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Review Article

The effect of vehicle protection on spine injuries in military conflict

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Abstract

BACKGROUND CONTEXT: To evaluate the effect of critical time periods in vehicle protection on spine injuries in the Global War on Terror.

PURPOSE: To characterize the effect of method of movement on and around the battlefield during Operation Enduring Freedom and Operation Iraqi Freedom from 2001 to 2009 in terms of its impact on the incidence and severity of spinal fractures sustained in combat.

STUDY DESIGN/SETTING: Retrospective study.

PATIENT SAMPLE: Mounted and dismounted American servicemembers who were injured during combat.

METHODS: Extracted medical records of servicemembers identified in the Joint Theater Trauma Registry from October 2001 to December 2009. Methods of movement were defined as mounted or dismounted. Two time periods were compared. Cohorts were created for 2×2 analysis based on method of movement and the time period in which the injury occurred. Time period 1 and 2 were separated by April 1, 2007, which correlates with the initial fielding of the modern class of uparmored fighting vehicles with thickened underbelly armor and a V-shaped hull. Our four comparison groups were Dismounted in Time Period 1 (D1), Dismounted in Time Period 2 (D2), Mounted in Time Period 1 (M1), and Mounted in Time Period 2 (M2).

RESULTS: In total, 1,819 spine fractures occurred over the entire study period. Four hundred seventy-two fractures (26%) were sustained in 145 servicemembers who were mounted at the time of injury, and 1,347 (74%) were sustained by 404 servicemembers who were dismounted ($p<.0005$). The incidence of fractures in the dismounted cohort (D1+D2) was significantly higher than in the mounted cohort (M1+M2) in both time periods (D1 vs. M1, 13.75 vs. 3.95/10,000 warrior-years [$p<.001$] and D2 vs. M2, 11.15 vs. 4.89/10,000 warrior-years [$p<.0001$]). In both the mounted and dismounted groups, the thoracolumbar (TL) junction was the most common site of injury (36.1%). Fractures to the TL junction (T10–L3) increased significantly from Time Period 1 to 2 (34% vs. 40% of all fractures, respectively, $p=.03$). Thoracolumbar fractures were significantly more severe in that there were more Arbeitsgemeinschaft fur Osteosynthesefragen/Magerl Type A injuries versus all TL fractures, 1.75 versus 2.68/10,000 or 27% of all spine fractures in Time Period 1

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The disclosure key can be found on the Table of Contents and at www.TheSpineJournalOnline.com.

This study was conducted under a protocol reviewed and approved by the Brooke Army Medical Center Institutional Review Board and in accordance with the approved protocol.

The opinions or assertions contained herein are the private views of the author and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

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versus 40% in Time Period 2 (p=.007). Furthermore, there were significantly fewer minor fractures (spinous process and transverse process fractures) (p<.0001). In Time Period 2, significantly more TL spine fractures were classified as major fractures, according to the Denis classification system, in both the mounted and dismounted groups; M1 group, 61 of 226 (27%) versus the M2 group, 86 of 246 (34%) (p<.0005) and 173 of 786 (22%) in the D1 group versus 193 of 561 (34%) in the D2 group. The spinal cord injury (SCI) incidence did not change in the mounted groups in Time Period 1 (7 of 71, 9.9%) versus Time Period 2 (7 of 74, 9.5%) (p=.935). In the dismounted groups, SCI actually decreased from D1 (55 of 228, 24%) to D2 (28 of 176, 16%) (p=.0428).

CONCLUSIONS: The incidence of spine fractures and SCI is significantly higher in dismounted operations. The data suggest that current uparmored vehicles convey greater protection against spinal fracture compared with dismounted operations in which servicemembers are engaged on foot, outside their vehicles. The TL junction is at greatest risk for spine fractures sustained in mounted and dismounted combat operations. Recently, the incidence of TL fractures, especially severe fractures, has significantly increased in mounted operations. Although there has been an increased incidence of TL spine fractures, in context of the number of servicemembers deployed in support of Operation Enduring Freedom/Operation Iraqi Freedom, these severe fractures still represent a relatively rare event.

