INJURY PATTERNS AND SOURCES OF NON-EJECTED OCCUPANTS IN TRIP-OVER CRASHES: A SURVEY OF NASS-CDS DATABASE FROM 1997 TO 2002

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ABSTRACT

The objective of this study was to investigate the main injury patterns and sources of non-ejected occupants (i.e. no full/partial ejection) during trip-over crashes, using the NASS-CDS database. Specific injury types and sources of the head, chest, and neck were identified. Results from this study suggest that cerebrum injuries, especially subarachnoid hemorrhage, rib fractures, lung injuries, and cervical spine fractures need to be emphasized if cadaveric tests or numerical simulations are designed to study rollover injury mechanisms. The roof has been identified as the major source for head and neck injuries. However, changing the roof design alone is not likely to improve rollover safety. Instead, the belt restraint systems, passive airbags, roof structure, and new innovations need to be considered in a systematic manner to provide enhanced rollover occupant protection.

In general, rollover crashes are high speed events and hence are associated with a higher fatality rate and a more serious injury rate than other crash types. Rollover crashes are receiving increasing attention from the safety community. In 2003, 48,125 passenger vehicles were involved in rollover crashes in the United States. Although it only represented 2.5% of all crash types, it accounted for nearly 21% of all fatal crashes [NHTSA 2003].

During the last several years, many studies have been conducted to determine the patterns and sources of injury in rollover crashes. However, few of them have emphasized the identification of cases that can be simulated numerically or tested in the laboratory to explore potential use of enhanced restraint systems. Many previous studies of the NASS database have demonstrated that serious injuries were most frequently seen in the head and thorax, thus emphasizing the need to set up experiments and numerical models to look into these body regions [Parenteau et al. 2000, 2001a]. They also noted that trip-over crashes accounted for more than 50% of all rollover crashes; therefore trip-over tests are adopted as one of the laboratory-based rollover test modes to evaluate real-world rollover crashes [Parenteau et al. 2001b, 2003, Viano and Parenteau 2004]. More recently, Bedewi et al. (2003) found from the NASS database that head injuries associated with roof contact were the most frequently coded injury type-source combination. Coded sources of injury for other body regions were also analyzed in that study.

Although all of these previous studies have indicated similar results for the most vulnerable body regions and the most frequent injury sources during rollover crashes, very few of them identified specific injuries in each body region - an important parameter for future replication in laboratory experiments and/or numerical simulations to investigate rollover injury mechanisms. In contrast, Atkinson et al. (2004) made a very detailed analysis of the NASS database to determine specific types of injury and noted that subarachnoid hemorrhage (SAH), unilateral lung contusion, clavicle fracture, cervical spine fracture without cord injury, and spleen laceration were the most common injuries to the head, thorax, shoulder, neck, and abdomen, respectively. However, their study did not distinguish the rollover initiation type and seat belt usage, which are two critical conditions needed for experimental and numerical simulations. Only coded sources of head injuries were analyzed in that study, but the seating position was not identified.

The objective of this study was to investigate the most frequent injury patterns and coded sources of injury during the most common type of rollover crashes, although it is well known that rollovers are complex crash incidents that are particularly chaotic, unpredictable and violent in nature. Specific injuries and their respective coded injury sources were analyzed based on different conditions such as seat belt usage, seating positions, and other parameters. Results from this study may potentially be helpful in the design of cadaveric experiments and development of numerical models to investigate rollover injury mechanisms.

METHODS

DATA – In this study, occupant injury data were extracted from the NASS-CDS database, maintained by the National Center for Statistics and Analysis (NCSA), for crashes between the years of 1997 and 2002. Commercially available software SAS (SAS Institute, Cary, NC) was used to retrieve the raw data and DBMS (Conceptual Software, Houston, TX) was used to translate the SAS data into Access (Microsoft, Redmond, WA) which was used for data analysis.

OCCUPANT AND INJURY SELECTION –The definitions of all the rollover initiation types are based on NASS-CDS coding manual [NCSA 1997]. About 60% of all rollover cases with MAIS 2 to 6 injuries were initiated by trip-over (Table 1). A trip-over, as defined by the NASS database, is when the vehicle's lateral motion is suddenly slowed or stopped, inducing a rollover. The opposing force may be produced by a curb, pot-holes, or pavement/soil dug into by a vehicle's wheels. Therefore injuries due only to trip-over crashes were considered in this study. Because injury mechanisms of ejected occupants were too random to yield meaningful result, only non-ejected occupants older than 12 years of age were analyzed further. (Note that partial-ejection cases were excluded from this analysis). Moreover, belted and unbelted occupants were analyzed separately due to the difference in rollover kinematics. Only occupants seated in the front seats were considered for injury source analysis, and drivers and front seat passengers were analyzed separately.

