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Severe soft tissue injuries of the upper extremity in motor vehicle crashes involving partial ejection: the protective role of side curtain airbags

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ABSTRACT

Introduction: Partial ejection (PE) of the upper extremity (UE) can occur in a motor vehicle crash (MVC) resulting in complex and severe soft tissue injuries (SSTI). This study evaluated the relationship between partial ejection and UE injuries, notably SSTIs, in MVCs focusing on crash types and characteristics, and further examined the role of side curtain airbags (SCABs) in the prevention of partial ejection and reducing SSTI of the UE.

Methods: Weighted data was analyzed from the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) from 1993 to 2012. Logistic regression models were used to assess the relationship of PE with SSTI of the UE and the effect of SCABs in both nearside impacts and rollover collisions. Crash Injury Research and Engineering Network (CIREN) case studies illustrated PE involving SSTI of the UE, and long term treatment.

Results: Rollover and nearside impact collisions had the highest percentages of partial ejection, with over half occurring in rollover collisions. Annually over 800 SSTIs of the UE occurred in all MVCs. For nearside lateral force impacts, a multivariable analysis adjusting for belt use and delta V showed a 15 times (OR 15.35, 95% CI 4.30, 54.79) greater odds of PE for occupants without SCABs compared to those with a SCAB deployment. No occupants (0 of 51,000) sustained a SSTI of the UE when a SCAB deployed in nearside impacts, compared to 0.01% (114 of 430,000) when SCABs were unavailable or did not deploy. In rollover collisions, a multivariable analysis adjusted for number of quarter turns and belt use showed 3 times the odds (OR 3.02, 95% CI 1.22, 7.47) of PE for occupants without SCABs compared to those with a SCAB deployment. Just 0.17% (32 of 19,000) of the occupants sustained a SSTI of the UE in rollovers with a SCAB deployment, compared to 0.53% (2294 of 431,000) of the occupants when SCABs were unavailable or did not deploy. CIREN case studies illustrated the injury causation of SSTI of the UE due to partial ejection, and the long term treatment and medical costs associated with a SSTI to the UE.

Conclusions: The majority of severe soft tissue injuries (SSTI) of the upper extremity (UE) involved partial ejection out the nearside window of outboard seated occupants in nearside impacts and rollover collisions. Real world case studies showed that SSTIs of the upper extremity require extensive treatment, extended hospitalization and are costly. Occupants without a side curtain airbag (SCAB) deployment had an increase in the odds of partial ejection. SCAB deployments provided protection against partial ejection and prevented SSTIs of the UE, with none occurring in nearside impacts, and a small percentage and reduction occurring in rollover collisions compared to those where SCABs were unavailable or did not deploy.

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1. Introduction

Despite widespread use of safety belts, partial ejection in motor vehicle crashes (MVCs) remains a problem, with challenges in both prevention and management of the associated injuries (Funk et al., 2012; Giavotto, 2003a; Latifi et al., 2014). Partial ejection (PE) dramatically increases injury severity and contributes to the morbidity and mortality of crash victims (Godrick, 2002; Keifer et al., 1996; Latifi et al., 2014). A recent study showed that while seatbelts are 99.8% effective in preventing complete ejections in rollover crashes, they are only 38% effective in preventing partial ejections (Funk et al., 2012). Newer restraint systems such as side-curtain airbags (SCABs) further mitigate, but do not eliminate the risk of partial ejection (Funk et al., 2012; Godrick, 2002; Malliaris et al., 1996). SCABs are designed to deploy in moderate to severe side impacts, providing coverage over the nearside windows and interior frame to protect the occupant as well as prevent ejection or direct contact with a striking vehicle or external objects. Some late model vehicles include sensors that also trigger deployment during rollover crashes to mitigate ejection and provide additional protection (Kahane, 2014).

Most research on partial ejection and SCAB development has focused on head and thoracic injuries (Griffin et al., 2012; McGwin et al., 2004). The upper extremities (UE) can also be partially ejected from the vehicle's window or sunroof during a crash. The resultant contact with the ground or external object can result in devastating severe soft tissue injuries (SSTI) of the upper extremity that includes crush, amputation, and deglovings. Studies have demonstrated the profound impact these injuries have on patients' health and quality of life (Bakker et al., 2013; Ball et al., 2009; Harris and Wood, 1978; Nikitins et al., 2003). Other studies have examined partial ejections involving injuries to the upper extremities, but SSTIs of the UE are highly morbid injuries that have not been evaluated (Bakker et al., 2013; Ball et al., 2009; Harris and Wood, 1978; Nikitins et al., 2003; Wraighte et al., 2011).