Keywords: Spine fracture; Spinal cord injury; Combat trauma; Mode of transportation

Introduction

Current combat tactics, communication, and protection continue to evolve since the beginning of the conflicts in Southwest Asia in 2001 [1]. The improvised explosive device (IED) has emerged as the primary cause of traumatic morbidity and mortality for our servicemembers [2]. With new threats, the United States (US) military has responded with an ongoing evolution of protective measure. Improvements in individual protective gear have increased survival in US forces, although the extremities remain exposed leading to severe extremity injuries in survivors [3–10]. These high-energy injuries consume a disproportionate amount of medical resources and are responsible for most long-term disabilities [7,8,11]. In addition to severe extremity injuries, spinal fractures represent another source of significant long-term disability, in fact behind upper extremity amputation, spinal injury leads to the second greatest level of disability for combat-injured servicemembers [11]. Military surgeons at all echelons of care have anecdotally noted a ‘‘significant increase’’ in spinal injuries over the course of this conflict and a temporal relation with the introduction of the latest generation in uparmored vehicles [12]. The purpose of this study is to evaluate the effect of critical time periods in vehicle protection on spine injuries in the Global War On Terrorism before and after the introduction of the latest generation in uparmored vehicles.

Methods

A retrospective analysis was performed after institutional review board approval using the Joint Theater Trauma Registry to identify spinal injuries with *International Statistical Classification of Diseases, Ninth Edition* codes (Table 1) among American servicemembers serving in Operation Iraqi Freedom or Operation Enduring Freedom. Demographic information, final disposition, and spinal injury data were extracted from medical records from October 2001 to December 2009.

Methods of movement were defined as mounted (movement in a military vehicle) or dismounted (movement on foot). Cohorts were created for 2×2 analysis based on method of movement at time of injury and the time period in which the injury occurred. Two time periods were compared. Time Period 1 (before April 1, 2007) was selected to correlate with the initial fielding of the latest generation in uparmored vehicles, which is a series of vehicles that all have thickened underbelly armor, a raised chassis, and V-shaped hull capable of deflecting munitions from below [13–15]. Time Period 2 (on or after April 1, 2007) was anytime after the vehicle fielding. Our four comparison groups were Dismounted in Time Period 1 (D1), Dismounted in Time Period 2 (D2), Mounted in Time Period 1 (M1), and Mounted in Time Period 2 (M2). Incidence was calculated for fracture location, level, time, and type using troop levels based on the Congressional Research Report [16]. Injury mechanisms (blunt and penetrating) were analyzed for mounted and dismounted soldiers. Fractures were grouped into major and minor per the classification system of Denis and Arbeitsgemeinschaft fur Osteosynthesefragen (AO)/Magerl Type A and other [17–19]. The Fisher exact test was used to compare incidence and proportion of spine injury between mounted and dismounted soldiers as well as spinal trauma occurrence before and after April 2007. All calculations were performed using SPSS version 16.0 (SPSS, Inc., Chicago, IL, USA). Significance was set at p≤.05.

Results

Because of inadequate documentation for the purposes of this research, records from October 2001 to March 26,

Table 1
JTTR query by ICD-9

ICD-9 codes used for patient search	ICD-9 interpretation
192, 225	Cauda equina syndrome
336	Unspecified disease of spine
721–724	Other spinal disorders and intervertebral disc disorders
805	Spine fracture
806	Spine fracture with cord injury
839	Spine dislocation
876	Open wound of back
952	SCI

JTTR, Joint Theater Trauma Registry; ICD-9, *International Statistical Classification of Diseases, Ninth Edition*; SCI, spinal cord injury.