Table 1 – Distribution of Initiation Types for Rollover Crashes with MAIS 2 to 6 Injuries

Rollover Initiation Type	**Number of vehicles**	**Percent**
Trip-Over	814	**60.3%**
Collision with another vehicle	168	12.5%
Bounce-Over	131	9.7%
Flip-Over	68	5.0%
Fall-Over	67	5.0%
Climb-Over	43	3.2%
End-Over-End	28	2.1%
Turn-Over	16	1.2%
Other rollover types	14	1.0%
Total	1349	100.0%

INJURY DEFINITION – AIS 90 (AAAM, Des Plaines, IL) was used to determine specific injuries. Different injury distributions were examined in terms of body region, type of anatomic structure, specific anatomic structure and level.

OTHER ISSUES FOR DATA ANALYSIS – Since the aim of this study was to identify the most common injury patterns and sources, only unweighted data were analyzed. Weighting factors were not used, because they are based on the number of vehicles on the road and are hence not appropriate for individual injuries. Separate data analysis based on different vehicle types (passenger cars, SUVs, vans, and pickup trucks) were not considered in this study because a previous study showed that there was no significant difference in terms of injury patterns among different vehicle types [Bedewi et al. 2003].

RESULTS

Following the aforementioned selection criteria, 634 occupants and 1,790 occupant injuries were extracted. The injuries were further subdivided into 1,070 for belted and 720 for unbelted occupants.

INJURY DISTRIBUTION BY INJURY SEVERITY – A total of 419 belted and 215 unbelted rollover occupants sustained a total of 1070 and 720 AIS 2 to 6 injuries, respectively. Table 2 shows the number of injuries distributed by AIS level. Again, it should be noted that only non-ejected occupants were analyzed in this study. As a result, the number of belted occupants was higher than the number of unbelted occupants. The average number of injuries was 2.55 and 3.35 for each belted and unbelted occupant, respectively. Results indicate that the seatbelt is very effective in reducing the number of injuries, even though only non-ejected occupants were considered.

Table 2 – Number of Injuries Sustained by Non-ejected Rollover Occupants Distributed by Injury Severity

AIS level	Belted		Unbelted	
	Number	Percent	Number	Percent
2	640	59.8%	384	53.3%
3	303	28.3%	204	28.3%
4	75	7.0%	85	11.8%
5	43	4.0%	39	5.4%
6	9	0.8%	8	1.1%
Total	1,070	100.0%	720	100.0%

INJURY DISTRIBUTION BY BODY REGION – The most commonly injured body regions, sorted for all AIS 2 to 6 and AIS 3 to 6 injuries, were the head, chest, and neck for belted occupants (Table 3). For unbelted occupants, the head, chest, and neck still ranked as the top 3 body regions with AIS 3 to 6 injuries (Table 4). For this reason, only these three body regions were analyzed further in the following sections to determine specific type of injuries.

Table 3 – Injury Distribution for Belted Occupants by Body Region
(Bold face indicates the top three body regions)

Body Region	**AIS 2 to 6 injuries**		**AIS 3 to 6 injuries**	
	Number	**Percent**	**Number**	**Percent**
Head	321	**30.0%**	163	**37.9%**
Chest	138	**12.9%**	107	**24.9%**
Neck	95	**8.9%**	38	**8.8%**
Forearm	46	4.3%	25	5.8%
Thigh	19	1.8%	19	4.4%
Abdomen	66	6.2%	18	4.2%
Leg (Lower)	39	3.6%	16	3.7%
Arm	21	2.0%	14	3.3%
Pelvic	47	4.4%	13	3.0%
Back	57	5.3%	5	1.2%
Other Regions	221	20.7%	12	2.8%
Total	1070	100.0%	430	100.0%

Table 4 – Injury Distribution for Unbelted Occupants by Body Region
(Bold face indicates the top 3 body regions)

