Incidence of Primary Blast Injury in US Military Overseas Contingency Operations

A Retrospective Study

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Objectives: The present retrospective study was performed to determine the incidence and outcome of primary blast injury and to identify possible changes over the course of the conflicts between 2003 and 2006.

Summary Background Data: Combat physicians treating patients injured in overseas contingency operations observed an increase in the severity of explosion injuries occurring during this period.

Methods: This retrospective study included service members injured in explosions between March 2003 and October 2006. The Joint Theater Trauma Registry provided demographic information, injury severity score, and International Classification of Diseases 9 codes used to diagnose primary blast injury. Autopsy reports of the last 497 combat-related deaths of 2006 were also reviewed.

Results: Of 9693 admissions, of which 6687 were injured in combat, 4765 (49%) were injured by explosions: 2588 in 2003–2004 and 1935 in 2005–2006. Dates of injury were unavailable for 242 casualties. Injury severity score (9 ± 10 vs. 11 ± 10, $P < 0.0001$) and incidence of primary blast injury (12% vs. 15%, $P < 0.01$) increased. The return-to-duty rate decreased (40% vs. 18%, $P < 0.001$), but mortality remained low (1.4% vs. 1.5%, P = NS). There was no significant difference in incidence of primary blast injury between personnel who were killed in action and those who died of wounds at a medical facility.

Conclusions: Injury severity and incidence of primary blast injury increased during the 4-year period, whereas return-to-duty rates decreased. Despite increasingly devastating injuries, the mortality rate due to explosion injuries remained low and unchanged.

(*Ann Surg* 2010;251: 1140–1144)

In recent years, numerous reports in the medical literature have reviewed a variety of pertinent trauma topics on Overseas Contingency Operations (OCOs) in Iraq and Afghanistan.[1] Surgeons and critical care intensivists have described their combat experiences and have shared valuable lessons in combat casualty care.[2–7] Multiple reports have described the types of injuries encountered in the combat environment by various medical units.[8–11] Whatever the specialty, the message has been clear: As in previous conflicts, explosions are still a major cause of injury and death on the modern battlefield.[12,13] Military physicians are striving to determine the best methods to triage[14] and treat patients[15–18] and to reconstruct[19] the wounded areas resulting from these complex and devastating injuries—and they are succeeding.[20]

The lethality of an explosion is determined by its explosive energy, ability to produce fragments, location (closed vs. open space),[21,22] and proximity to its victims. The Centers for Disease Control and Prevention has described 4 categories of blast injury: primary, secondary, tertiary, and quaternary.[23] Primary blast injuries are caused when the blast wave propagates from the detonation center through the victim, causing damage to predominantly air-filled organs. The most frequently described effects of the blast wave are tympanic membrane rupture, blast lung injury, and intestinal blast injury.[22] The injurious effects of the blast wave are far more pronounced in a closed space[21,22] because instead of dissipating, the wave may be enhanced as it reflects and reverberates off surfaces. Secondary blast injuries are caused by fragments and by far have had the most lethal effects of the explosions seen in OCO.[3,24] Tertiary blast injuries occur when a victim is physically displaced by forceful air movement or is crushed during structural collapse.[25] Quaternary injuries include burns and inhalational injury, and additionally all other injuries not classified as primary, secondary, or tertiary. The US Department of Defense also recognizes a fifth category of blast injury—quinary—which results from the toxic byproducts of the explosion, such as radiation, metals, bacteria, viruses, and inhalants.[26] In civilian reports of terrorist bombing incidents in Israel,[27] Spain,[28] and Ireland,[29] physicians have provided estimates of the incidence of primary blast injuries among victims. Published data from the rates of observed injuries give one an indication of whether explosions occurred in a predominantly open or closed space. OCO data addressing primary blast injury is limited but suggests that the rates of blast lung and intestinal blast injury are low compared with the rates reported by the civilians.[30–32]The difference in the incidence rates may be to the predominance of military explosions being in open spaces in contrast to closed spaces for civilians.[21,22]One study found the rate of tympanic membrane rupture among 120 wounded patients to be 7%.[33] The present retrospective study was performed to determine the incidence of primary blast injury and to identify possible changes over the course of the conflicts.