2003 were not used in this analysis. From March 2003 to December 2009, 598 servicemembers with spinal injuries were identified.

Forty-nine patients were further excluded from this analysis because of helicopter crashes (27), injury mechanism (12) (back flip, construction work or documented accident), unknown mode of injury (7), and unknown mode of transport (3). Five hundred forty-nine patients with 1,819 fractures had complete data for analysis. Average age of the injured was 26.5 years with a mean injury severity score of 23.5. All but nine injured servicemembers were male. Of those who survived to reach a combat support hospital in Iraq or Afghanistan, 14 of 598 (2.8%) eventually expired at the hospital. Most injuries occurred during combat operations, but 15% of patients in Time Period 1 and 17% in Time Period 2 sustained fractures in noncombat activities. There was no difference in mortality rate between time period or mechanism of injury (MOI).

Of the total fractures, 279 were cervical, 543 thoracic, 787 lumbar, and 210 sacral. The thoracolumbar (TL) junction (T10–L3) was the most common site of injury (36.1%), and the incidence and severity of fractures occurring at this level increased from Time Period 1 to 2. Of the total fractures, 472 (26%) were sustained in 145 servicemembers who were mounted at the time of injury, and 1,347 (74%) were sustained by 404 servicemembers who were dismounted ($p<.0005$). Explosives produced most injuries, accounting for 52.6% of injuries in Time Period 1 and 60.4% in Time Period 2 ($p=.22$). The dismounted servicemembers were injured by explosion in 270 of 404 (67%) occurrences with 201 identified as an IED. Of the mounted servicemembers, 63 of 145 (43%) were injured by explosion with 61 identified as an IED. Of the dismounted servicemembers, 88 of 404 (22%) were injured by gunshot, with only 1 of 145 (0.7%) of the mounted. Twelve dismounted servicemembers and three mounted servicemembers were injured by another type of explosion (land mine, rocket-propelled grenade, mortar). Falls from height injured 41 of 404 (10%) dismounted and 1 of 145 (0.7%) mounted servicemembers. The incidence of spinal cord injury (SCI) was 21% in Time Period 1 and 12% in Time Period 2.

For Group D1, SCIs occurred in 55 of 228 (24%) and 28 of 176 (16%) for Group D2 ($p=.0428$). The SCI incidence did not change in the mounted groups in Time Period 1 (7 of 71, 9.9%) versus Time Period 2 (7 of 74, 9.5%) ($p=.935$) (Table 2).

During this time period, a total exposure risk of 571,775 servicemember-years existed for the Time Period 1 (March 1, 2003–March 30, 2007) and 503,200 servicemember-years for Time Period 2 (April 1, 2007–December 31, 2009). In these calculations, one servicemember-year is equivalent to a single calendar year of exposure to the combat environment. The overall incidence of spine fractures did not change from Time Period 1 to Time Period 2—17.7 fractures/10,000 servicemember-years versus 16.0 fractures/10,000 servicemember-years, respectively ($p=.98$). When comparing mounted (M1+M2) to dismounted (D1+D2), the overall incidence of spine fractures was not significantly different for each cohort over time ($p=.28$–$.88$) Although, in both time periods, the incidence of fractures in the dismounted cohort (D1+D2) was significantly higher than in the mounted cohort; M1 versus D1: 3.95 versus 13.75/10,000 servicemember-years ($p<.001$) and M2 versus D2: 4.89 versus 11.15/10,000 servicemember-years ($p<.0001$) (Table 3).

