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ORIGINAL RESEARCH

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Isolated vehicle rollover is not an independent predictor of trauma injury severity

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Objectives: The objective of this study was to determine if vehicle rollover in a motor vehicle crash is an independent predictor of major injury.

Methods: A retrospective cohort study of all patients injured in motor vehicle crashes presenting to a major trauma center between July 2012 and June 2016 was conducted. Crashes were classified into groups: non-rollover, isolated rollover (without other mechanisms of injury), or mixed-mechanism rollover (with other mechanisms of injury). Associations between rollover group, other covariates (entrapment, encapsulation, ejection, death on scene, high speed, seat belt usage, airbag deployment, trauma team activation), and major injury (injury severity score >15, major surgery, intensive care unit admission, or in-hospital death) were tested using binary logistic regression models. Vehicle rollover was categorized either as "present" or "absent" on 1 model or as either "none," "isolated," or "mixed mechanism" in the other.

Results: In 2446 motor vehicle crashes, there were 423 rollovers (196 isolated, 227 mixed mechanisms). Compared with crashes without rollovers, the prevalence of patients with major injury was lower in crashes with isolated rollovers and higher in crashes with mixed-mechanism rollovers (13.8% vs 9.5% vs 27.5%, respectively; $P < 0.001$). Rollover (present vs absent) was not an independent predictor of major injury (odds ratio [OR], 1.10; 95% confidence interval [CI], 0.78–1.53). Patients in crashes with mixed-mechanism but not isolated rollovers had increased odds (OR, 2.04; 95% CI, 1.41–2.96) of major injury compared with patients from crashes without rollovers.

Conclusions: Patients from crashes with isolated vehicle rollovers may not need to be transported to a trauma center as they carry a lower risk of injury.

KEYWORDS

crash mechanism, major injury, major trauma, mechanism of injury, motor vehicle accidents, prehospital care, road traffic crashes, rollover crashes, trauma team activation, trauma triage

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1 | INTRODUCTION

1.1 | Background

The field triage of the injured patient consists of the following 4 sequential assessments: (1) physiological criteria, (2) anatomical criteria, (3) mechanism of injury, and (4) special considerations (eg, pregnancy).[1] Vehicle rollover in motor vehicle crashes was removed as a mechanism of injury criteria in a 2006 review of the Field Triage Scheme by the US National Expert Panel on Field Triage.[2] The increased injury severity associated with vehicle rollover[3,4] was believed to result from an occupant being ejected either partially or completely from the vehicle.[5]

1.2 | Importance

Worldwide, the inclusion of specific mechanisms of injury, such as vehicle rollover in trauma triage guidelines is controversial.[6–10] There is disagreement about trauma center destination, that is, transport first to a local emergency department (ED) or directly to a level 1 trauma center based on specific injury mechanisms.[11,12] Vehicle rollover continues to be considered when making such field triage decisions.[13] Moreover, rollover also is used as a second-tier mechanism of injury triage criterion for trauma team activation in many EDs when first-tier criteria such as physiological and anatomical criteria are not met.[14] The use of rollover as a triage criterion necessitates re-examination. Clinical evidence for the safe removal of isolated rollover as a trauma triage criterion may lead to more efficient service planning and use of health system resources.

Crashes categorized as "isolated," pure or primary vehicle rollover,[15,16] do not involve planar impact, that is, a collision with another vehicle or object, nor do they involve intrusion into the passenger compartment or ejection from the vehicle. These types of rollover crashes are less likely to lead to severe injury or fatality compared with rollover crashes that involve some element of planar impact.[15]

1.3 | Goals of this investigation

The objective of this study was to determine if vehicle rollover is an independent predictor of major injury in a motor vehicle crash. The null hypothesis is that major injury is unrelated to whether a vehicle rolled over. The specific aims were the following: (1) to determine if vehicle rollover is an independent predictor of major injury and (2) to determine if the nature of the vehicle rollover, that is, whether it occurred in isolation or with other crash mechanisms, such as planar impact, ejection, and entrapment, is predictive of major injury.

