions that occur in enclosed spaces create different blast waveforms than those that occur in the open because blast waves reflect off of the surfaces of environmental features such as buildings and terrain. These reflections can increase the intensity and duration of the atmospheric over pressure thereby increasing the risk of primary blast injury. Blasts in totally enclosed spaces can lead to very complex wave forms with many peak overpressures resulting from interacting reflections [47]. In addition, the risk of secondary, tertiary, and quaternary blast injury can increase when explosions occur in enclosed spaces.

While there is no question that both closed and penetrating TBIs can result from secondary and tertiary blast mechanisms, it is not known if primary blast forces can cause TBI because there are few clinically documented cases of it [48]. This lack of clinical data is due in part to difficulty determining whether a blast related TBI was caused by primary, secondary, or tertiary mechanisms. There is evidence from animal studies suggesting that brain tissue is vulnerable to injury from primary blast forces. Studies involving rats, rabbits and pigs that were exposed to primary blast forces have found indications of neural degeneration and neuronal injury

or other effects such as decreases in electroencephalographic activity immediately following exposure to a blast wave [48]. However, the nature of the interaction between a blast wave and central nervous system tissue is not known [32]. Therefore, the suggested mechanisms of primary blast injury to the central nervous systems of humans are theoretical and, to date, no experimental evidence demonstrating such effects exists.

The Army's increased incidence of hospitalizations for TBIs with associated extra-cranial injuries after the commencement of OEF/OIF may also reflect the heavy reliance on explosive weapons by enemy forces. This is likely because blasts produce many forms of energy, each of which is essentially a different injury mechanism. Air filled organs are vulnerable to injury from the blast wave but many more body regions are vulnerable to injury if the body is set in motion, from objects set in motion, such as shrapnel, and from thermal energy. Studies of civilians have shown that the proportions of those who were injured in terrorist bombings and had injuries in multiple body regions were significantly higher than the proportions of patients injured by other mechanisms [1,38]. These studies also found that as many as 62% of those injured in terrorist bombings had injuries in 2 or more body regions and 30% had injuries in 3 or more regions [1,38].

The comparisons of TBI-related hospitalization rates from the active duty Army to estimated rates from the age-comparable segment of the US civilian population provided some additional perspective on the possible impact of OEF/OIF on TBIs in the Army. In 2005–2006, the Army's hospitalization rates for moderate and severe TBIs were each significantly lower than the estimated civilian rates for these injuries (Table 2). Table 2 also shows that the Army's hospitalization rate for severe TBIs in 2005–2006 was significantly lower than the civilian rate in 2000–2001 and that the Army's hospitalization rate for moderate TBIs in 2005–2006 was comparable to the civilian rate from 2000–2001. These findings suggest that severe TBIs probably pose less of a public health problem in the Army despite the substantial increase in hospitalization rates that seem to have resulted from OEF/OIF. They also suggest that moderate TBIs probably pose no more of a public health problem in the Army than in the civilian population and could possibly pose less of a problem as well. There are two possible related explanations for these findings. First, the Army's hospitalization rates for moderate and severe TBIs in peacetime have tended to be lower than those in the age-comparable segment of the civilian population probably because of a healthy worker ef-

fect [22]. The other possible explanation is that the low combat intensity in OEF/OIF has not produced enough moderate and severe TBIs to exceed the magnitude of the healthy worker effect.

Mild was the only TBI severity category in which the Army's hospitalization rate was significantly higher than the civilian rate in 2005–2006 (Table 2). The Army's hospitalization rate for mild TBIs in 2005–2006 was also significantly higher than the civilian rate in 2000–2001 (Table 2). These findings suggest that mild TBIs may pose more of a public health problem in the Army than in the civilian population because of OEF/OIF but it is not possible to determine how much of the excess is due to an actual increase in the occurrence of mild TBIs and how much is simply the result of the military identifying more mild TBIs because of screening programs. No comparable TBI screening process is known to occur in civilian hospitals, therefore, the incidence of mild TBI hospitalizations in the civilian population estimated from the NHDS may be lower than the actual incidence. On the other hand, false positive screening results have probably inflated the number of mild TBI diagnoses made in military hospitals to some degree because of the difficulty of distinguishing mild TBI from other common wartime health problems, such as acute stress reactions and PTSD.