There was no significant difference between the incidence of major fractures in the M2 group; M2 86 of 246 (34%) versus D2 193 of 561 (34%) ($p=.879$). There was a significant increase in the proportion of spine fractures that were classified as major in the M1 group, 61 of 226 (27%), and M2, 86 of 246 (34%) ($p<.0005$). The dismounted group also showed a significant increase in major fractures over time with 173 of 786 (22%) in the D1 group and 193 of 561 (34%) in the D2 group. Minor fractures did not occur commonly in the M1 group; M1 165 of 226 (73%) versus D1 611 of 786 (78%) group ($p=.843$). Minor fractures did not occur commonly in the M2 group; M2 159 of 246 (67%) versus D2 362 of 561 (65%) group ($p=.644$). A 29% decrease in minor fractures occurred over time in the mounted groups with 165 of 226 (73%) in M1 and 159 of 246 (44%) in M2 ($p=.050$). A significant decrease in minor fractures occurred over time in the dismounted groups with 611 of 786 (78%) in D1 and 362 of 561 (64%) in D2 ($p=.003$) (Table 4). Although the overall incidence of fractures did not change between time periods studied, there was a change in the location of these injuries. Fractures to the TL region (T10–L3) increased significantly

Table 2
Incidence of SCI

Injury	M1	D1	M2	D2	p
SCI	7/71 (9.9%)		7/74 (9.5%)		.935
SCI		55/228 (24%)		28/176 (16%)	.0428

SCI, spinal cord injury; M1, Mounted in Time Period 1; D1, Dismounted in Time Period 1; M2, Mounted in Time Period 2; D2, Dismounted in Time Period 2.

Table 3
Fracture incidence (expressed per 10,000 years)

Type	M1	D1	M2	D2	T1	T2	p
All fractures	3.95	13.75					<.0001
All fractures			4.89	11.15			<.0001
All fractures					17.7	16.0	.098

M1, Mounted in Time Period 1; D1, Dismounted in Time Period 1; M2, Mounted in Time Period 2; D2, Dismounted in Time Period 2.

from Time Period 1 to Time Period 2 (34% vs. 40% of all fractures, respectively; p=.03). The incidence of major TL fractures using the definition of Denis [17,18] increased 60% in the cohort in Time Period 2 to 2.84/10,000 servicemember-years from 1.78/10,000 servicemember-years; p=.0002. The incidence of minor TL fractures did not change (4.76 vs. 4.27/10,000 servicemember-years; p=.89) over time. These TL fractures were significantly more severe in that there were more AO/Magerl Type A injuries versus all TL fractures, 1.75 versus 2.68/10,000 or 27% of T1 versus 40% of T2 (p=.007) and significantly fewer minor fractures (spinous process and transverse process fractures) (p<.0001) (Table 5) [19,20].

Although the incidence of severe TL fractures was higher, the overall incidence of TL fractures (Denis major and minor combined) was not different between the two time cohorts, 6.5 versus 7.1/10,000 servicemember-years (p=.14). When sorting each time cohort by method of movement, the incidence of overall TL fractures in the M2 group was significantly higher than M1 (1.73 vs. 1.28/10,000 servicemember-years; p=.03). In fact, fractures including all levels of the thoracic and lumbar spines were significantly more for M2 than M1 (p=.01). Over time, the incidence of TL fractures in the dismounted cohort decreased (4.81 for D1 vs. 4.41/10,000 soldier-years for D2; p=.84) (Table 5). Since the fielding of the latest generation of up-armored vehicle, there has been a significant concentration of spinal fractures to the TL junction in the mounted cohort, and these fractures are more severe than they were before April 1, 2007.