The Bottom Line

It takes a lot of energy to make a car rollover in a crash, but that energy does not necessarily result in injury of the occupants. In this study of 423 rollover crashes, <10% of patients had major injury if rollover was an isolated event with no ejection of the patient and no occupant compartment damage. As dramatic as a rollover crash is, assess your scene, the car, and your patient before making assumptions.

2 | METHODS

2.1 | Study design and setting

An observational study was undertaken using a retrospective cohort design. The study was conducted at the Royal Brisbane and Women's Hospital ED, which is 1 of 2 level 1 trauma centers in the city of Brisbane, Australia. Greater Brisbane is about 15,800 square kilometers (6100 square miles) with 2.4 million inhabitants and includes 5 other level 2 or 3 trauma centers. The ED, which has an annual census of about 90,000 patients, accepts trauma referrals from rural and remote areas outside the city. These patients typically arrive by aeromedical (helicopter and fixed wing) transport after stabilization in a local hospital. Primary response at crash sites is provided solely by Queensland ambulance, a government emergency medical service (EMS), with usually 1 critical care and 1 to 2 junior paramedics.

The Royal Brisbane and Women's Hospital Human Research Ethics Committee approved the study. The Strengthening the Reporting of Observational Studies in Epidemiology statement and checklist were followed.

2.2 | Selection of participants

Participants were included in the study if they were >15 years of age, occupants of a motor vehicle involved in a crash, and presented to the ED between July 2012 and June 2016. Participants were identified, and data sourced from, the hospital trauma registry, which records the mechanism of injury including whether a patient was involved in a motor vehicle crash. The registry includes both prehospital and in-hospital data about all patients brought to the ED, whether directly or indirectly via another hospital.

2.3 | Outcomes

The primary outcome was major injury, defined as either an injury severity score (ISS) >15 or major surgery (intracranial, thoracic, abdominal, pelvic, or spinal) on the day of the crash or the following day, intensive care unit (ICU) admission, or in-hospital death. This composite measure of "major injury" is similar to that used by other investigators.[17,18] The ISS was missing in 1.6% of participants, thus "major injury" was coded as missing in the absence of another component of the composite measure. Major surgery and ICU admission were coded as absent if they were not documented to have occurred in the trauma registry data set. Hospital discharge data (died or survived) were complete for all patients.

2.4 | Measurements

The following 5 predictor variables were obtained directly from the trauma registry data set: rollover, speed, entrapment, encapsulation, and death on scene. Vehicle rollover was defined as a vehicle overturned by at least 1 quarter turn, that is, on its side.[11] The presence of a rollover was determined by the prehospital paramedic staff, documented in their case reports, and recorded in the trauma registry. Speed at the time of crash was estimated and documented by the paramedics in kilometers per hour or described using words. For the study, "high speed" was defined as >60 kilometers (37 miles) per hour[14] or if described as "high speed" in the paramedics' notes. Entrapment was defined as being trapped by a part of the vehicle that is pressing on some part of the body. The vehicle would have to be cut apart to free the victim. Encapsulation was defined as not being able to get out of the vehicle because the doors or windows were stuck and had to be opened by rescuers to free the victim (prolonged extrication). Death on scene was defined as the death of another person in the same crash but not necessarily in the same vehicle. All variables were observable except for speed, which was estimated by the paramedics. They were considered present if documented and absent if not documented in the trauma registry data set.

On review of the information from the trauma registry data set, the investigators created 2 additional variables: planar impact and a qualified vehicle rollover. Planar impact was defined as a frontal, side, rear, or roof impact with another vehicle or a fixed/non-fixed object before, during, or after the rollover.[15] Planar impact was not directly reported by the paramedic but were indirectly determined by 2 authors upon review of the accident details recorded as free text in the registry data set. Key words indicative of a planar impact included the following: hit, head-on, T-bone, rear-end, collision, clip, nudge, swipe, into tree/pole, and through fence/barrier. Only vehicle rollovers were reviewed for the presence of planar impact. Non-rollover crashes were assumed to involve a planar impact because a motor vehicle crash can only occur if there was a planar impact, that is, a collision. The qualified vehicle rollover was categorized as non-rollover, isolated rollover, and mixed-mechanism rollover. Isolated rollover was defined as a rollover without planar impact, ejection, entrapment, and encapsulation. A mixed-mechanism rollover was defined as a rollover with either planar impact, ejection, entrapment, or encapsulation.