METHODS

The Joint Theater Trauma Registry (JTTR) is a database of demographic, diagnostic, and treatment data from medical records of combat-wounded patients who are treated in Afghanistan, Iraq, Germany, or continental US military medical facilities. After Institutional Review Board approval for this study, the JTTR was searched for the records of all service members wounded by explosions between March 2003 and mid-October 2006 in OCOs. These dates were selected to assure data sets as complete as possible. Data included demographics such as age, gender, injury severity score (ISS), mechanism of injury, and International Classification of Diseases (ICD) 9 codes on which to diagnose primary blast injury.

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Supported by the US Army Medical Research and Material Command.

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ISSN: 0003-4932/10/25106-1140
DOI: 10.1097/SLA.0b013e3181e01270

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
01 JUN 2010	**N/A**	-

4. TITLE AND SUBTITLE	
Incidence of primary blast injury in US military overseas contingency operations: a retrospective study	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
Ritenour A. E., Blackbourne L. H., Kelly J. F., McLaughlin D. F., Pearse L. A., Holcomb J. B., Wade C. E.,	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **United States Army Institute of Surgical Research, JBSA Fort Sam Houston, TX 78234**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**5**	

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

Long-term mortality and the incidence of return to military duty were also assessed.

Diagnoses in the JTTR are listed according to ICD9 codes, which were searched for the terms "explosive," "explosion," "blast," and "overpressure" to find diagnostic codes that would indicate which patients had a primary blast injury. The following E-codes relating to primary blast and explosion injury were identified:

- 979.0: terrorism involving explosion of marine weapons,
- 979.2: terrorism involving other explosions and fragments,
- 992: injury due to war operations by explosion of marine weapons,
- 993: injury due to war operations by other explosion,
- 388.11: acoustic trauma (explosive) to ear, otitic blast injury,
- 965: assault by firearms and explosives,
- 985: injury by firearms, air guns, and explosives (undetermined whether accidentally or purposefully inflicted),
- 993.4: effects of air pressure caused by explosion, and
- 993: effects of air pressure.

The JTTR was searched for these codes with no results. No specific codes for blast lung injury/pulmonary blast injury or intestinal blast injury were found.

The most common types of primary blast injury described in the literature are tympanic membrane rupture, blast lung injury, and intestinal blast injury. Since no specific codes were located to indicate primary blast injury, criteria were used to allow the investigators to determine which patients were likely to have primary blast injury based on the data available in the JTTR. Tympanic membrane rupture was defined as ICD9 code 872.61 (open wound of ear drum) in an explosion-injured patient. Since pneumothorax and/or pulmonary hemorrhages have been described as resulting from blast lung injury,[27] codes 860.4 (traumatic pneumothorax, closed) and 861.21 (pulmonary contusion, closed) were searched in the JTTR. The records of the explosion-injured patients with closed pneumothoraces and/or closed pulmonary contusions were reviewed. Patients found to have rib fractures, scapula fractures, or open wounds to the chest or abdomen were included in the study but were considered to have injuries caused by secondary or tertiary explosive mechanisms.

Previous reports have described the most common manifestations of intestinal blast injury as mesenteric hematomas or perforation of the colon or small intestine and have excluded blunt and penetrating trauma.[22] Therefore, using appropriate ICD9 codes, we searched the JTTR for closed injuries to the stomach, small intestine, or colon. Consistent with earlier studies, the JTTR records were then reviewed. Patients with evidence of blunt (pelvic fractures, abdominal wall hematomas) or penetrating trauma (open wounds to torso) that could account for their visceral injuries were not considered as having a diagnosis of intestinal blast injury but rather blunt or penetrating trauma. This method is consistent with a previously published study focusing on explosion-injured casualties.[27]

