INJURY RISK FOR CHILDREN AND ADOLESCENTS INVOLVED IN ROLLOVER CRASHES

Aditya Belwadi
Caitlin Locey
Matthew R. Maltese
Kristy B. Arbogast
The Center for Injury Research and Prevention, The Children's Hospital of Philadelphia
Philadelphia, USA
Rachel Hammond
Westat Biostatistics and Data Management Core, The Children's Hospital of Philadelphia
Philadelphia, USA
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ABSTRACT

Rollover crashes account for more than 33% of all motor vehicle related fatalities and have the highest fatality risk at 1.37% in the U.S. There is increased awareness of the high fatality rate associated with this crash type, but there is very limited pediatric-specific data related to rollover crashes in the United States. Previous studies based on data almost twenty years old have revealed that nearly ten percent of all children involved in motor vehicle crashes are in rollover crashes, with the risk of fatality and injury for children in rollovers being nearly twice that of non-rollover crashes. Recent focus on rollover mitigation has resulted in implementation of countermeasures, making it important to evaluate rollover risk for child occupants with a more current data set.

Thus, to provide a contemporary analysis of rollover crashes involving young people, we queried the National Automotive Sampling System's Crashworthiness Data System (NASS-CDS) from 1998-2011. Rollover crashes for passenger vehicles of model year 1998 or newer with at least one restrained occupant between 0 and 19 years of age were included. Occupant frequency was examined with number of quarter turns, vehicle type, vehicle specific rollover event, rollover type and direction, airbag deployment and Electronic Stability Control availability. Further, occupant age, restraint type, seating position, occupant role, and proximity to the roll direction were analyzed. Univariate and multivariate logistic regression models of MAIS 2+ and MAIS 3+ injury were built to establish the relationship between the key factors and the injury outcomes.

The study cohort consisted of 1560 occupants weighted to represent 515,470 occupants. Results indicate that children restrained in FFCRS or booster seats were less likely to sustain an MAIS 2+ injury than lap/shoulder restrained occupants in a rollover crash. The abdomen was the most commonly injured body region at the AIS 2+ level while the head was most common at the AIS 3+ level, followed by the thorax and spine (for weighted data). However, for unweighted data, the head was the most commonly injured body region followed by the spine at the AIS 2+ level while the head was most common at the AIS 3+ level, followed by the thorax and upper extremities. The variations between the weighted and unweighted distributions points out some of the challenges with conducting child-specific analyses with NASS-CDS, as some cases have extremely high sample weights. Averages of 2.8-quarter turns were associated with an MAIS 2+ injury. Because there were limited cases with rollover mitigation technologies (ESC and airbags), their protective benefits in rollover crashes could not be ascertained.

INTRODUCTION AND BACKGROUND

Motor vehicle crashes (MVC) are the leading cause of unintentional injury deaths among ages 5-24 years in the U.S. (Centers for Disease Control, 2010). In 2010 alone, motor vehicle crashes killed 32,885 individuals (Traffic Safety Facts, 2012) and injured over 2.2 million others (NHTSA). Of these fatalities, 4,400 were occupants 0-19 years of age (WISQARS Fatal Injury Reports query, February 2013). Additionally, pediatric risk of exposure to motor vehicle crashes is significant because children and adolescents travel nearly as much as adults. Prevention of fatalities, injury, and disability associated with MVC must be a priority for ensuring our children's overall health.

Attention has been placed on understanding injury and fatality risk in rollovers for adult occupants due to the large percentage of fatalities attributed to this crash type. Although the number of rollover fatalities have decreased from 10,200 in 2005 to 7,600 in 2010 due to overall reduction in miles travelled combined with the adoption of mitigation technologies, the percentage of fatalities due to rollovers has increased from 30.9% in 2000 to 34.5% in 2010 (NHTSA Traffic Safety Facts, 2012).

Research in the 1990's and early 2000's examined rollover risk for child occupants. Rivara et al. (2003) utilized NASS-CDS and Fatality Analysis Reporting System (FARS) datasets (data from 1993-1998) and found that nearly ten percent of all children in crashes experience a rollover, with the risk of fatality and injury for children in rollovers being nearly twice that of non-rollover crashes. In this analysis, when the data set was restricted to SUVs, there were more child occupants involved in rollovers (60%) than in non-rollover crashes because SUVs were 11 times more likely to be in a rollover than a passenger car (Rivara et al., 2003). A review of the FARS database (data from 1996-2006) by Viano and Parenteau (2008) identified rollovers as the most common crash type resulting in fatality (20.3%) for the 0-7 year-old. Data reviewed from the Partners for Child Passenger Safety dataset (data from 1998-2005) showed the risk of injury to occupants 0 to 15 years of age was more than 6 times higher in rollover crashes compared to other crash modes (Kallan et al., 2006). Daly et al. (2006) studied child occupants in SUVs and passenger cars in all types of crashes (data from 2000-2003) and found an equivalent risk of injury for children in the two vehicle types. The authors suggested that despite a seeming advantage for SUVs due to being on average more than 1,300 pounds heavier, this advantage was offset by several factors--primarily a rollover risk nearly two and a half times higher compared to that of passenger cars.