A final predictor was examined, namely, ED trauma team activation categorized as the following: (1) trauma respond, (2) trauma alert, or (3) none (Appendix I, online supplement). A "trauma respond" was activated by the ED triage nurse upon EMS notification of an incoming unstable patient who needs definitive airway management, has physiological derangement (oxygen saturation <90%, respiratory rate >30 breaths per minute, heart rate >130 or <50 beats per minute, systolic blood pressure <100 mmHg, or Glasgow Coma Scale [GCS] score ≤9), or has penetrating trauma to the neck, chest, abdomen, or pelvis. In a "trauma respond," ED, radiology, trauma-surgical services, operating theater, and blood bank staff are notified via the pager system. A multidisciplinary team is required to be present to receive the patient in the ED. A "trauma alert" is activated by the ED triage nurse if the patient is stable but has met specific mechanism of injury criteria including rollover or specific anatomical patterns of injury criteria such as open long bone fractures. In a "trauma alert," only ED staff is required to be present to receive the patient in the first instance. Trauma team activation data were complete and used as a surrogate for prehospital vital signs, which was missing in up to 11% of cases.

2.5 | Analysis

Planar impact was determined independently by 2 authors (S.M., K.C.) unblinded to the study objective. Its interrater reliability was assessed using the κ statistic. Trauma team activation was dichotomized as either "trauma respond" or "not trauma respond" for analysis. Outcomes were compared between groups using the χ^2 test.

In a univariate analysis, associations between major injury and its predictors were measured using unadjusted odds ratios (ORs). For the multivariable analyses, the relationship between the major injury with rollover (2-level factor variable: rollover and non-rollover) was sought after adjusting for covariates (speed of the vehicle, seat belt usage, airbag deployment, ejection from vehicle" entrapment and encapsulation within the vehicle, and death on scene) using a binary logistic regression model. In a second model, the relationship between major injury and a qualified rollover (3-level factor variable: non-rollover, isolated rollover, and mixed-mechanism rollover) was determined. The difference between the full model (with rollover as a covariate) and a nested model (without rollover) was assessed using the log likelihood χ^2 test. The goodness of fit was assessed using the Hosmer-Lemeshow test. Multicollinearity was assessed using the variance inflation factor. Interaction terms were explored. Statistical analysis was performed using Stata 15.1 (StataCorp, College Station, TX).

There were 2446 cases for the study's 9 predictor variables. The observation-to-predictor ratio thus exceeded the suggested 10 to 1 minimum ratio and 100 minimum number of cases.[19,20]

3 | RESULTS

3.1 | Characteristics of study participants

In 2446 motor vehicle crashes, there were 423 (17%) rollovers (Figure 1). Participants in crashes with rollovers were younger and