Discussion

Despite nearly 10 years of combat, there are only a few case series in the medical literature documenting the incidence and characteristics of spinal injuries sustained in the Global War On Terrorism. Attempts have been made to systematically describe injury patterns, causes, and nature of injuries sustained by US military personal in combat. Parsons et al. [21] described 16 spine injuries from Operation Just Cause in 1993. Spine injuries represented 30% of fatalities and the most significant source of long-term morbidity among those soldiers wounded. Schoenfeld et al. [22] studied a US Army Brigade Combat Team in Iraq for 15 months and found that 65% of spine injuries were because of blunt trauma, 21% were closed fractures, and 19% medically evacuated. Blair et al. then analyzed all spinal column and SCIs sustained in Operation Iraqi Freedom/Operation Enduring Freedom and reported that 598 soldiers had sustained 2,101 injuries, 92% of which were fractures. An explosive mechanism accounted for 56% of all injuries, and 71% of all injuries were because of a blunt mechanism (unpublished data, Blair JA, Patzkowski JC, Schoenfeld AJ, Cross Rivera JD, Grenier ES, Lehman RA, Hsu JR, STReC. 2011). Previously, Ragel et al. [23] suggested an increased propensity toward severe TL fractures in the patients they treated at a single combat support hospital in Afghanistan, during a time encompassed by our Time Period 2. They reported a disproportionate incidence of distractive forces complicating compression fractures in the TL spine and postulated that the IED versus vehicle attacks produces a specific injury mechanism, which includes not only vertical/axial load but also a propensity toward hyperflexion. They astutely observed that although the IED versus vehicle attack mechanism is not identically reproduced in civilian/noncombat injuries, it probably combines physical elements of jet pilot ejection and helicopter crashes (almost pure vertical/axial-directed force) with those seen in ordinary motor vehicle collisions (horizontal deceleration producing hyperflexion, especially in the setting of a waistline fixed by a lap belt).

Helgeson et al. [24] noted an increase in healthy combat casualties subjected to high-energy trauma sustaining lumbosacral dissociations. The fine details of the MOI and vehicle type cannot be reported because this information is classified. Also, we can speculate that a potential survivor bias exists in this study because severe spine injuries have been demonstrated in fatalities from earlier in the conflict [25].

Our investigation represents the first study to analyze spine injuries with respect to method of movement on

Table 4
Statistical analysis for fractures

Fracture type	M1	D1	M2	D2	p
Denis/major	61/226 (27%)	173/786 (22%)			<.0005
Denis/major			86/246 (34%)	193/561 (34%)	.879
Denis/major	61/226 (27%)		86/246 (34%)		<.0005
Denis/minor	165/226 (73%)		159/246 (44%)		.05
Denis/minor		611/786 (78%)		362/561 (64%)	.003
All TL	1.28/10,000		1.73/10,000		.03
All TL		481/10,000		4.41/10,000	.84

M1, Mounted in Time Period 1; D1, Dismounted in Time Period 1; M2, Mounted in Time Period 2; D2, Dismounted in Time Period 2; TL, thoracolumbar.

Table 5
Statistical analysis for fractures (expressed per 10,000 years)

Fracture type	Time 1	Time 2	p
TL (Denis/major)	1.78	2.84	.0002
TL (Denis/minor)	4.76	4.27	.89
TL (AO/Magerl A)	1.75	2.68	.0007
TL (Denis major/minor)	6.5	7.1	.14
T10–L3 (mounted)	1.28	1.73	.03
T10–L3 (dismounted)	4.81	4.41	.84

TL, thoracolumbar; AO, Arbeitsgemeinschaft fur Osteosynthesefragen.

and around the battlefield. The dismounted servicemembers had increased incidence of spine fractures versus the mounted servicemembers, while total fracture rates did not change significantly over time (T1+T2). Injury severity as seen in both Denis/major and AO/Magerl type injuries became more prevalent versus the total fracture cohort. This occurred while rates of total and minor fractures decreased among the mounted and dismounted. Total major/minor fractures and minor TL fractures did not change between time cohorts. Fracture increases in the TL levels increased among the mounted with significantly higher incidence of major fractures, whereas differences among the dismounted slightly decreased. Dismounted servicemembers were noted to have higher rates of SCI in both time periods, but the rate of SCI dropped in the dismounted cohort and remained constant in the mounted cohort between the two time periods studied.