Vehicle manufacturers and restraint suppliers have responded to the heightened awareness of increased fatality and injury risk associated with rollover crashes. They have introduced improved technology such as Electronic Stability Control (ESC), Roll Stability Control (RSC), as well as the improvement of advanced restraints such as frontal and side airbags. In addition, in 2003 NHTSA began evaluating rollover resistance in its NCAP program, spurring design changes by vehicle manufacturers in order to improve their NCAP evaluations. With these vehicle specific changes, there is a need to examine more recent data to understand the risk of injury (both overall and body region specific) in rollover crashes for children 0-19 years of age.

The objective of this project was to estimate AIS 2+ and AIS 3+ risk of injury for children and adolescents 0 to 19 years of age involved in a rollover crash using the NASS-CDS dataset from 1998 through 2011.

METHODS

The National Automotive Sampling System's Crashworthiness Data System (NASS-CDS) was the primary data source for this study. The NASS-CDS dataset provides detailed information for a random sample of motor vehicle crashes ranging in severity from minor to fatal. Approximately 5,000 cases per year are collected from Primary Sampling Units (PSU's) across the United States. A trained crash investigation team gathers information about the crash by visiting the impact location and inspecting and photographing the involved vehicles. Restraint usage and occupant contact locations are determined from a close examination of the vehicle interior. Occupant characteristics such as age, anthropometry, and injury are ascertained by interviewing the crash victims and reviewing police and emergency medical service reports and medical records. Individual cases are weighted (based on the NASS-CDS weighing factors) to represent the entire U.S. population.

To create the study cohort, cases were gathered from the NASS-CDS dataset using the following inclusion and exclusion criteria:

Inclusion Criteria:

- Passenger vehicle or light truck (GVWR <10,000 lbs /4536 kg)
- Model year 1998 or newer
- Vehicle involved in a rollover event (number of quarter turns ≥1 or end-over-end)
- Occupant age 0-19 years

Exclusion Criteria:

- Occupant unrestrained or unknown if restrained

MAIS 2+ and MAIS 3+ Injury risks were examined overall and stratified by the following vehicle-based and occupant-based variables (Table 1 and Table 2):

Table 1: Stratification– Vehicle Based

Variable of Interest	Values
Quarter Turns	1 through 16, End-Over-End
Vehicle Type	Minivan/van, Passenger Car, Pickup/Light Truck, SUV
Vehicle Specific Event Number	1 (Single Vehicle Single Event) and >1
Rollover Type and Direction	Longitudinal (Left Sided, Right Sided), End-Over-End
Airbag Deployment	Deployed During Crash, Deployed (Details Unknown), No Deployment
ESC Availability	Standard, Not Available, Optional, Unknown

Primary vs. Principal Rollover Event-- A "Vehicle Specific Event Number" variable was derived from the NASS-CDS "event" table. Because crashes are often complicated and may involve several vehicles in addition to the case vehicle, the event count can include events in which the case vehicle was not involved. Thus, "Vehicle Specific Event Number" is the rollover event number when only events in which the case vehicle was involved were counted. If vehicles had more than one rollover event, the first rollover event number was used. For cases with Vehicle Specific Event Numbers equaling one, the rollover is considered the "primary" event. It is important to note that a "primary" rollover is not necessarily a single-vehicle/single-event type crash as subsequent events may happen after rollover.

Within the NASS-CDS "VE" (Vehicle Exterior) table, crash events are ranked by severity using delta-V and damage extent. For crashes in which the most harmful event (i.e. "event of greatest delta V") was a non- collision rollover with the object contacted indicated as "overturn – rollover (excludes end-over-end)" or "rollover – end-over-end", the rollover is considered to be the "principal" event; that is, the rollover is the most severe event in the crash. For crashes where rollover is the primary event, it is also possible that the rollover is the principal event.

Airbag-- The availability and deployment of any airbag by occupant seating position is summarized by the variables "Air Bag Availability" and "Air Bag Deployment". However, while these variables give an overview of airbag for the case occupants they do not provide information regarding type of airbag or deployment event. Beginning in 2000, NASS-CDS incorporated an expanded dataset of detailed airbag information, found in the "airbag" and "bagseat" tables. Specific availability and deployment details were gathered for each airbag location (e.g., steering wheel hub, top instrument panel, roof side rail, seat back), rather than combining all airbag information by seating position. Use of this data allows investigators to capture whether multiple airbags were available for each occupant, what type, and whether all or some of these deployed. This detailed airbag information was included in this analysis for case years 2000-2010.