The Army's hospitalization rate for TBIs with associated extra-cranial injuries in 2000–2001 was significantly lower than the civilian rate at that time. However in 2005–2006, the Army's hospitalization rate for these patients was significantly higher than in the civilian population. Interestingly, the Army's hospitalization rate for TBIs with associated extra-cranial injuries in 2005–2006 was similar to the civilian rate in 2000–2001 (Table 2). This suggests that, at the very least, the Army's hospitalization rate for TBIs with associated injuries may have risen enough to become comparable to that in the civilian population assuming the civilian rate remained constant throughout the study period. On the other hand, if the civilian rate actually decreased during that period, it is possible that the Army's hospitalization rate for these TBI patients did exceed the civilian rate. In either case, a possible explanation for the Army's higher incidence of TBIs with associated extra-cranial injuries is that blasts from explosive weapons appear to be a major cause of injury in OEF/OIF, but they are rare in the civilian population. A study of blast-related TBIs in a US civilian trauma center identified only 89 blast injury cases out of 57,392 patients treated over an 11-year period [5]. However, to some extent, the Army's increased incidence of hospitalizations for

TBIs with other associated injuries could also be the result of TBI screening, especially among those with mild TBIs, rather than an increase in the actual occurrence of these cases. Moss and Wade found that having an undiagnosed mild TBI was associated with having other injuries that were usually more severe than the TBI [33].

This paper has several strengths and limitations. A major strength is that it used data about all active duty Army personnel hospitalized with a recorded TBI diagnosis. This is a unique characteristic of military medical databases because there are very few and unlikely reasons why a hospitalization would not be reported in the SIDR. If this did happen it would most likely involve a service member treated at a civilian hospital who then paid the bill out of pocket rather than using the military's health insurance, which covers all service members [3]. Another strength is that the mechanism of injury is reported for every patient in the SIDR and that injury mechanism coding in the military is relatively accurate. One study of cause-of-injury coding at military hospitals found that only 12% of the records reviewed had a major coding error [3].

A major limitation is that the exact number of soldiers hospitalized for a TBI sustained in OEF/OIF could not be determined from the data used; therefore, the impact of OEF/OIF on TBI-related hospitalizations in the Army had to be surmised. Another limitation is that differences between the Army's and civilians' hospitalization rates could have been affected by annual fluctuations in the estimated number civilian TBI hospitalizations due to annual variation in the sample size the NHDS is based on. This may have accounted for the excess incidence of hospitalization for TBIs with associated extra-cranial injuries in the Army in 2005–2006 relative to the civilian population.

The TBI severity estimations in this analysis were undoubtedly influenced by limitations inherent in the ICD-9 CM and AIS coding systems. Until 2004, brief LOC was defined by the ICD-9CM as LOC lasting up to 59 minutes. However, 30 minutes is typically regarded as the upper threshold for defining mild TBI in terms of LOC [2]. Furthermore, LOC duration is usually unknown for sizable proportions of patients with a TBI diagnosis. In cases where there is prolonged LOC or sufficient information about the extent of anatomic injury, such as evidence of a cerebral laceration or contusion, determining severity is relatively unambiguous since these injuries are usually considered moderate or severe. But when anatomic information is insufficient for determining TBI severity, LOC duration is the only

other information available in the ICD-9 system that can be used. Therefore, it is likely that patients with concussion diagnoses who had LOC lasting longer than 30 minutes were misidentified as having a mild TBI.

5. Conclusion

The incidence of TBI-related hospitalization in the active duty US Army doubled from FY2000 to FY2006. The largest annual increases in the Army's TBI hospitalization rates for several important injury characteristics, especially cause of injury, coincided with commencement of OEF/OIF, which strongly suggests that these conflicts had a substantial the relative impact of on the incidence of TBIs in the Army. However, despite these increases, the Army's hospitalization rates for moderate and severe TBIs in 2005–2006 did not exceed those from the age-comparable segment of the US civilian population. But the Army's hospitalization rates for mild TBIs and for TBI patients with associated extra-cranial injuries did exceed civilian rates in 2005–2006 even though both were lower than civilian rates prior to OEF/OIF. These findings suggest that the relative impact of OEF/OIF on the incidence of more serious TBIs in the military is not as great as might have been expected but they have had relatively more of an impact on the incidence of mild TBIs and TBIs with associated extracranial injuries. However, the incidence of mild TBIs and TBIs with associated extra-cranial injuries in the Army after OEF/OIF may also be inflated to some degree because of retrospective TBI screening, which is identifying some mild TBIs that would otherwise have not been identified and could also be misidentifying some stress reactions as mild TBIs.