The JTTR was also searched for disposition. Disposition is coded at the end of treatment at medical facilities in Afghanistan, Iraq, Germany, and military hospitals in the United States. Options for disposition entries in the JTTR include return to duty, death, transfer between facilities, discharged from a facility, and awaiting final disposition. We assessed return-to-duty rates after receiving in-patient care (in Afghanistan, Iraq, Germany, or the United States) as a measure of conservation of combat readiness. The JTTR was searched for mortality rates of all patients in the study. The mortality rate of patients found to have primary blast injury was also evaluated by using the publicly available Department of Defense Personnel and Procurement Statistics online (Directorate for Information Operations and Reports).[34]

Our first objective was to determine whether the incidence of primary blast injury, injury severity, and mortality among the US service members as a result of combat explosions had increased in 2005 and 2006 compared with 2003 and 2004. A priori patients injured in combat explosions were divided into 2 groups based by the date they were wounded. Service members injured between March 2003 and the end of December 2004 were grouped together and were defined as injuries and deaths due to combat explosions in 22 months of combat. Data from service members injured between January 2005 and October 2006 were grouped together and were defined as injuries and deaths during the subsequent 22 months of combat operations. Patients whose date of injury was not listed in the JTTR (242 patients, 5%) were not included in this part of the data analysis but were included in other parts of the study. Demographics, mechanisms of injury, incidence of primary blast injury, and ISS were compared between the 2 groups. Return-to-duty rate and mortality outcomes were also compared.

To determine whether JTTR data underestimated the effect of primary blast injury by evaluating only patients who survived transport to a medical treatment facility (MTF), the authors undertook an autopsy review to determine whether the incidence of primary blast injury was higher among patients killed in action than patients who died of their wounds. "Killed in action" refers to personnel who died prior to receiving care at an MTF, where interventions are frequently physician-level. "Died of wounds" is defined as death following admission to an MTF.[35] Three of the study investigators (J.F.K., D.F.M., and A.E.R.) reviewed the autopsy reports of the last 497 combat deaths of 2006. The autopsy reports produced by the Armed Forces Institute of Pathology describe internal and external injuries from a forensic perspective. Additionally, autopsy photographs were reviewed with the written reports. The 3 reviewers reached consensus on all cases. Tympanic membranes were not evaluated during the autopsies, and no autopsy reports explicitly documented blast lung injury or intestinal blast injury as a finding. Therefore, the reviewers used the criteria consistent with those used in the JTTR chart review to determine which patients likely had primary blast injuries. Patients with autopsy findings of "pulmonary hemorrhages" after an explosion and in the absence of blunt or penetrating thoracic trauma were considered to have blast lung injury. Similarly, patients with mesenteric hematomas or intestinal perforation without blunt or penetrating abdominal trauma were considered to have intestinal blast injury. Explosion victims categorized as having died of wounds were compared with those killed in action to determine whether there was a significant difference in incidence of blast lung injury or intestinal blast injury between the 2 groups.

Statistical Analysis

Data for all patients in the study were recorded in Excel (Microsoft, Redmond, WA) and analyzed with SAS (version 9.1, SAS Institute, Cary, NC). Univariate analyses were performed using 2-sample Student t tests for continuous variables and χ^2 tests for categorical variables. Statistical significance was attributed at $P < 0.05$. Continuous data are presented as mean ± SD Standard Deviation (SD) unless otherwise specified.

RESULTS

During the study period from March 2003 through October 2006, a total of 9693 deployed US military personnel were admitted to an MTF, received medical care for injuries, and were entered into the JTTR. A total of 6687 (69%) were injured in combat. Of these, 4765 (71%) were injured in explosions and constituted our study population. The mean age was 26 ± 7 years (range, 18–59), and 97% of patients were male. The mean ISS was 9 ± 10 (range, 1–75).

Overall, 64% (n = 3050) of US service members injured in explosions were wounded by improvised explosive devices (IEDs). Fewer service members were injured by other explosive mechanisms: 15% (n = 730) by rocket-propelled grenades and grenades, 12% (n = 547) by mortars, 3% (n = 162) by land mines, and 6% (n = 276) by unspecified "other" explosives. For our study population, 31% (1466) were able to return to military duty after medical treatment was complete. The mortality rate in admitted casualties was 1.4% (n = 67). Demographic and outcome data are summarized in Tables 1 and 2.