ESC -- Electronic Stability Control (ESC) availability was determined for vehicles of model year 2005 and newer using information released by NHTSA's safercar.gov website (http://www.safercar.gov/Vehicle+Shoppers/Resources/Vehicles+with+ESC). Vehicle year, make, and model fields were matched to the NASS-CDS data, and vehicles were assigned an ESC availability of "standard", "optional", or "not available". Vehicles with model year prior to 2005 or vehicles that did not have an exact match between the datasets were given an ESC availability of "unknown".

Table 2: Stratification– Occupant/Restraint Based

Variable of Interest	Values
Age Group (years)	0-2, 3-5, 6-8, 9-15, 16-19
Restraint Type	Rear Facing Child Restraint System (RFCRS), Forward Facing Child Restraint System (FFCRS), Booster Seat, Lap Belt only, Lap-Shoulder Belt
Seating Position	Front (Left, Center, Right), Row 2 (L, C, R), Row 3 (L, C, R), Row 4 (R)
Occupant Role	Driver, Passenger
Side of Seating Position vs. Roll Direction (Sidedness)	Center, Far side, Nearside, End-Over-End

Occupant Variables-- Occupants were assigned to an age group by age in years. Restraint type was determined by combining the expanded "childseat" dataset and the manual and automatic belt use variables. Seating position was summarized by side of the vehicle (left, center, right), and row number, with row 1 considered the "front row" and rows 2-4 considered as the "rear rows". Sidedness, or side of seating position vs. roll direction, examined the relationship between seating position side and direction of longitudinal roll. For example, an occupant seated in the rear left in a left sided rollover was considered nearside. Center-seated occupants in any row were classified as "center" regardless of roll direction.

Statistical Analysis -- Results of logistic regression modeling were expressed as adjusted/unadjusted odds ratios with corresponding 95% CI. Because injury is a relatively rare event, the odds ratio can be interpreted as a good estimate of relative risk. Summary statistics were calculated using sampling weights available from the NASS-CDS database using the survey functions in SAS, version 9.2 (SAS Institute, Cary, NC). All analyses were conducted using weighted data and variance estimates were calculated to account for the complex sampling methodology. Univariate logistic regression models were created to determine the association between variables of interest and MAIS 2+ and MAIS 3+ outcomes. A multivariable model was fit to include the covariates determined to be significant with a p-value <0.10 in the univariate models. A final model consisted of all factors that were associated with the outcome in the multivariable model with a p-value <0.05. Bivariate analyses were employed to examine the relationship between study variables, where we chose to include only one covariate in the multivariable model if any bivariate relationships were statistically significant. The weighted estimates were calculated as either means or proportions, with the associated 95% confidence intervals (CI) and standard errors (SE).

RESULTS AND DISCUSSION

Analysis of Rollover Events – Vehicle Based

2407 occupants aged 0-19 years in a passenger vehicle of model year 1998 or newer in a rollover collision were identified. 847 of these occupants had a restraint status of "unrestrained" or "unknown if restrained" and were subsequently excluded from the dataset. 1560 occupants met the inclusion and exclusion criteria, equating to 515,470 occupants when weighted.

Of the 1560 occupants, 8.0% involved minivans or large vans, 38.7% involved passenger cars, 16.6% involved pick-up and light trucks, and 36.8% involved SUV's (Table 3). It was interesting to observe an almost equal distribution between passenger cars and SUV's.

Table 3: Distribution by Vehicle Type

Vehicle Type	Unweighted Occupants	Weighted Occupants	Weighted Percent (%)	SE of %
Minivan/Van	146	41,047	8.0	3.7
Passenger Car	544	199,240	38.7	6.4
Pickup/Light Truck	214	85,578	16.6	5.0
SUV	656	189,605	36.8	8.5

Prior to 1997, NASS reported the extent of the rollover by partitioning the number of quarter-turns into five categories - 1, 2, 3, 4+ and end-over-end. After 1997, a larger number of categories have been recorded. To aid comparison with the literature, Table 4 summarizes cases up to 16-quarter turns along with end-over-end cases (which occur about the horizontal axis of the vehicle). However, in the injury risk analysis, end-over-end cases were not included as data was analyzed continuously for quarter turns 1 through 16.

26.2% of cases had only one-quarter turn while 33.7% had at least one complete roll (4 quarter turns). 73.6% of the cases had at least two-quarter turns. End-over-end rollovers were rare, accounting for only 0.2% (9 cases unweighted) of the distribution. Bedewi et al. (2004) and Hu et al. (2008) hypothesized that two or more quarter turns may expose the roof to ground contact and thereby the occupant to roof contact.