A combination of mechanisms has led to a significant increase overall and in severity of TL fractures in the mounted servicemember regardless of the classification used. Intrinsic to this transition level, acceleration/deceleration forces may occur more commonly as each level carries more respective weight. The reason for this significant observation can be found in its unique biomechanical location, resulting in a higher rate of AO/Magerl Type A fractures [26]. The latest generation of uparmored vehicle does not seem to be protective from major TL fractures with a concentration of the fractures at the TL junction with increasing severity seen in cohort T1 versus T2.

At least 61% of the spine fractures occurred from explosion. Unlike civilian trauma where falls from height are the most common or second most common MOI for blunt spinal trauma, it is relatively uncommon in combat at 10% in our series [27–29]. These increases may be multifactorial in nature such as changes in operational tempo, vehicle design, explosion type, and improved enemy tactics playing significant roles. Undoubtedly, some of the explanation for increased rates of spinal injuries is secondary to increased survivability as a result of improved force protection.

Overall SCI was approximately 18%, which is within the range reported for civilian trauma [27–29]. However, when fractures that are likely to produce SCI are reviewed, specifically Magerl A fractures, the rate of SCI is significantly higher than that reported in civilian trauma [17,27–31]. Spinal cord injury was unchanged for M1 and M2. Spinal cord injury actually decreased in the dismounted group. Spinal cord injury in these groups is likely caused by secondary effects such as fragments or tertiary effects such as acute angulation and deceleration from blasts [30]. At this time, we cannot say whether the latest generation uparmored vehicle is more protective against SCI. With respect to the capabilities of the latest generation of uparmored vehicles to protect against spinal fractures, our data suggest that over the same time period in which these vehicles were introduced, the incidence of TL fractures, especially major fractures, has increased. This does not define a causal relationship but a temporal one. In the same time, the focus of military operations shifted from Iraq to Afghanistan, where enemy tactics and weaponry, including IEDs, may have been significantly different. Likewise, it takes years to "rollout" a new series of combat vehicles, and the description of vehicle involved in mounted attacks was not reliably documented. Lastly, this study outlines a second-order effect that has resulted from the advent of multiple layers of force protection, including the latest generation of uparmored vehicles.

In addition, although statistically there has been an increased incidence of specific spine fractures, it should be noted that this is in units of 10,000 servicemember-years. This is still a relatively rare event, but the impact is so severe that it demands our attention. This is consistent with the civilian literature [31].

It should be emphasized that force protection is a process and not an end point. As of the writing of this article, the US military has fielded at least two successive improved seat designs in these vehicles that absorb energy and mitigate injury. The effect of these modifications on spinal injury remains to be assessed.

As with all studies, this study has limitations. First and foremost, this is a retrospective study. Inherent to retrospective studies, data quality and quantity could not be controlled. Furthermore, fractures were classified according to the available medical records, including radiology reports using morphology-based classification systems. The vast majority of images were not reviewed. To address these limitations, we are specifically reviewing the complete medical records and images for all TL fractures occurring since April 1, 2007, in a separate study. There is the potential survivor bias in this study because severe spine injuries have been demonstrated in fatalities from earlier in the conflict [25], and recent data suggest that wounded servicemembers are surviving with higher and higher injury burden [8]. Finally, the fine details of the MOI and vehicle type cannot be reported because this information is classified.

Spinal injuries represent about 5% of the casualty burden from current combat operations. Our study quantified an obvious conclusion that dismounted soldiers are less protected against severe injury in today's combat environment than mounted soldiers. The incidence of spinal fractures was significantly higher in the dismounted cohort. Introduction of the latest uparmored vehicle did not increase the rate of spine injury. These vehicles are protective against spine fractures in general, but it appears that preventing injuries to the TL junction in the mounted servicemember is an area that needs continued focus. The overall incidence of spinal fractures has not changed over the course of these conflicts, but there has been a significant increase in TL fractures, especially more severe morphological types, related to mounted combat operations since April 2007. This increase is likely multifactorial, and further studies are needed to elucidate this relationship. Our study points to a specific area for future research and design activities, which is already in process.

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