References

[1] L. Aharonson-Daniel, Y. Klein and K. Peleg, ITG, Suicide bombers form a new injury profile, *Ann Surg* **244** (2006), 1018–1023.

[2] American Congress of Rehabilitation Medicine, Definition of mild traumatic brain injury, *J Head Trauma Rehabil* **8** (1993), 86–88.

[3] P.J. Amoroso, G.S. Smith and S. Bell Nicole, Qualitative assessment of cause-of-injury coding in US military hospitals: NATO Standardization Agreement (STANAG) 2050, *Am J Prev Med* **18**(3S) (2000), 174–187.

[4] Association for the Advancement of Automotive Medicine, *The Abbreviated Injury Scale: 1990 Revision*, Des Plaines, Ill. Association for the Advancement of Automotive Medicine, 1990.

[5] G.V. Bochicchio, K. Lumpkins, J. O'Connor, M. Simard, S. Schaub, A. Conway, K. Bochicchio and T.M. Scalea, Blast injury in a civilian trauma setting is associated with a delay in diagnosis of traumatic brain injury, *Am Surgeon* **74** (2008), 267–270.

[6] L.A. Brenner, B.J. Ivins, K. Schwab, D. Warden, L.A. Nelson, M. Jaffee and H. Terrio, Traumatic brain injury, posttraumatic stress disorder, and postconcussive symptom reporting among troops returning from Iraq, *J Head Trauma Rehab*, in press.

[7] R.A. Bryant, Disentangling mild traumatic brain injury and stress reactions, *NEJM* **358** (2008), 525–527.

[8] M.E. Carey, Learning from traditional combat mortality and morbidity data used in the evaluation of combat medical care, *Mil Med* **152** (1987), 1–6.

[9] T.P. Davis, B.A. Alexander, E.W. Lambert, R.B. Simpson, D.V. Unger, J. Lee, M.L. Snyder and W.A. Liston, Distribution and care of shipboard blast injuries (USS Cole DDG-67), *J Trauma* **55** (2003), 1022–1028.

[10] C. Dennison and R. Pokras, Design and operation of the National Hospital Discharge Survey: 1988 redesign, *Vital Health Stat* **1**(39) (2000).

[11] Downloaded from ftp://ftp.cdc.gov/pub/Health_Statistics/NHCS/Datasets/NHDS/.

[12] S.G. Gerberich, R.W. Gibson, D. Fife, J.S. Mandel, D. Aeppli, C.T. Le, R. Maxwell, S.J. Rolnick, C. Renier, M. Burlew and R. Matross, Effects of brain injury on college academic performance, *Neuroepidemiology* **16** (1997), 1–14.

[13] J.S. Gondusky and M.P. Reiter, Protecting military convoys in Iraq: An examination of battle injuries sustained by a mechanized battalion during Operation Iraqi Freedom II, *Mil Med* **170** (2005), 546–549.

[14] W.D. Gouvier, M. Uddo-Crane and L.M. Brown, Base rates of post-concussional symptoms, *Arch Clin Neuropsychol* **3** (1988), 273–278.

[15] J. Gunstad and J. Suhr, Expectation as etiology versus the good old days: Postconcussion syndrome symptom reporting in athletes, headache sufferers, and depressed individuals, *J Int Neuropsychol Soc* **7** (2001), 323–333.

[16] C.W. Hoge, D. McGurk, J.L. Thomas, A.L. Cox, C.C. Engel and C.A. Castro, Mild traumatic brain injury in US soldiers returning from Iraq, *NEJM* **358** (2008), 453–463.

[17] IOM (Institute of Medicine), Chapter 11: Conclusions and recommendations, in: *Gulf War and Health, Volume 7: Long-term Consequences of Traumatic Brain Injury*, Washington, DC: The National Academies Press, 2009.