Body Region	**AIS 2 to 6 injuries**		**AIS 3 to 6 injuries**	
	Number	**Percent**	**Number**	**Percent**
Head	213	**29.6%**	142	**42.3%**
Chest	116	**16.1%**	90	**26.8%**
Neck	47	6.5%	28	**8.3%**
Abdomen	65	**9.0%**	19	5.7%
Thigh	17	2.4%	17	5.1%
Forearm	24	3.3%	15	4.5%
Arm	13	1.8%	5	1.5%
Back	58	8.1%	5	1.5%
Leg (Lower)	15	2.1%	5	1.5%
Face	36	5.0%	4	1.2%
Other Regions	116	16.1%	6	1.8%
Total	720	100.0%	336	100.0%

HEAD INJURY – For AIS 2 to 6 head injuries, loss of consciousness (LOC) and brain injury were the top two injury types, and brain injury was much more common than skull fracture for both belted and unbelted occupants (Table 5). For belted occupants, LOC was the most frequent type of head injury compared to brain injury for unbelted occupants. Injury to the cerebrum accounted for 85.8% and 89.7% of brain injuries for belted and unbelted occupants, respectively (Table 6). Additionally, cranial vault fractures occurred more frequently than basilar skull fractures for both belted and unbelted occupants (Table 7).

Table 5 – Distribution of Head Injury by Type of Anatomic Structure (Bold face indicates the top injury type)

Injury type	Belted		Unbelted	
	Number	Percent	Number	Percent
LOC	135	**42.1%**	72	33.8%
Brain injury	120	37.4%	107	**50.2%**
Skeletal	45	14.0%	32	15.0%
Skin	15	4.7%	1	0.5%
Vessels	3	0.9%	-	-
Nerves	2	0.6%	-	-
Whole Area	1	0.3%	1	0.5%
Total	321	100.0%	213	100.0%

Table 6 – Brain Injury Distributed by Anatomical Region (Bold face indicates the top injured anatomical region)

Injured Region	Belted		Unbelted	
	Number	Percent	Number	Percent
Cerebrum	103	**85.8%**	96	**89.7%**
Brain Stem	11	9.2%	8	7.5%
Cerebellum	6	5.0%	3	2.8%
Total	120	100.0%	107	100.0%

Table 7 – Skeletal Head Injury Distributed by Fracture Location (Bold face indicates the top fractured location)

Fracture Location	Belted		Unbelted	
	Number	Percent	Number	Percent
Vault	29	**64.4%**	18	**56.3%**
Base	15	33.3%	13	40.6%
Unknown	1	2.2%	1	3.1%
Total	45	100.0%	32	100.0%

Using AIS 90, it was further discovered that subarachnoid hemorrhage (SAH) was the most common brain injury for both belted (14%) and unbelted (19%) occupants (Table 8).

Table 8 – Top 5 Specific Head Injuries with AIS 2 to 6

Belted	Unbelted
Subarachnoid Hemorrhage 26 (14.0%)	Subarachnoid Hemorrhage 27 (19.1%)
Closed Vault Fracture 18 (9.7%)	Intraventriclar Hemorrhage 8 (5.7%)
Scalp Laceration 10 (5.4%)	Cerebrum Multiple Contusion 6 (4.3%)
Intraventriclar Hemorrhage 9 (4.8%)	Subdural Hematoma 5 (3.5%)
Basilar skull Fracture 8 (4.3%)	Cerebrum Laceration 5 (3.5%)

CHEST INJURY – For AIS 2 to 6 chest injuries, rib cage fracture and lung injury were the two predominant injury types (Tables 9 to 11). Combining Tables 9 and 10, rib cage fractures accounted for 43.6% and 43.0% of all the chest injuries in belted and unbelted occupants, respectively. Similarly, lung injury accounted for 33.6% for belted and 24.0% for unbelted occupants of all the chest injuries.