Table 4: Distribution by Quarter Turns

Quarter Turns	Unweighted Occupants	Weighted Occupants	Weighted Percent (%)
1	295	135,239	26.2
2	419	155,704	30.2
3	104	49,219	9.5
4	381	120,401	23.4
5	66	11,473	2.2
6	161	27,186	5.3
7	22	2,411	0.5
8	60	9,368	1.8
9	12	561	0.1
10	18	1,713	0.3
11	3	195	0.0
12	8	630	0.1
16	2	40	0.0
End-Over-End	9	1,203	0.2

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In 70.1% of the cases, the rollover was not the first event in the crash (Table 5). Of the 564 cases (unweighted) in which the vehicle specific event number was equal to one, 475 cases had rollover as the most severe event. Note: 411 were single vehicle single event rollover crashes, i.e., pure rollovers (Bose et al. 2011, Crandall et al. 2011). The other 153 cases were those which had subsequent planar events after the initial rollover. Of the 996 crashes (unweighted) in which vehicle specific event number was greater than one, 456 cases had the rollover event as the event of greatest severity.

Table 5: Distribution by Vehicle Specific Event Number

Vehicle Specific Event Number	Unweighted Occupants	Weighted Occupants	Weighted Percent (%)	SE of %
1	564	153,886	29.9	7.1
>1	996	361,584	70.1	7.1

The distribution of occupants by occupant role is given in Table 6. Rolls towards the driver's side accounted for 60.4% of overall rollover crashes, while rolls towards the passenger side occurred in 39.3%. Further, when the occupant seating position was compared to the roll direction, the distribution was 55.9% nearside to roll while 30.9% were far sided. In contrast, for adult drivers, roll direction was evenly divided between left and right (Bedewi et al. 2004, Hu et al. 2008).

Table 6: Distribution by Rollover Type, Direction, Occupant Role with Sidedness

	Unweighted Occupants	Weighted Occupants	Weighted Percent (%)	SE of %
Rollover Type and Direction				
End-Over-End	9	1203	0.2	0.1
Longitudinal	1551	514,267	99.7	0.1
Left-Sided	850	311,299	60.4	2.9
Right-Sided	701	202,969	39.3	2.8
Occupant Role				
Driver	489	219,160	42.5	6.5
Passenger	1071	296,310	57.4	6.5
Sidedness				
Center	127	64,620	12.5	5.3
Far side	679	159,751	30.9	6.8
Nearside	731	288,309	55.9	3.2
Other/Unknown	14	1,587	0.3	0.21
End Over End	9	1,203	0.2	0.15

Table 7 describes the availability and deployment conditions for airbags in included cases. 61.0% of occupants had at least one airbag available in their seating position. This included both frontal airbags as well as side and curtain airbags typically thought to be rollover countermeasures. In 52.5% of these cases, there was no deployment at any time during the crash. Only in 7.9% of crashes was there an airbag deployment. However, because delta-v is not calculated for non-horizontal rollover events, it is extremely challenging to interpret the lack of deployment in those 592 cases. Detailed airbag information from the dataset including the type of airbag deployed (Bottom Instrument Panel, Door Panel, Mid - Instrument Panel, Roof Side Rail, Seat Back, Steering Wheel Hub, Top Instrument Panel, and Any Air Bags Deployed) for included cases falling within the 2000-2010 case years are listed in Table A1 under Appendix A.

Table 7: Distribution by Airbag Availability and Deployment

Airbag	Unweighted Occupants	Weighted Occupants	Weighted Percent (%)	SE of %
Airbag Availability				
Any Available	838	314,701	61.0	2.4
Disconnected	6	524	0.1	0.0
Not Reinstalled	1	10	0.0	0.0
Not Collected	8	1,551	0.3	0.1
Not Equipped	707	198,684	38.5	2.4
Airbag Deployment				
Deployed	233	41,204	7.9	2.5
Not Deployed	592	271,086	52.5	4.0
Deployed, details unknown	4	1,183	0.2	0.2
Unknown	9	1,228	0.2	0.1

In order to have a better understanding whether rollover was indeed the principal event, Table 8 lists the events of highest and second highest delta-v. 73.2% of the cases had rollover as the event of highest delta-v.

Table 8: Distribution by Rollover as the Principal Event

	Unweighted Occupants	Weighted Occupants	Weighted Percent (%)	SE of %
Rollover is Event of Highest Delta V	843	377,336	73.2	4.1
Rollover is Event of 2nd Highest Delta V	467	89,872	17.4	3.1
Other Event is Event of Highest Delta V	170	35,745	6.9	1.5
Rollover Severity Unknown	80	12,517	2.4	0.3

With the proliferation of ESC in the vehicle fleet, (all model year 2012+ vehicles under 10,000 lbs gross vehicle weights are equipped with ESC), Table 9 lists the availability of ESC as standard equipment in the NASS-CDS dataset reviewed. Prior to vehicle model year 2005, a comprehensive list of vehicles with ESC was not available. 302 cases (unweighted) out of the 1560 rollover cases reviewed (vehicle model year 2005 onwards) could be linked to the safercar.gov list of vehicles with ESC. 23.8% (unweighted) of those 302 cases had ESC as standard equipment while 54.9% did not have them. 21.2% of the cases had ESC listed as "optional" for the corresponding vehicle make, model, and year; however, there was no data available within the NASS-CDS dataset to ascertain whether ESC was installed or used for these vehicles.