[18] IOM (Institute of Medicine), Chapter 3: Epidemiology of adult traumatic brain injury, in: *Gulf War and Health: Volume 7: Long-term Consequences of Traumatic Brain Injury*, Washington DC: The National Academies Press, 2009.

[19] G.L. Iverson and R.T. Lange, Examination of postconcussion-like symptoms in a healthy sample, *Appl Neuropsychol* **10** (2003), 137–144.

[20] G.L. Iverson, J.A. Langlois, M.A. McCrae and J.P. Kelly, Challenges associated with post-deployment screening for mild traumatic brain injury in military personnel, *Clin Neuropsychol* **23** (2009), 1299–1314.

[21] G.L. Iverson, Misdiagnosis of the persistent postconcussion syndrome in patients with depression, *Arch Clin Neuropsychol* **21** (2006), 303–310.

[22] B.J. Ivins, K.A. Schwab, G. Baker and D.L. Warden, Hospital admissions associated with traumatic brain injury in the US Army during peacetime: 1990's trends, *Neuroepidemiology* **27** (2006), 154–163.

[23] E. Jones, N.T. Fear and S. Wessely, Shell shock and mild traumatic brain injury: A historical overview, *Am J Psychiatry* **164** (2007), 1641–1645.

[24] H.A. Kahn and C.T. Sempos, *Statistical Methods in Epidemiology*, New York: Oxford University Press, 1989.

[25] J.L. Kashuk, P. Halperin, G. Caspi, C. Colwell and E.E. Moore, Bomb explosions in acts of terrorism: Evil creativity challenges our trauma systems, *J Am Coll Surg* **209** (2009), 134–140.

[26] J. Keegan, *A History of Warfare*, New York: Vintage Books, 1994.

[27] J.E. Kennedy, M.S. Jaffee, G.A. Leskin, J.W. Stokes, F.O. Leal and P.J. Fitzpatrick, Posttraumatic stress disorder and posttraumatic stress disorder-like symptoms and mild traumatic brain injury, *JRRD* **44** (2007), 895–920.

[28] N.S. King, PTSD and traumatic brain injury: Folklore and fact? *Brain Inj* **22** (2008), 1–5.

[29] R.A. Mayou, J. Black and B. Bryant, Unconsciousness, amnesia, and psychiatric symptoms following road traffic accidents, *Br J Psychiatry* **177** (2000), 540–545.

[30] S. Meares, E.A. Shores, A.J. Taylor, J. Batchelor, R.A. Bryant, I.J. Baguley, J. Chapman, J. Gurka, K. Dawson, L. Capon and J.E. Marosszesky, Mild traumatic brain injury does not predict acute postconcussion syndrome, *J Neurol Neurosurg Psychiatry* **79** (2008), 300–306.

[31] Military Agency for Standardization, STANAG 2050 MED (Edition 5): Standardized Classification of Diseases, Injuries, and Causes of Death. Brussels, Belgium: North Atlantic Treaty Organization, 1989.

[32] D.F. Moore, R.A. Radovitzky, L. Shupenko, A. Klinoff, M.S. Jaffee and J.M. Rosen, Blast physics and central nervous system injury, *Future Neurol* **3** (2008)1–8.

[33] N.E.G. Moss and D.T. Wade, Admission after head injury: How many occur and how many are recorded? *Injury* **27** (1996), 159–161.

[34] C.K. Murray, J.C. Reynolds, J.M. Schroeder, M.B. Harrison, O.M. Evans and D.R. Hospenthal, Spectrum of care provided at an Echelon II medical unit during Operation Iraqi Freedom, *Mil Med* **170** (2005), 516–520.

[35] National Center for Injury Prevention and Control, *Report to Congress on Mild Traumatic Brain Injury in the United States: Steps to Prevent a Serious Public Health Problem*, Atlanta, GA: Centers for Disease Control and Prevention, 2003.

[36] A.K. Ommaya, A.M. Salazar, A.L. Dannenberg, A.K. Ommaya, A.B. Chervinsky and K. Schwab, Outcome after traumatic brain injury in the US military medical system, *J Trauma* **41** (1996), 972–975.