Table 9 – Chest Injury Distribution by Type of Anatomic Structure
(Bold face indicates the top injury type)

Type Of Anatomic Structure	**Belted**		**Unbelted**	
	Number	**Percent**	**Number**	**Percent**
Skeletal	72	**51.4%**	56	**46.3%**
Internal Organs	57	40.7%	55	45.5%
Vessels	10	7.1%	10	8.3%
Whole Area	1	0.7%	0	0%
Total	140	100.0%	121	100.0%

Table 10 – Skeletal Chest Injury Distribution by Fracture Location
(Bold face indicates the top fracture location)

Fracture Location	**Belted**		**Unbelted**	
	Number	**Percent**	**Number**	**Percent**
Rib Cage	61	**84.7%**	52	**94.5%**
Sternum	11	15.3%	3	5.5%
Total	72	100.0%	55	100.0%

Table 11 – Thoracic Internal Organ Injury Distribution
(Bold face indicates the top injured internal organ)

Internal Organ	**Belted**		**Unbelted**	
	Number	**Percent**	**Number**	**Percent**
Lung	47	**82.5%**	29	**51.8%**
Heart	4	7.0%	3	5.4%
Thoracic Cavity	3	5.3%	12	21.4%
Diaphragm	2	3.5%	5	8.9%
Trachea and Main Stem Bronchus	1	1.8%	-	-
Pleura Laceration	-	-	4	7.1%
Pericardium	-	-	2	3.6%
Septum Laceration	-	-	1	1.8%
Total	57	100.0%	56	100.0%

NECK INJURY – The majority of AIS 2 to 6 neck injuries was vertebral fracture for both belted (84.2%) and unbelted occupants (78.3%), as shown in Table 12. Vertebral dislocation is not prevalent, which occurred even less frequently than spinal cord injury.

Table 12 – Neck Injury Distribution by Specific Anatomic Structure
(Bold face indicates the top injury type)

Specific Anatomic Structure	Belted		Unbelted	
	Num	Percent	Num	Percent
Vertebral Fracture without Cord Injury	80	**84.2%**	36	**78.3%**
Cord Injury	7	7.4%	5	10.9%
Vertebral Dislocation without Fracture and Cord Injury	5	5.3%	4	8.7%
Disc Injury	3	3.2%	-	-
Nerve Root Injury	-	-	1	2.2%
Total	95	100%	46	100%

COMBINED HEAD-NECK INJURY – Combined head-neck injury was also analyzed (Table 13). Note that the number of head injuries with neck injury needs not be the same as the number of neck injuries with head injury because multiple head injuries can occur with one neck injury and vice versa. The rate of head injury occurring with neck injury was not high for both belted (16.2%) and unbelted (10.8%) occupants. Additionally, less than 40% of the neck injuries occurred with concomitant head injuries for both belted and unbelted occupants. These results indicate that head and neck injury are not highly correlated in rollover crashes.

Table 13 – Number of Combined Head and Neck Injuries

Injury Type		Belted		Unbelted	
		Num	Percent	Num	Percent
Head Injury	Head Injury with Neck Injury	52	16.2%	23	10.8%
	Head Injury without Neck Injury	269	83.8%	190	89.2%
	Total Head Injury	321	100%	213	100%
Neck Injury	Neck Injury with Head Injury	34	35.8%	18	39.1%
	Neck Injury without Head Injury	61	64.2%	28	60.9%
	Total Neck Injury	95	100%	46	100%

Further analyses show that no predominant type of head injury occurred concomitantly with neck injury. On the contrary, fracture of vertebral bodies in the cervical spine had a very high probability (9 out of 12, 75%) of coexisting with head injuries in belted occupants. A similar trend in unbelted neck injury occupants was not found.

SOURCE OF HEAD INJURY – For head injury, the roof or convertible top was the predominant coded source of injury regardless of seating position (driver or passenger side), with or without seat belt usage (Table 14). Combining the roof with both front header and bilateral roof rail, this roof assembly was coded as the injury source for more than 60% of all head injury cases, except for unbelted drivers. While the roof assembly was still the predominant coded injury source (43%) for unbelted drivers, other unknown sources also increased. Based on the data analyzed, unbelted occupants have a higher probability of impacting frontal structures, such as the frontal header and windshield, in rollover crashes, indicating that the seat belt is very effective in restraining occupants in the forward direction.