Table 9: Distribution by ESC Availability

ESC Availability	Unweighted Occupants	Weighted Occupants	Weighted Percent (%)	SE of %
Standard	72	14,484	2.8	1.5
Not Available	166	30,653	5.9	1.2
Optional	64	10,434	2.0	0.7
Unknown	1258	459,898	89.2	2.7

Analysis of Rollover Events – Occupant and Restraint Based

Of the cases examined, 53.4% were occupants 16-19 years of age. Nearly 20% of the cases were occupants 9-15 years of age, followed closely by occupants 6-8 years of age (15.6%). Table 10 shows the complete distribution by age range.

Table 10: Distribution by Age

Age (years)	Unweighted Occupants	Weighted Occupants	Weighted Percent (%)	SE of %
0-2	150	27,929	5.4	0.8
3-5	146	29,079	5.6	1.1
6-8	115	80,501	15.6	4.8
9-15	328	102,585	19.9	6.7
16-19	821	275,376	53.4	5.0

Despite approximately 27% of the occupants being less than 9 years of age and likely of the size for which a child restraint system (CRS) is required, only 14.1% were restrained in some type of CRS (including RFCRS, FFCRS, or booster seats) (Table 11). The lap shoulder belt was the most common form of restraint (81.9%).

Table 11: Distribution by Restraint Type

Restraint Type	Unweighted Occupants	Weighted Occupants	Weighted Percent (%)	SE of %
RFCRS	33	5672	1.1	0.3
FFCRS	120	21,458	4.2	1.5
Booster Seat	56	45,549	8.8	5.7
Lap Belt	60	7,075	1.4	0.6
Lap/shoulder Belt	1220	422,062	81.9	4.6
Unknown/Other CRS	61	11,945	2.3	0.4
Unknown/Other Belt	10	1,708	0.3	0.1

With respect to occupant seating position (Table 12), front left/driver (42.5%) and front right (18.9%) were the most common locations while all seating positions in the rear rows had a similar frequency (approximately 12%).

Table 12: Distribution by Seating Position

Seat Position	Unweighted Occupants	Weighted Occupants	Weighted Percent (%)	SE of %
Front Left (driver)	489	219,160	42.5	6.5
Front Middle	12	854.087	0.2	0.0
Front Right	364	97,626	18.9	5.1
Rear Rows Left	269	66,631	12.9	3.8
Rear Rows Middle	115	63,766	12.4	5.3
Rear Rows Right	297	65,847	12.8	3.7
Other/Unknown	14	1,587	0.3	0.2

***Note: Rear rows are a combination of the second, third and fourth rows**

Injury Analysis

Injury risk was investigated using the Abbreviated Injury Scale (AIS, AAAM, IL) maximum score (MAIS) of 2+ and 3+ as outcomes. 1027 of the included 1560 occupants (unweighted) sustained at least one injury scoring AIS 1-7 (AIS 7 indicates injured, unknown severity); 4005 unique injuries (unweighted) were sustained. For all included case occupants, the odds of an MAIS 2+ injury was 5.5%, and the odds of an MAIS 3+ injury was 2.0% in rollover crashes.

Univariate logistic regression models were created to determine the association between variables of interest and MAIS 2+ and MAIS 3+ outcomes. Tables 13 through 16 list only those variables, which have a significant association with the outcomes.

The remainder of the variables (Vehicle Type, Rollover Direction and Sidedness) had no significant outcomes.

Table 13 lists the odds ratio for MAIS 2+ and MAIS 3+ injury for restraint type based on a univariate logistic regression model. Lap/shoulder belt was used as the reference group. For MAIS2+ injury risk, those in booster seats and FFCRS had a significantly lower risk of the injury compared to those in lap shoulder belts while those in lap belts were 4.5 times more likely to be injured. For MAIS 3+ injury, only the elevated risk in lap belts remained.

Table 13: Odds ratio for MAIS 2+ and MAIS 3+ Injury for Restraint Type

Restraint Type	Outcome	Odds Ratio	LCL	UCL	P-Value
Booster Seat	MAIS 2+	0.14	0.02	0.93	0.042
	MAIS 3+	0.32	0.04	2.64	0.288
FFCRS	MAIS 2+	0.32	0.19	0.55	<.0001
	MAIS 3+	0.78	0.43	1.42	0.412
Lap Belt	MAIS 2+	4.55	1.94	10.66	0.001
	MAIS 3+	8.23	1.89	35.80	0.005
RFCRS	MAIS 2+	0.71	0.11	4.66	0.724
	MAIS 3+	1.03	0.11	9.30	0.979
Lap/shoulder Belt	MAIS 2+	1.00	--	--	--
	MAIS 3+				

***LCL = Lower Confidence Limit; UCL=Upper Confidence Limit**

Examining age group, those occupants aged 0-2 and 6-8 years had a significantly lower risk of MAIS 2+ injury compared to the 16-19 year olds (Table 14). None of the MAIS3+ results for age was statistically significant.