Primary Blast Injury

A total of 582 patients (12% of all patients injured by explosions) were found to have primary blast injuries. The most common primary blast injury was tympanic membrane rupture, found in 425 (9%) patients injured in explosions. Blast lung injury and intestinal blast injury were rare, occurring in 172 (3.6%) and 5 patients (0.1%), respectively (Table 3). Of total, 63% of the patients with blast lung injury had an ISS >15, and 60% of those with intestinal blast injury. When patients with tympanic membrane rupture were compared with patients without tympanic membrane rupture, there was no significant difference between return to duty (33% vs. 31%), and mortality (0.5% vs. 1.5%). Only 12% (20/172) of patients with blast lung injury had tympanic membrane rupture. Conversely, 4.7% (20/425) of patients with tympanic membrane rupture had a blast lung injury.

2003 to 2004 Versus 2005 to 2006

To determine changes in explosion and injury patterns over the course of OCOs, patients were divided into early (March 2003–December 2004) and recent (January 2005–October 2006) groups. Each group comprised combat explosion injuries over a period of 22 months. Explosions accounted for 75% of battle injuries in the early group and 78% in the recent group. The number of patients injured in explosions in the early group was 2588 (54% of total) versus 1935 (41%) in the recent group. The remaining 242 patients (5% of the total study population) did not have dates of injury or final disposition listed in the JTTR and were not included in this analysis. The populations in the early and the recent injury groups were similar in age (26 ± 7 vs. 26 ± 6 years old, no significant difference) and gender (97.2% vs. 97.7% male, no significant difference). However, the 2 groups of patients did have different injury patterns. Table 4 summarizes the differences between the 2 groups. The patients in the earlier group had a lower ISS (9 ± 10 vs.11 ± 10, $P < 0.0001$) and a lower rate of primary blast injury overall (12% vs. 15%, $P < 0.01$). Although there was no difference in tympanic membrane rupture rates or intestinal blast injury between the 2 time periods, early explosions resulted in a lower rate of blast lung injury (3.1% vs. 4.6%, $P < 0.01$). Patients who were injured earlier had a higher rate of return to duty (40% vs. 18%, $P < 0.001$) compared with those injured later in OCO. Although more recently injured patients had a higher ISS and a higher incidence of primary blast injury than the early group, the mortality rates remained unchanged (1.4% vs. 1.5%, no significant difference).

TABLE 1. Summary of Demographics

Parameter	n	%	Average ± SD	Range
Age	4765		26.06 ± 6.58	18–59
Gender (male)	4642	97.4		
ISS	4667		9.27 ± 9.94	1–75

ISS indicates injury severity score; SD, standard deviation.

TABLE 2. Summary of Type of Explosion

Mechanism	n	%
Total	4765	100.0
Improvised explosive device	3050	64.0
Grenade/rocket-propelled grenade (RPG)	730	15.3
Mortar	547	11.5
Land mine	162	3.4
Unspecified explosive	276	5.8

Killed in Action Versus Died of Wounds

The preceding data analysis reflects only patients who survived long enough to receive care at an MTF. To determine whether our review had underestimated the incidence of primary blast injury by excluding patients who died shortly after injury (killed in action), we performed an autopsy review to see whether the rate of primary blast injury was higher among those killed in action than those who died of wounds. Of 497 autopsies reviewed, 381 (77%) deaths were caused by explosion-related injuries between June 7, 2006 and December 31, 2006 and comprised our study population for this part of the investigation. The mean age was 25 ± 6 (range, 18–57), and 98% were male. The mean ISS was 53 ± 22. Of the explosion-related fatalities, 303 (80%) were classified as "killed in action" and 78 (20%) "died of wounds." Otoscopic examination was not included as part of the autopsies; so the rate of tympanic membrane rupture is not known. The incidence of blast lung injury was not significantly different among service members who were killed in action compared with those who died of wounds (2.3% vs. 1.3%, no significant difference), and the incidence of intestinal blast injury was 2.0% versus 2.5% (no significant difference).