[37] B.D. Owens, J.F. Kragh, J.C. Wenke, J. Macaitis, C.E. Wade and J.B. Holcomb, Combat wounds in Operation Iraqi Freedom and Operation Enduring Freedom, *J Trauma* **64** (2008), 295–299.

[38] K. Peleg, L. Aharonson-Daniel, M. Stein, M. Michaelson, Y. Kluger, D. Simon, Israeli Trauma Group and E.K. Noji, Gunshot and explosion injuries: Characteristics, outcomes, and implications for care in terror-related injuries in Israel, *Ann Surg* **239** (2004), 311–318.

[39] G.E. Powell, Mild traumatic brain injury postconcussion syndrome: The importance of base rates in diagnosis and clinical formulation, *J Neurol Neurosurg Psychiatry* **79** (2008), 237.

[40] T. Ropp, *War in the Modern World, New Revised Edition*, New York: Collier Books, 1962.

[41] R. Ruff, Two decades of advances in understanding of mild traumatic brain injury, *J Head Trauma Rehabil* **20** (2005), 5–18.

[42] W. Rutland-Brown, J.A. Langlois, K.E. Thomas and Y.L. Xi, Incidence of traumatic brain injury in the United States, 2003, *J Head Trauma Rehabil* **21** (2006), 544–548.

[43] A.I. Schneiderman, E.R. Braver and H.K. Kang, Understanding the sequelae of injury mechanisms and mild traumatic brain injury incurred during the conflicts in Iraq and Afghanistan: Persistent postconcussive symptoms and post-traumatic stress disorder, *Am J Epidemiol* **167** (2008), 1446–1452.

[44] K.A. Schwab, B. Ivins, G. Cramer, W. Johnson, M. Sluss-Tiller, K. Kiley, W. Lux and D. Warden, Screening for traumatic brain injury in troopsreturning from deployment in Iraq and Afghanistan: Initial investigation of the usefulness of a short screening tool for traumatic brain injury, *J Head Trauma Rehabil* **22** (2007), 377–389.

[45] A.W. Selassie, M.L. McCarthy, P.L. Ferguson, J. Tian and J.A. Langlois, Risk of post-hospitalization mortality among persons with traumatic brain injury, South Carolina 1999–2001, *J head Trauma Rehabil* **20** (2005), 257–269.

[46] L. Smith-Seemiller, N.R. Fow, R. Kant and M.D. Franzen, Presence of post-concussion syndrome in patients with chronic pain versus mild traumatic brain injury, *Brain Inj* **17** (2003), 199–206.

[47] J.H. Stuhmiller, Y.Y. Phillips and D.R. Richmond, Chapter 7: The physics and mechanisms of primary blast injury, in: *Conventional Warfare: Ballistic, Blast, and Burn Injuries*, R.F. Bellamy and R. Zajtchuk, eds, Washington, DC, Office of the Surgeon General, 1990.

[48] K.H. Tabor, D.L. Warden and R.A. Hurley, Blast-related traumatic brain injury: What is known? *J Neuropsychiatry Clin Neurosci* **18** (2006), 141–145.

[49] H. Terrio, L.A. Brenner, B.J. Ivins, J.M. Cho, K. Helmick, K. Schwab, K. Scally, R. Bretthauer and D. Warden, Traumatic brain injury screening: Preliminary findings in a US Army brigade combat team, *J Head Trauma Rehabil* **24** (2009), 14–23.

[50] The Johns Hopkins University and Tri-Analytics, Inc. *ICDMAP-90*. 1998.

[51] D. Thurman and J. Guerrero, Trends in hospitalization associated with traumatic brain injury, *JAMA* **282** (1999), 954–957.

[52] R. Whitaker, H. Kemp and A. House, Illness perceptions and outcome in mild head injury: a longitudinal study, *J Neurol Neurosurg Psychiatry* **78** (2007), 644–646.

[53] R.L. Wood, Post concussional syndrome: All in the mind's eye! *J Neurol Neurosurg Psychiatry* **78** (2007), 552.

[54] R.L. Wood, Understanding the 'miserable minority': a diasthesis-stress paradigm for post-concussional syndrome, *Brain Inj* **18** (2004), 1135–1153.