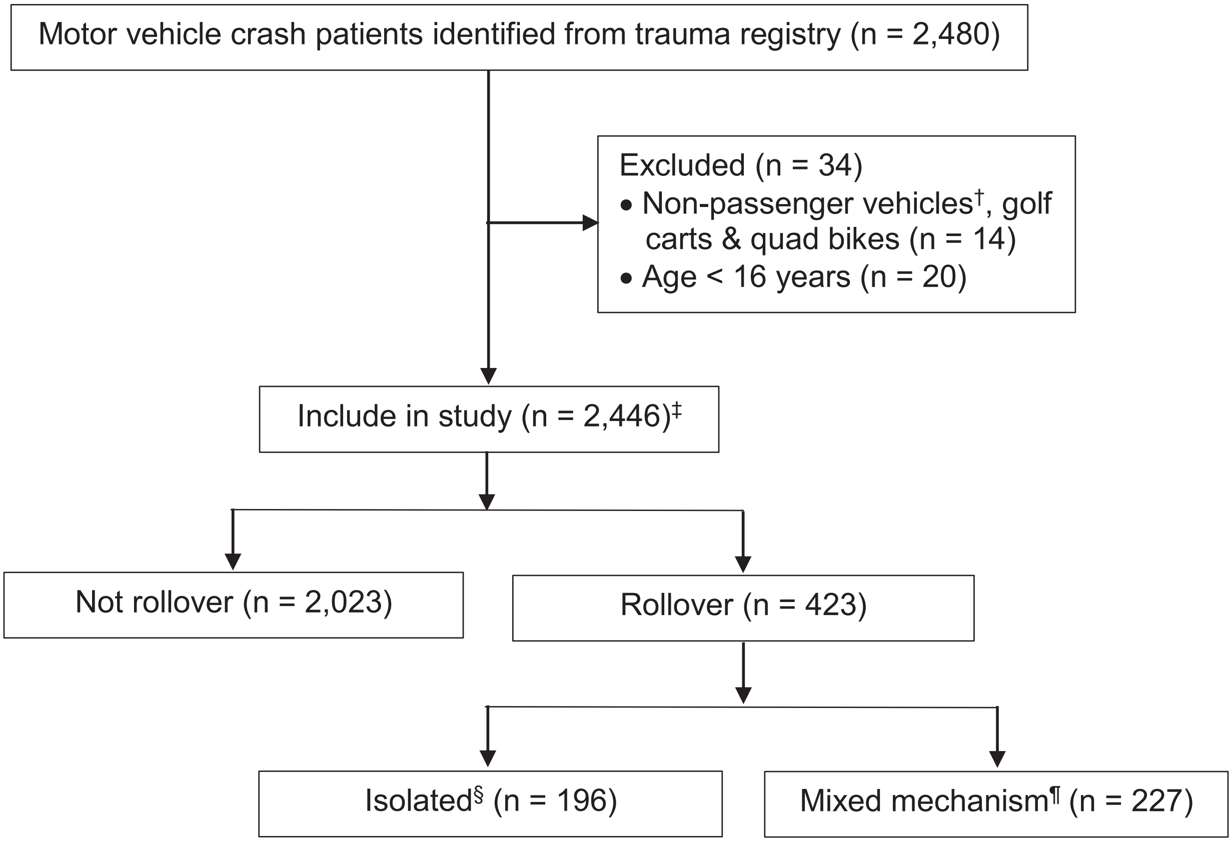

FIGURE 1 Study sample. †Non-passenger vehicles included tractors, evacuators, and ride-on lawn mowers. ‡Included 7 (0.3%) patients who presented twice in separate crashes on separate days. §Rollover without planar impact, ejection, entrapment, or encapsulation. ¶Rollover with planar impact, ejection, entrapment, or encapsulation

more likely to be males compared with other participants (Table 1). The proportion of participants with any abnormal prehospital vital signs was similar in the rollover and non-rollover groups. ED "trauma respond" was activated in about 1 in 20 cases in both groups. There was a greater proportion of patients with major injury in the mixed-mechanism rollover group compared with the non-rollover and isolated rollover groups (27.5% vs 13.8% vs 9.5%, respectively; $P < 0.001$; Table 2). There appeared to be a lesser proportion of major injury in the isolated rollover compared with the non-rollover group.

3.2 | Main results

In the univariate analysis, major injury was associated with rollover, high speed, not wearing seat belt, no airbag deployment, ejection, entrapment, encapsulation, death on scene, and ED "trauma respond" activation (Table 3). In the multivariable model with a 2-factor rollover variable (rollover, non-rollover), rollover was not a statistically significant predictor of major injury (OR, 1.10; 95% confidence interval [CI], 0.78–1.53) after adjusting for other predictors, which all remained statistically significant (Table 4). Activation of an ED "trauma respond" had the strongest association with major injury (OR, 22.0; 95% CI, 12.7–38.2).

The percentage agreement between the 2 authors for coding planar impact was 85% with a κ statistic of 0.69. Examples of disagreement included whether "into a ditch" and "hit the curb" constituted a planar impact. Disagreement was resolved by consensus resulting in 167 (39%) and 256 (61%) planar and non-planar impacts, respectively. The absence of planar impact, ejection, entrapment, and encapsulation defines an isolated rollover. Conversely, the presence of any 1 of the aforementioned characteristics defines a mixed-mechanism rollover. The categorization of a qualified rollover resulted in 196 (46%) and 227 (54%) isolated and mixed mechanisms, respectively, in the rollover group.