DISCUSSION

This retrospective review of 4765 US military personnel covered a total of 44 consecutive months of injuries and deaths caused by combat explosions in OCOs. The study population reflects the military population currently in combat theaters, mostly young men. We determined that a wide range of injury severity results from explosions and that almost two-thirds of explosion injuries have been caused by IEDs, with grenades/rocket-propelled grenades and mortars being the next most common causes. Approximately one-third of service members injured in explosions and admitted to a combat support hospital were ultimately able to return to duty, and their mortality was low at 1.4%.

Of the total study population, 12% were found to have received primary blast injuries. The most common form was tympanic membrane rupture, which was found in 9% of explosion-injured patients and 73% of those with primary blast injuries. The more severe pulmonary and intestinal blast injuries were rare and were found in only 3.6% and 0.1% of explosion-injured patients and 30% and 0.9%, respectively, of patients with primary blast injuries. There was no significant difference in return-to-duty rate or mortality between explosion-injured patients with or without tympanic membrane rupture. However, our data demonstrate that approximately 1 in every 10 patients who receives medical care for explosion-related injuries has tympanic membrane rupture. A single institution study of tympanic membrane rupture from combat explosions in burned patients[36] demonstrated a higher incidence of tympanic membrane rupture (16%) than our study. In their patient population, these authors found that more than one-third of perforations were high-grade and that surgical intervention was required in over 50% of cases. Our data support the conclusions of this earlier study that all patients exposed to an explosion should undergo

TABLE 3. Primary Blast Injury Incidence, Injury Severity Score (ISS), and Outcomes

					Return to Duty		Mortality	
Incidence	n	% of Total	ISS (Average) ± SD	ISS Range	n	%	n	%
Explosion-injured patients	4765	100.0	9.3 ± 9.9	1–75	1466	31.1	67	1.4
Primary blast injury*	582	12.2	12.6 ± 10.4	4–54	168	28.9	20	3.4
Tympanic membrane rupture	425	8.9	9.9 ± 8.9	4–50	138	32.5	2	0.5
Blast lung	172	3.6	20.3 ± 10.4	5–54	35	20.3	18	10.5
Intestinal blast	5	0.1	25.4 ± 12.1	14–54	0	0	2	40

*Twenty patients had both TM rupture and blast lung.
ISS indicates injury severity score; SD, standard deviation.

TABLE 4. Comparison of Explosion-Related Injuries Between March 2003 and December 2004 Versus January 2005 to October 2006

2003–2004 vs. 2005–2006

Parameter	2003–2004	2005–2006	*P* <
No. patients* (n)	2588	1935	
ISS (average)	8.5 ± 9.8	10.6 ± 10.2	0.0001
Primary blast injury (%)	11.5	14.5	0.01
Tympanic membrane rupture (%)	8.7	10.3	NS
Blast lung (%)	3.1	4.6	0.01
Intestinal blast (%)	0.1	0.1	NSD
Return to duty (%)	39.9	18.0	0.001
Mortality (%)	1.4	1.5	NSD

*Dates of injury or final outcomes were not available for 242 patients.
NSD indicates no significant difference.

otoscopic examination prior to discharge to assess for tympanic membrane rupture and thus allow for appropriate treatment and continuing care. Although most tympanic membrane ruptures will heal spontaneously, some will require surgical intervention.[37] Permanent hearing impairment can affect combat effectiveness.[38] Tympanic membrane rupture is not indicative of primary lung and intestinal injury. If there is a primary blast-induced brain injury, the group with tympanic membrane injury is likely to have the highest incidence.[39]

Our data demonstrated that IEDs caused an increasing proportion of explosion-related injuries and that ISSs were significantly higher in the more recent 2 years of combat. The incidence of primary blast injury overall also increased from 12% to 15% during this period. The percentage of wounded service members able to return to military duty after treatment of combat-explosion injuries in 2005–2006 was half of what it was in 2003–2004. In spite of the increasing sophistication of explosives[40] inflicting more severe injury and greater disability, the mortality rate from explosion injuries has remained low and unchanged (1.5%). This finding is a testament to the training, ability, and effectiveness of the military medical team, which ranges from buddy aid and medic intervention shortly after injury to the expertise offered by surgical and intensive care personnel in combat theaters, the evacuation teams, and the world-class level IV and V care in the fixed facilities in Germany and in the United States.