Table 14: Odds ratio for MAIS 2+ and MAIS 3+ Injury for Age Group

Age Group	Outcome	Odds Ratio	LCL	UCL	P-Value
0-2 years	MAIS 2+	0.23	0.08	0.67	0.008
	MAIS 3+	0.56	0.20	1.56	0.266
3-5 years	MAIS 2+	0.77	0.34	1.75	0.536
	MAIS 3+	1.11	0.55	2.22	0.775
6-8 years	MAIS 2+	0.33	0.12	0.95	0.041
	MAIS 3+	0.24	0.04	1.49	0.125
9-15 years	MAIS 2+	0.42	0.14	1.24	0.114
	MAIS 3+	0.95	0.32	2.77	0.918
16-19 years	MAIS 2+	1.00	--	--	--
	MAIS 3+				

For occupant seating position, the front right (2.3x) and front center (4.5x) had a statistically significant increase in MAIS2+ injury risk compared to the rear row left. It was interesting to note that for the front left seating position (i.e. the driver), we could not detect a difference compared to the rear row left (Table 15).

Table 15: Odds ratio for MAIS 2+ and MAIS 3+ Injury for Seating Position

Seating Position	Outcome	Odds Ratio	LCL	UCL	P-Value
Front Left	MAIS 2+	1.99	0.88	4.54	0.100
	MAIS 3+	1.35	0.45	4.11	0.594
Front Center	MAIS 2+	4.55	1.39	14.88	0.012
	MAIS 3+	4.64	0.55	39.22	0.159
Front Right	MAIS 2+	2.29	1.15	4.57	0.018
	MAIS 3+	1.86	0.74	4.67	0.186
Rear Rows Center	MAIS 2+	0.73	0.12	4.46	0.736
	MAIS 3+	1.04	0.09	12.22	0.975
Rear Rows Right	MAIS 2+	1.45	0.69	3.07	0.328
	MAIS 3+	0.82	0.20	3.35	0.783
Rear Rows Left	MAIS 2+	1.00	--	--	--
	MAIS 3+				

For every one unit increase in quarter turns, the odds of having an MAIS 2+ injury increased by 33% ($p<0.0001$) (Table 16). Similar finding were seen for MAIS 3+ injuries. An average of 2.8-quarter turns (2.33-3.19), was associated with an MAIS 2+ injury.

Table 16: Odds ratio for MAIS 2+ and MAIS 3+ injury for Quarter Turns

	Outcome	Odds Ratio	LCL	UCL	P-Value
Quarter Turns	MAIS 2+	1.33	1.28	1.42	<.0001
	MAIS 3+	1.45	1.21	1.57	<.0001

For injured occupants, the distribution of injuries by body region for AIS 2+ and AIS 3+ injury severity were tabulated. From Table 17, for all AIS 2+ injuries the abdomen was the body region with the highest proportion of injuries (44.6%) followed by the head (21.6%). However, for unweighted percentages, the body region making up the highest proportion of injuries was head (44.6%) followed by the spine (17.1%) and upper extremities (12.7%).

For AIS 3+ injuries, the head was the number one body region at 37.4% of the injuries, followed by the thorax (20.7%) and spine (17.9%). For unweighted percentages, the body region making up the highest proportion of injuries was head (48.1%) followed by the spine (20.4%) and upper extremities (9.3%).

Table 17: Distribution of Injuries by Body Region

AIS 2+ for Injured Occupants				
Body Region	**Unweighted Occupants**	**Weighted Occupants**	**Unweighted Percent (%)**	**Weighted Percent (%)**
Face	46	4,191	6.2	4.1
Head	279	21,860	37.8	21.6
Neck	1	124.12	0.1	0.1
Upper Extremity	94	10,693	12.7	10.6
Thorax	83	5,338	11.2	5.3
Abdomen	32	45,193	4.3	44.6
Spine	126	9,338	17.1	9.2
Lower Extremity	75	4,473	10.1	4.4
Unspecified	3	86.7	0.4	0.1

AIS 3+ for Injured Occupants				
Body Region	**Unweighted Occupants**	**Weighted Occupants**	**Unweighted Percent (%)**	**Weighted Percent (%)**
Face	14	1,340	4.1	6.6
Head	165	7,637	48.1	37.4
Neck	0	--	0.0	--
Upper Extremity	20	1,558	5.8	7.6
Thorax	70	4,229	20.4	20.7
Abdomen	12	584.1	3.5	2.9
Spine	32	3,646	9.3	17.9
Lower Extremity	27	1,312	7.9	6.4
Unspecified	3	86.7	0.9	0.4

Univariately, restraint type, age, seating position, and number of quarter turns were significantly associated with the odds of sustaining an MAIS 2+ injury among pediatric rollover occupants. After examining bivariate relationships among these covariates, we found that restraint type, age, and seating position were all significantly correlated. Therefore, only restraint type was included in the multivariable model with number of quarter turns. After observing these variables in a full multivariate model and then reducing the factors based on those that were not significant with a p-value <0.05, all factors were still significantly associated with MAIS 2+ injury.