In the multivariable model with a 3-factor rollover variable (non-rollover, isolated rollover, mixed-mechanism rollover) and non-rollover as the reference group, isolated rollover appeared less likely to be associated with major injury compared with non-rollover (OR, 0.58; 95% CI, 0.33–1.01; Table 5). In contrast, mixed-mechanism rollover was twice as likely to be associated with major injury compared with non-rollover (OR, 2.04; 95% CI, 1.41–2.96; Table 5). When reparameterized with isolated rollover as the reference group, mixed-mechanism rollover was 3.5 times more likely to be associated with major injury compared with isolated rollover (OR, 3.52; 95% CI, 1.87–6.60; Table 5).

The preceding 2 models represent different ways to examine the same data. The difference between the 2 models is the categorization

TABLE 1 Demographics, prehospital vital signs, and emergency department trauma team activation in 2446 patients from motor vehicle crashes between 2012 and 2016, classified by whether the crash involved a vehicle rollover

		Vehicle rollover		
	Total, N = 2446	Isolated or mixed mechanism, N = 423	None, N = 2023	P[a]
Demographics				
Age, median (IQR), year	34 (24–53)	28 (21–44)	36 (24–54)	<0.001
Male, n (%)	1277 (52.2)	266 (62.9)	1011 (50.0)	<0.001
Prehospital vital signs, n (%)				
Respiration >30 per minute	51 (2.3)	13 (3.4)	38 (2.1)	0.142
Heart rate >130 or <50 per minute	89 (4.0)	17 (4.2)	72 (3.9)	0.776
Systolic BP <100 mmHg	121 (5.5)	19 (4.8)	102 (5.6)	0.505
GCS score ≤9	79 (3.4)	18 (4.4)	61 (3.2)	0.232
Composite vital signs, n (%)				
Any abnormal vital sign (R, HR, SBP, GCS)	277 (12.8)	52 (13.4)	225 (12.6)	0.670
ED trauma team activation, n (%)				0.053
Trauma respond	115 (4.7)	21 (5.0)	94 (4.7)	
Trauma alert	2057 (84.1)	348 (82.3)	1709 (84.5)	
None	274 (11.2)	54 (12.8)	220 (10.9)	

Isolated = motor vehicle crash with rollover but no planar impact, ejection, entrapment, or encapsulation. Mixed mechanism = motor vehicle crash with rollover and 1 or >1 of the following: planar impact, ejection, entrapment, and encapsulation. None = motor vehicle crash without a rollover. Percentages shown differ from the percentages of column totals (n/N) because of missing data. BP, blood pressure; ED, emergency department; GCS, Glasgow Coma Scale; IQR, interquartile range.

[a]Chi-square test for comparison between vehicle rollover groups.

TABLE 2 Outcomes for 2446 patients from motor vehicle crashes between 2012 and 2016, classified by whether vehicle rollover occurred in isolation to other crash mechanisms, in combination with other crash mechanisms, or not at all

	Vehicle rollover			
Outcome	Isolated, N = 196; n (%)	Mixed mechanism, N = 227; n (%)	None, N = 2023; n (%)	P[a]
ISS >15[b]	16 (8.4)	48 (21.6)	209 (10.5)	<0.001
Major surgery	4 (2.0)	24 (10.6)	69 (3.4)	<0.001
ICU admission	13 (6.6)	43 (18.9)	182 (9.0)	<0.001
Death in hospital	2 (1.0)	3 (1.3)	25 (1.2)	0.957
Major injury[c]	18 (9.5)	61 (27.5)	274 (13.8)	<0.001

Isolated = motor vehicle crash with rollover but no planar impact, ejection, entrapment, or encapsulation. Mixed mechanism = motor vehicle crash with rollover and 1 or >1 of the following: planar impact, ejection, entrapment, or encapsulation. None = motor vehicle crash without a rollover. ISS, injury severity score.

[a]Chi-square test for comparison between groups.

[b]ISS was missing in 50 (2%) patients: 6 patients with isolated rollovers, 5 patients with mixed-mechanism rollovers, and 39 patients without rollovers. Percentages shown differ from the percentages of column totals (n/N) because of missing data.