An important limitation of our study is that the JTTR, although continuously updated, is subject to a delay between time of patient care and entry of diagnoses into the database. Publicly reported casualty data suggest that the number and the severity of explosions have been increasing throughout the conflict.[40] However, our recent group includes fewer patients than the early group. The most likely explanation for this finding is the data entry delay. It may have introduced a selection bias into the most recent group. Patients whose treatment concluded rapidly because of recovery or death may be more likely to have a complete record and be entered into the JTTR sooner. Thus, our data may not represent patients with protracted hospital courses who commonly recover or who may ultimately succumb to their wounds.

Explosions in closed spaces like buses have been shown to result in a higher incidence of primary blast injury among civilian terrorist bombing victims than explosions in open spaces (77.5% vs. 34.2%).[22] In our patient population, it was difficult to determine whether the patients with primary blast injuries were more frequently injured in closed or open space explosions because of incomplete information in the medical records. However, irrespective of where these almost 5000 explosion casualties were physically located when injured, the low incidence of primary blast injury (12%), using a similar definition of injury, suggests that our patients were largely involved in open-space explosions. This fact is important because the physics of open-space explosions is well known, whereby the primary blast overpressure waves degrade in a tertiary fashion and are dissipated within a distance of 10 feet from the explosion epicenter.[41] Casualties close enough to the explosion epicenter are usually dead from a combination of primary secondary and tertiary blast injuries. Consequently, survivors of open-space explosions are predominantly injured by the fragments that are thrown thousands of feet.[41]

The JTTR has data on patients who receive medical treatment, but these data do not account for the injuries of service members killed in action. Additionally, the JTTR does not include data on injured patients who do not receive care at an MTF. A higher rate of tympanic membrane rupture and blast lung injury among nonsurvivors compared with survivors has been reported in the civilian trauma literature, consistent with the higher prevalence of closed-space explosions in the civilian population.[22] We determined that primary blast injury was not higher among service members killed in action compared with those who died of wounds. This finding is again consistent with open-space explosions and rapid dissipation of the primary blast overpressure wave. In addition, we wanted to determine whether patients could have potentially survived the explosion had pulmonary or blast injury not been a factor. A panel of investigators reviewed the autopsies and photographs of 497 recent deaths from combat injuries. The reviewers concluded that the patients who had been close enough to the explosion to sustain blast lung or intestinal blast injury had a multitude of other catastrophic injuries from secondary, tertiary, and quaternary mechanisms of blast injury. In open-space explosions, casualties close enough to the explosion epicenter to have a primary blast injury are shredded by fragments as well. Only the few fortunate enough to be partially shielded by an impervious object suffer a primary blast injury and live.

Every day, military physicians in OCOs treat both combat casualties and local civilians injured by explosions. As military physicians have become more familiar with the injury patterns of explosions, treatment better suited to this particular type of patient has evolved. Continuously collected data from MTFs is a unique source of information for this injury pattern that is unavailable elsewhere. Thus, the JTTR provides a nontraditional public health resource for the study of explosive injury to direct informed selection of superior materials and methods in the treatment of this devastating injury.

In using any registry, there are inherent limitations. In the present study, the use of the ICD9 codes selected may be insufficient to correctly classify blast lung injury. The observation of a significant number of patients (37%–40%) classified as having lung or intestinal blast injury with an ISS <15 and a high return to duty rate suggest some of these patients may have been misclassified based on ICD9 codes. If this was the case the incidence rates would be reduced.

In conclusion, the ISS and the incidence of primary blast injury increased from 2003 to 2006, while return-to-duty rates in explosion-injured patients decreased by half. Because most of explosions are open-space, isolated primary blast lung and intestinal blast injury are essentially not the causes of combat deaths. In spite of increasingly devastating injuries, the mortality due to explosion injury has remained low and unchanged.

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