Table 18 lists the odds ratio for MAIS 2+ and MAIS 3+ injury based on a multivariate model accounting for restraint type and number of quarter turns. Those occupants in FFCRS had a lower risk of MAIS 2+ injury compared to lap/shoulder belts, while those in lap belt only restraints had an increased risk of MAIS 2+ injury. Lap belt only restrained occupants had greater risk for an MAIS 3+ injury as compared to those restrained in lap shoulder belts. For number of quarter turns, one unit increase in the number of quarter turns was associated with an odds ratio of 1.33 (p<0.001) and 1.45 (p<0.001) for MAIS2+ and MAIS 3+ respectively.

Table 18: Odds ratio for MAIS 2+ and MAIS 3+ Injury with a Multivariate Model accounting Restraint Type and Quarter Turns

	Outcome	**Odds Ratio**	**LCL**	**UCL**	**P-Value**
Restraint Type					
Booster Seat	MAIS 2+	0.22	0.04	1.28	0.092
	MAIS 3+	0.55	0.09	3.35	0.515
FFCRS	MAIS 2+	0.35	0.22	0.57	<.0001
	MAIS 3+	0.88	0.50	1.56	0.655
Lap Belt	MAIS 2+	4.35	1.50	12.62	0.007
	MAIS 3+	7.77	1.27	47.40	0.026
RFCRS	MAIS 2+	0.81	0.11	5.93	0.832
	MAIS 3+	1.19	0.12	11.97	0.882
Lap/shoulder Belt	MAIS 2+	1.00	--	--	--
	MAIS 3+				
Quarter Turns					
Quarter Turns	MAIS 2+	1.32	1.25	1.39	<.0001
	MAIS 3+	1.36	1.22	1.51	<.0001

CONCLUSIONS

An unweighted 1560 cases (weighted n=515,470) meeting the inclusion and exclusion criteria (restrained occupants aged 0-19 years in a rollover crash-involved passenger vehicle of model year 1998 or newer) were identified from NASS-CDS. Results indicate that:

- The most commonly involved age group was 16-19 year olds, making up 53.4% of the weighted population, followed by 9-15 years olds comprising 20%.
- The lap shoulder belt was the most common form of restraint (82%). Univariate analysis showed that children restrained in FFCRS or booster seats were less likely to sustain an MAIS 2+ injury than lap/shoulder belt restrained occupants. Lap belt restrained occupants were much more likely to be injured. Multivariate analysis again showed that FFCRS odds ratio for MAIS 2+ injury (Odds Ratio=0.35, p<0.0001)

was significantly lower than the lap/shoulder belt reference value, while lap belt MAIS 2+ odds ratio (OR=4.35, p=0.007) was significantly higher. The protective benefit of proper restraint in rollover crashes is apparent.

- Occupants were most likely to be drivers (42.5%), then front right passengers (18.9%), with rear rows left (12.9%), center (12.4%), and right (12.8%) showing very similar occupant distributions. Front right (OR=2.29, p=0.018) and front center (OR=4.55, p=0.012) seating positions showed a higher likelihood of MAIS 2+ injury than the rear left seating position.
- The included rollover crashes experienced up to 16-quarter turns; 2-quarter turn crashes were most common (30.2%), followed by 1 quarter turn (26.2%) and 4 quarter turns (23.4%). Most rollover crashes consisted of at least 2-quarter turns. Multivariate analysis shows that number of quarter turns is a significant predictor of both MAIS 2+ and MAIS 3+ injury risk, with odds ratios of 1.32 (p<0.001) and 1.36 (p<0.001) respectively for each additional quarter turn. An average of 2.8-quarter turns (2.33-3.19) was associated with an MAIS 2+ injury.
- For individual AIS 2+ injuries, the abdomen was the body region with the highest weighted proportion of injuries: 44.6%; followed by the head at 21.6%. However, for unweighted percentages, the body region making up the highest proportion of injuries was head (44.6%) followed by the spine (17.1%) and upper extremities (12.7%). For AIS 3+ injuries, the head was the most injured body region at 37.4% of injuries, followed by the thorax (20.7%) and spine (17.9%). For unweighted percentages, the body region making up the highest proportion of injuries was head (48.1%) followed by the spine (20.4%) and upper extremities (9.3%). The variations between the weighted and unweighted distributions points out some of the challenges with conducting child-specific analyses with NASS-CDS, as some cases have extremely high sample weights.
- The protective benefit of air bags and rollover mitigation technologies such as ESC could not be evaluated due to limited cases for which that data is available. However, ESC was standard for 2.8% of the included case vehicles, and optional in an additional 2.0%.
- More complex multivariate modeling is needed to study the combined effect of significant factors such as restraint system, age, vehicle type, crash severity and countermeasures such as airbags and ESC on the injury outcomes. In addition, understanding which constellation of factors result in injuries to which specific body regions is of interest to further injury mitigation.