Table 14 – Top 5 Sources of Head Injury

	Driver	Front Seat Passenger
Belted	Roof or Convertible Top 114 (47.5%)	Roof or Convertible Top 29 (49.2%)
	Roof Left Side Rail 38 (15.8%)	Right A-Pillar 8 (13.6%)
	Noncontact Injury 15 (6.3%)	Noncontact Injury 4 (6.8%)
	Unknown Source 12 (5.0%)	Roof Right Side Rail 4 (6.8%)
	Left B-Pillar 11 (4.6%)	Unknown Source 3 (5.1%)
Unbelted	Roof or Convertible Top 30 (24.4%)	Roof or Convertible Top 17 (43.6%)
	Unknown Source 16 (13.0%)	Front Header 6 (15.4%)
	Front Header 10 (8.1%)	Other Front Object 6 (15.4%)
	Unknown Exterior of Other Vehicle 10 (8.1%)	Windshield 4 (10.3%)
	Roof Left Side Rail 9 (7.3%)	Roof Right Side Rail 3 (7.7%)

SOURCE OF CHEST INJURY –Although no predominant chest injury coded source could be identified, side interior surfaces and belt webbing/buckle were the most commonly coded sources for belted occupants (Table 15). For unbelted front seat passengers, it was interesting to note that the steering wheel was a significant coded injury source and accounted for 25% of the chest injuries indicating that kinematics of unbelted front seat passengers could be very complicated.

SOURCE OF NECK INJURY – For neck injury, the roof was the predominant coded source of injury for belted occupants (Table 16). Combining the roof with both bilateral roof rails and front header, the roof assembly was coded as the injury source for more than 70% of neck injuries for both the belted driver and the front seat passenger. For unbelted occupants, no obvious injury source could be identified, but it was interesting to note that the windshield was responsible for about 50% of all neck injuries in unbelted front seat passenger. Due to the limited number of cases involving front seat passengers, this result needs to be investigated further.

Table 15 – Top 5 Sources of Chest Injury

	Driver	Front Seat Passenger
Belted	Left Side Interior Surface 28 (25.9%)	Right Side Interior Surface 7 (29.2%)
	Belt Webbing/Buckle 20 (18.5%)	Unknown Source 6 (25.0%)
	Left Side Hardware Or Armrest 12 (11.1%)	Belt Webbing/Buckle 5 (20.8%)
	Steering Wheel 12 (11.1%)	Seat, Back Support 2 (8.3%)
	Roof Or Convertible Top 11 (10.2%)	Four Sources (Tied) 1 (4.2%)
Unbelted	Steering Wheel 21 (26.6%)	Steering Wheel 6 (25.0%)
	Left Side Interior Surface 14 (17.7%)	Roof Or Convertible Top 6 (25.0%)
	Unknown Source 9 (11.4%)	Unknown Source 5 (20.8%)
	Right Instrument Panel And Below 8 (10.1%)	Right Side Interior Surface 2 (8.3%)
	Right Side Interior Surface 6 (7.6%)	Five Sources (Tied) 1 (4.2%)

Table 16 – Top 5 Sources of Neck Injury

	Driver	Front Seat Passenger
Belted	Roof Or Convertible Top 44 (62.9%)	Roof Or Convertible Top 10 (71.4%)
	Unknown Source 8 (11.4%)	Ground 2 (14.3%)
	Seat, Back Support 4 (5.7%)	Unknown Source 1 (7.1%)
	Roof Left Side Rail 3 (4.3%)	Right B-Pillar 1 (7.1%)
	Front Header 3 (4.3%)	-
Unbelted	Roof Or Convertible Top 13 (38.2%)	Windshield 5 (50.0%)
	Unknown Source 8 (23.5%)	Roof Or Convertible Top 2 (20.0%)
	Right B-Pillar 6 (17.6%)	Roof Right Side Rail 2 (20.0%)
	Noncontact Injury 2 (5.9%)	Noncontact Injury 1 (10.0%)
	Left Side Interior Surface 2 (5.9%)	-

DISCUSSION

The current study was aimed at providing critical information needed for designing cadaveric tests and numerical simulations to investigate injury mechanism during rollover crashes. Specific types of injury in three different body regions and respective NASS coded injury sources were analyzed for different seating positions. Although the number of cases in some categories of injuries was relatively small and could not achieve statistical significance, trends observed may be very helpful for the stated goal.

Based on the data analyzed in this study, trip-over is the most prevalent initiation type in all the rollover crashes, which is consistent with previously reported studies by Parenteau et al. (2003) and Viano and Parenteau (2004). Note that different types of rollover need different test setups to simulate the crash. Therefore, it will not be practical to conduct all possible experimental and numerical simulation scenarios, if the type of rollovers was not restricted. Based on this assumption, only injuries in trip-over rollover crashes were selected for this study. Thus, results from this study are particularly useful when designing soil-trip and curb-trip tests to study trip-over injuries [Parenteau et al. 2003].

