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Epidemiology of moderate-to-severe injury patterns observed in rollover crashes

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ABSTRACT

Background: Previous epidemiological studies have highlighted the high risk of injury to the head, thorax, and cervical spine in rollover crashes. However, such results provide limited information on whole-body injury distribution and multiple region injury patterns necessary for the improvement and prioritization of rollover-focused injury countermeasures.
Methods: Sampled cases representing approximately 133,000 U.S. adult occupants involved in rollover crashes (between 1995 and 2013) sustaining moderate-to-severe injuries were selected from the National Automotive Sampling System Crashworthiness Data System database. A retrospective cohort study, based on a survey of population-based data, was used to identify relevant whole body injury patterns.
Results: Among belted occupants injured in rollover crashes, 79.2% sustained injuries to only one body region. The three most frequently injured (AIS2+) body regions were head (42.1%), upper extremity (28.0%), and thorax (27.1%). The most frequent multi-region injury pattern involved the head and upper extremity, but this pattern only accounted for 2.3% of all of occupants with moderate or worse injuries.
Conclusions: The results indicated that for rollover-dominated crashes, the frequently observed injury patterns involved isolated body regions. In contrast, multi-region injury patterns are more frequently observed in rollovers with significant planar impacts. Identification of region-specific injury patterns in pure rollover crashes is essential for clarifying injury mitigation targets and developing whole-body injury metrics specifically applicable to rollovers.

1. Introduction

The present work seeks to describe the whole body patterns of injury observed in rollover crash-involved occupants. Rollover motor vehicle crashes account for a disproportionate number of serious injuries and fatalities (35% of all occupant fatalities) compared to crashes in planar modes (e.g. frontal, side and rear impacts) in the United States (NHTSA, 2012). While only accounting for 2% of crashes, the annual comprehensive healthcare cost associated with the rollover victims was 40 billion dollars in 2002 (33% of all motor vehicle related trauma costs) (Digges, 2002). Owing to the high frequency of injury and related heath burden associated with rollover crashes, the National Highway Traffic Safety Administration (NHTSA) identified rollover safety research including injury epidemiology, dynamic crashworthiness evaluation, and evaluation of restraint performance as top research priorities (NHTSA, 2011). To this effect, current research efforts are focused on identifying targets for injury risk prediction (Kerrigan et al., 2014) and biofidelity assessment (Zhang et al., 2014) through a better understanding of mechanisms related to rollover-related injuries.

Field data studies of rollover crashes have identified crash, occupant and vehicle factors that are associated with the severity of injuries sustained by the victims. These factors primarily include, but are not limited to, seat-belt usage (Moore et al., 2005; Viano et al., 2007; Funk et al., 2012), occupant ejection (Gloeckner et al., 2006; Funk et al., 2012), seating position (Viano et al., 2007; Funk et al., 2012), number of rollover quarter-turns, vehicle roll direction (Viano et al., 2007; Parker et al., 2007; Funk et al., 2012),

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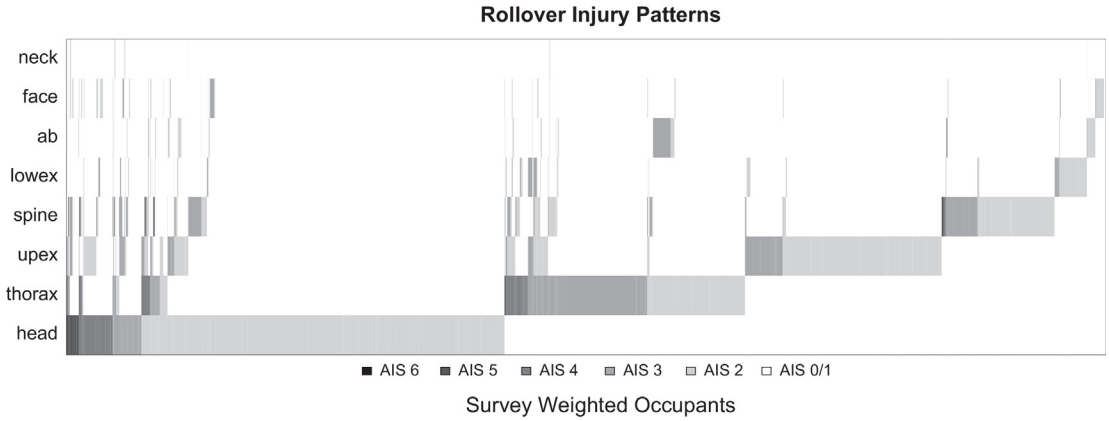

Fig. 1. Multivariate rollover injury patterns. Each occupant is represented by a vertical band with width proportional to survey-weight.