Severe soft tissue injuries are categorized into four patterns. The first two patterns involve minor to moderate loss of the outer layers of skin and tissues, while patterns 3 and 4 involve more devastating injuries with complete tissue and muscle loss; in some cases down to bone (Arnez and Khan, 2010). These injuries carry a very high morbidity and many patients require primary or secondary amputation. Overall, these injuries involve lengthy hospital stays, multiple complex reconstructive surgeries, and long courses of rehabilitation to restore structure and function to the limb (Bakker et al., 2013; Ball et al., 2009; Harris and Wood, 1978; Nikitins et al., 2003; Wraighte et al., 2011).

Multiple studies have also examined partial ejection involving other body regions and the effectiveness of SCABs, but none have focused on severe UE injuries associated with partial ejection, or the protective effect of SCABs in reducing SSTIs of the UE and ejection (Chong et al., 2011; Conroy et al., 2007; Funk et al., 2012; Goldman et al., 2005; Griffin et al., 2012; Jernigan et al., 2005; Latifi et al., 2014; Malliaris et al., 1996; McGwin et al., 2003; McGwin et al., 2004; McGwin et al., 2008; Moore et al., 2005; Richter et al., 2000). Motor vehicle crash characteristics of partial ejections associated with upper extremity (UE) injuries have not been systematically studied on a national level.

Two crash injury databases (National Automotive Sampling System Crashworthiness Data System- NASS CDS (U.S. Department of Transportation, 2017a) and the Crash Injury Research and Engineering Network-CIREN (U.S. Department of Transportation, 2017b)) were used to evaluate the prevalence and mechanisms that contribute to SSTI of the UE in the context of partial ejection during MVCs and further examine the preventive role of SCABs in reducing this injury pattern.

2. Methods

2.1. National Survey Database

NASS CDS is a nationwide crash data collection program sponsored by the United States Department of Transportation's National Highway Traffic Safety Administration (NHTSA). Datasets include weights, which account for the oversampling of crashes that result in fatalities and serious injuries, so that the data represents all police-reported, tow-away crashes in the United States (US) (Elliott et al., 2010). Survey weighted data analyses were conducted to account for the NASS-CDS sampling scheme, correcting for any coverage bias or non-response (NASS-CDS, 2013). Injuries to all vehicle occupants are documented and scored using the Abbreviated Injury Scale (AIS) (AAAM Abbreviated Injury Scale, 2005).

2.2. Crash Injury Research and Engineering Network (CIREN) case study selection

CIREN is a program also sponsored by NHTSA. CIREN subjects are enrolled by selection criteria involving more severe injuries with a focus on restrained occupants and crashes involving late model vehicles. CIREN case studies replicate the NASS CDS crash investigation methods and additionally include the complete course of treatment and biomechanical data abstracted by a multidisciplinary team of trauma care providers, engineers, and crash investigators. CIREN cases include injury causation scenarios that assign the probable mechanism of injury to each serious injury.

There were 12 CIREN patients located in the network (years 2002-14) that sustained severe soft tissue UE injuries involving partial ejection in a crash with the source of injury to the ground or external objects (U.S. Department of Transportation, 2017b). The first four CIREN cases were selected from the local CIREN center to present as detailed case studies and are approved for publishing. These cases best illustrated the specific crash types and mechanisms based on the weighted national analyses and results in this study. These cases also demonstrated the long term treatments and acute care costs associated with the treatment of a SSTI of the UE that in most cases was the only serious injury sustained.

2.3. NASS and CIREN crash investigations

In both NASS CDS and CIREN a scaled documentation of each crash site is performed. Exterior vehicle inspections are conducted that involve documenting direct and induced damage to assign a principal direction of force (PDOF) and calculate a change in velocity (delta V). An interior inspection is conducted that examines the restraint systems (seatbelts, airbags). Further inspection is conducted to locate occupant contact points identified by the presence of scuff patterns, dents, skin or fabric transfers and deformity of panels or structures. Examination surrounding potential ejection paths, nearside windows or the sunroofs, is also conducted looking for similar evidence and even the deformity of the exterior surfaces surrounding these paths where the body or upper extremity may have been trapped between the vehicle and the ground, especially in a rollover collision.

2.4. National survey database

Weighted NASS CDS data collected from 1993 to 2012 were used for this study. The study population consisted of outboard occupants seated in the first three rows, age 14 and older, in passenger vehicles excluding convertibles. Statistical regression models included unbelted occupants to increase generalizability. All occupants were stratified by similar seated positions and the specific ejection path or nearside window were assessed. The SCAB anal-