In real world crashes or laboratory experiments, it is almost impossible to control the kinematics of ejected occupants. Thus, only non-ejected occupants were considered in this study. Unless some common characteristics of injury can be identified, it is not possible to design countermeasures to prevent injury from random events. Although belted and unbelted occupants are both considered in this study, it is recommended that the seatbelt should always be used in design of testing and simulation. Recent increase in seatbelt usage rate certainly makes this suggestion reasonable for implementation of test protocols.

Several studies have suggested that the head and chest were the most frequently injured body regions in rollover crashes [Parenteau et al. 2001b, Bedewi et al. 2003, and Atkinson et al. 2004]. For the third most commonly injured body region, these studies reported different results. However, in this study, the neck was found to be the third most commonly injured body region for belted occupants with AIS 2 to 6 injuries and AIS 3 to 6 injuries. The reason for this inconsistency is not fully understood at this time.

Specific head, chest, and neck injuries found in the current study are similar to those reported by Atkinson et al. (2004). In cases with head injury, brain injury occurred much more frequently than skeletal fracture. The high incidence rate of SAH suggests that future numerical models designed to study trip-over rollovers should be capable of simulating this form of cerebral hemorrhage. This would pose a very challenging task to modelers. In chest injury, the occurrence of rib cage fracture is higher than internal organ injury. Most neck injuries are cervical spine fractures; therefore, future numerical models developed to study this injury mechanism should have the capability of simulating cervical spine fracture.

Regarding the NASS coded injury sources, the roof is identified as the major coded source for both head and neck injuries, which demonstrates the importance of avoiding or reducing the impact between head and roof. However, changing the roof design alone may not improve the head and neck injury protection. In 1975, Moffatt proposed a hypothesis that there was no causal relationship between roof crush and head or neck injury [Moffatt 1975]. Later, three series of rollover experiments were conducted using Chevrolet Malibus and Crown Victorias to test the Moffatt hypothesis [Orlowski et al. 1985, Bahling et al. 1990, Moffatt et al. 2003]. Results from those tests indicated that reinforcing the roof structure with a roll cage did not increase the protection level over standard roofs. Thus, improving occupant head and neck protection in rollovers needs to be approached in a systematic manner, such as a well-designed safety belt system equipped with pre-tensioners, new roof structures, ejection prevention curtain airbags, and other innovations.

Although the seatbelt is very useful in protecting occupants, sometimes it could also induce some chest injuries in very severe crashes. Consequently better seatbelt design can in part reduce chest injury during rollover crashes. For unbelted occupants, they have a tendency to move forward during a rollover, so the steering wheel and windshield become major sources of chest and neck injury.

For comparison purposes, an additional analysis on head injury types and coded sources for partially ejected occupants was conducted, revealing some interesting results. About 96% (598 out of 626) of the head injuries in partial ejection rollovers were sustained by unbelted occupants. Although it is logical to associate a higher incidence rate of skull fractures with partial ejections, there was no such trend because the ratio between skull fracture and brain injury is not higher among ejected occupants. For partially ejected occupants, the major coded source of head injury was the ground (70%) instead of the roof for both belted and unbelted occupants.

A couple of limitations should be noted. Firstly, the number of injury cases in some selected conditions, especially in those cases with unbelted and non-ejected front seat occupants, was very small and should be treated with caution. Nevertheless, results from a limited number of cases will be useful in providing directions to future studies. Secondly, although the coded injury sources in the NASS database are assessed by investigators based on available physical evidence, it is rather difficult to ensure its accuracy due to the complexity of a rollover crash. For example, while the current study identified the roof and associated structures as the major injury sources, changing roof design alone is not likely to improve rollover safety. Instead, the belt restraint systems, passive airbags, roof structure, and new innovations need to be considered in a systematic manner to provide enhanced rollover occupant protection.

CONCLUSIONS

Two conclusions are drawn from this study:

1) The head, chest, and neck are the most commonly injured body regions when considering non-ejected occupants during trip-over rollover crashes.

2) Cerebrum injuries, especially SAH, rib fractures, lung injury, especially lung contusions, and cervical spine fracture need to be investigated if cadaveric tests are designed to study rollover injury mechanisms. If numerical models are designed to predict injury during trip-over crashes, their capability for predicting these injures should be of major concerns.

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