vehicle roof crush (Mandell et al., 2010; Funk et al., 2012), vehicle type (Conroy et al., 2006) and involvement of multiple-event crashes (Bose et al., 2011; Funk et al., 2012). While these studies provide a useful description of how particular factors influence the occurrence of injuries, the analyses are focused on the frequency of injuries of a particular severity, or focused on injuries to single body regions (i.e. the risk of cervical spine injury as a function of vehicle roof crush). No previous study has considered the factors contributing to multi-system injury patterns, or the risk of individual occupants sustaining moderate (or more severe) injuries in multiple body regions. Investigations into the frequency and risks associated with multi-system trauma help to clarify the scope of risks to occupants in these crashes, and should be used to drive the development and assessment of injury mitigation countermeasures and provide a framework on which to evaluate the biofidelity of occupant surrogates for use in predicting occupant injury outcomes. Furthermore, with the exceptions of Bose et al. (2011) and Funk et al. (2012), previous studies included for analysis cases that had major planar crash events before, during, or after the rollover, which make it impossible to determine which crash mode or impact caused the injury, or restricted to single-event rollover crashes, which excludes a majority of rollover cases.

Retrospective analyses are limited in their ability to clarify injury mechanisms, but clear descriptions of both injury frequency/distribution and mechanism are necessary to accurately predict injury risk, evaluate potential benefits of injury countermeasures, and develop biofidelic surrogates. This study aims to address the limitations of previous studies, and to supplement the existing injury frequency and distribution data for rollover crash-involved occupants. Specifically, the goal of the current study is to analyze national-level rollover injury epidemiology with the objective of evaluating multiple body region injury patterns at different trauma severity levels.

2. Materials and methods

Our data source was years 1995–2013 of the National Highway Traffic Safety Administration's (NHTSA) National Automotive Sampling System Crashworthiness Data System (NASS-CDS) survey. The NASS-CDS provides nationally representative motor vehicle crash data based on a weighted annual sample of approximately 5000 police reported tow-away crashes (NHTSA, 2008). The dataset includes detailed information about the occupant, vehicle, crash kinematics, restraint usage and injury outcome including incidence of fatality and injury severity codes for each individual injury. Our analysis relied on the 1990 Abbreviated Injury Scale (AIS) (AAAM, 1990) injury codes provided in NASS-CDS years 1995–2007, and the 1998 update to AIS 1990 provided in years 2008–2013.

We selected for analysis occupants who were involved in 1 to 16 quarter-turn (about the longitudinal axis) rollover crashes. We excluded end-over-end rollovers because of their low frequency (<1% of all rollover crashes) and substantially different crash kinematics. We further screened the crashes to select only *primary rollover crashes* (Funk, 2012); in detail, these were crashes where the investigator deemed the rollover event, and not any other planar crash event, to be the most damaging event to the vehicle. These criteria were chosen to exclude rollover crashes involving significant vehicle damage due to planar collision with secondary vehicles or fixed objects. For our study, we further selected adult occupants (16 years and older) properly restrained by the 3-point seatbelt who were not ejected from the vehicle during the crash, and who were in vehicles at most 15 years old with gross vehicle weight rating less than 4536 kg. In 2009, NASS-CDS stopped fully investigating occupants in vehicles 10 or more years old, so occupants in these vehicles were also excluded. In order to focus specifically on rollover victims with substantial injuries, we finally excluded occupants with maximum AIS injury levels of 0 or 1. The selection criteria yielded 848 sampled occupants with total survey weight indicating these occupants represent approximately 133,000 occupants at the national level over the 1995–2013 time period.

All data management and analyses were performed in SAS version 9.4, and SAS procedures for analyzing complex sample surveys were used throughout. Fig. 1 was generated in R version 3.1.2.

3. Results

3.1. Descriptive

In order to describe the population of injured occupants and the risk factors for injury, we first carried out a descriptive analysis of relevant occupant, vehicle, and rollover characteristics for the selected occupants (Table 1). In addition to the variables described in Table 1, we also investigated the rollover initiation type. The large majority of the rollovers (79.8%, 95% CI: 75.1, 84.5) are coded in NASS-CDS as being "trip-overs," with single digit percentages or smaller in the remaining categories.

It is worth noting that the injured occupants are similar to overall NASS-CDS adult occupants. In particular, in all NASS-CDS cases from 1995 to 2013, the average age of adult occupants is 35.3, 10.6% are age 61 or older, 54.1% are male, 48.0% are in the normal BMI category, 4.0% are underweight, 30.9% are overweight, and 17.0% are obese (based on the classification by National Institute of Health