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APPENDIX A

Table A1: Distribution by Airbag Type and Deployment

Bottom Instrument Panel				
Bottom Instrument Panel	**Unweighted Occupants**	**Weighted Occupants**	**Weighted Percent (%)**	**SE of %**
Available - Not Deployed	1	1,266	0.2	0.2
Available - Deployed, Unknown Event	2	63.814	0.0	0.0
Not Available/Unknown If Available	1442	490,661	95.2	1.7
Detailed Air Bag Information Not Available	115	23,479	4.6	1.5
Door Panel				
Door Panel	**Unweighted Occupants**	**Weighted Occupants**	**Weighted Percent (%)**	**SE of %**
Available - Not Deployed	3	451.465	0.1	0.1
Available - Deployed After Rollover	2	208.95	0.0	0.0
Not Available/Unknown If Available	1440	491,330	95.3	1.6
Detailed Air Bag Information Not Available	115	23,479	4.6	1.5
Mid - Instrument Panel				
Mid - Instrument Panel	**Unweighted Occupants**	**Weighted Occupants**	**Weighted Percent (%)**	**SE of %**
Available - Not Deployed	138	53,574	10.4	2.6
Available - Deployed During Rollover	3	661.334	0.1	0.1
Available - Deployed Prior To Rollover	20	2,009	0.4	0.1
Available - Deployed, Unknown Event	8	413.248	0.1	0.0
Not Available/Unknown If Available	1276	435,334	84.5	3.6
Detailed Air Bag Information Not Available	115	23,479	4.6	1.5
Roof Side Rail				
Roof Side Rail	**Unweighted Occupants**	**Weighted Occupants**	**Weighted Percent (%)**	**SE of %**
Available - Not Deployed	50	12,060	2.3	0.9
Available - Deployed After Rollover	3	276.862	0.1	0.1
Available - Deployed During Rollover	37	6,134	1.2	0.4
Available - Deployed Prior To Rollover	7	749.802	0.1	0.1
Available - Deployed, Unknown Event	9	1,055	0.2	0.1
Not Available/Unknown If Available	1339	471,715	91.5	2.7
Detailed Air Bag Information Not Available	115	23,479	4.6	1.5
Seat Back				
Seat Back	**Unweighted Occupants**	**Weighted Occupants**	**Weighted Percent (%)**	**SE of %**
Available - Not Deployed	110	23,569	4.6	1.2
Available - Deployed After Rollover	2	87.703	0.0	0.0
Available - Deployed During Rollover	4	1,109	0.2	0.1
Available - Deployed Prior To Rollover	7	799.597	0.2	0.1
Available - Deployed, Unknown Event	16	2,648	0.5	0.4
Not Available/Unknown If Available	1306	46,3777	90.0	2.9
Detailed Air Bag Information Not Available	115	23,479	4.6	1.5

Steering Wheel Hub				
Steering Wheel Hub	**Unweighted Occupants**	**Weighted Occupants**	**Weighted Percent (%)**	**SE of %**
Available - Not Deployed	314	183,149	35.5	8.0
Available - Deployed After Rollover	4	321.216	0.1	0.0
Available - Deployed During Rollover	11	921.9844	0.2	0.1
Available - Deployed Prior To Rollover	84	21,176	4.1	1.9
Available - Deployed, Unknown Event	29	5,386	1.0	0.3
Not Available/Unknown If Available	1003	28,1035	54.5	5.2
Detailed Air Bag Information Not Available	115	23,479	4.6	1.5
Top Instrument Panel				
Top Instrument Panel	**Unweighted Occupants**	**Weighted Occupants**	**Weighted Percent (%)**	**SE of %**
Available - Not Deployed	102	24,793	4.8	1.7
Available - Deployed After Rollover	3	332.441	0.1	0.1
Available - Deployed During Rollover	3	183.868	0.0	0.0
Available - Deployed Prior To Rollover	34	5,498	1.1	0.4
Available - Deployed, Unknown Event	14	1,427	0.3	0.1
Not Available/Unknown If Available	1289	459,756	89.2	3.6
Detailed Air Bag Information Not Available	115	23,479	4.6	1.5
Any Air Bags Deployed				
Any Air Bags Deployed	**Unweighted Occupants**	**Weighted Occupants**	**Weighted Percent (%)**	**SE of %**
Available - Non Deployed	550	262,527	50.93	4.59
Deployed as a Result of Rollover	57	8,922	1.73	0.42
Deployed, Other Event	216	39,241	7.61	3.08
Not Available/Unknown if Available	737	204,780	39.73	2.55