[c]Patients were classified with major injury if they had ISS >15 (n = 273) or had ISS ≤15 and at least 1 other major outcome (n = 79) or had a missing ISS and at least 1 other major outcome (n = 1). Where ISS was missing, and there were no other major outcomes, "major injury" was also indicated as missing. This occurred in 49 (2%) patients: 6 patients with isolated rollovers, 5 patients with mixed-mechanism rollovers, and 38 patients without rollovers.

of rollover as isolated and mixed mechanism in the model with a 3-factor rollover variable. There was no significant multicollinearity between the predictor variables (variance inflation factors <2). There were no significant interactions between speed and seat belt usage and between speed and airbag deployment.

4 | LIMITATIONS

The study is affected by potential selection bias. Study participants were limited to those arriving to 1 major trauma center. Any patients in motor vehicle crashes with rollovers who were treated at a local

TABLE 3 Univariate associations between covariates and major injury

Covariate	Proportion with major injury (%)	Unadjusted OR (95% CI)	*P*
Rollover			
Yes	79/412 (19.2)	1.48 (1.11–1.97)	0.005
No	274/1985 (13.8)	1 (Reference)	
Entrapped			
Yes	77/129 (59.7)	10.7 (7.24–515.8)	<0.001
No	276/2268 (12.2)	1 (Reference)	
Death on scene			
Yes	27/54 (50.0)	6.19 (3.44–11.1)	<0.001
No	326/2343 (13.9)	1 (Reference)	
Ejected			
Yes	36/81 (44.4)	5.04 (3.11–8.13)	<0.001
No	317/2316 (13.7)	1 (Reference)	
Encapsulated			
Yes	63/175 (36.0)	3.75 (2.64–5.28)	<0.001
No	290/2222 (13.1)	1 (Reference)	
High speed (>60 kph[a])			
Yes	108/346 (31.2)	3.35 (2.54–4.38)	<0.001
No	245/2051 (12.0)	1 (Reference)	
Seat belt			
Not worn	45/131 (34.4)	3.33 (2.22–4.93)	<0.001
Worn	308/2266 (13.6)	1 (Reference)	
Airbag not deployed			
Not deployed	276/1560 (17.7)	2.12 (1.61–2.82)	<0.001
Deployed	77/837 (9.2)	1 (Reference)	
ED trauma team activation			
Trauma respond	95/114 (83.3)	39.2 (23.3–69.0)	<0.001
Trauma alert or none	258/2283 (11.3)	1 (Reference)	

CI, confidence interval; ED, emergency department; OR, odds ratio.
[a] >60 kilometers (37 miles) per hour or described as "high speed" in paramedic notes.

hospital but not transferred to the trauma center were not included in the study. Such patients may have died at the scene or not sustained any injuries and their omission in this analysis may bias the results.

Classification bias also was possible because the determination of planar impact and the classification of rollovers relied on the authors' subjective interpretation of paramedic case reports. Planar impact was only determined for rollovers and assumed to have occurred, that is, there was a collision, in non-rollover crashes. There is also a degree of subjectivity in the paramedic case reports themselves, particularly around the determination of high speed and the recognition of ejection, entrapment, and encapsulation. Furthermore, the classification of seat belt use can be subjected to bias reporting by the vehicle occupants to evade regulatory or legal penalties for not wearing safety restraints. There were no public safety records to cross-check these data.

Missing data may have also biased the results. For example, approximately 11% of patients had no documented prehospital vital signs. We used the ED "trauma respond" activation as a surrogate for abnormal prehospital physiology and anatomy because it was consistently documented in the trauma registry data set. "Trauma respond" was by far the strongest predictor of major injury in our regression model. Some investigators do not include vital signs in their models when examining the association between major injury and mechanisms of injury.[18] Compared with these models, the inclusion of "trauma respond" in our models would reduce the strength of the association between major injury with rollover and other covariates. This should not be an issue, however, because clinicians usually consider abnormal physiology and anatomy first before reviewing crash mechanisms.[5]

We used our locally documented "death on scene" rather than the more commonly reported "death in same vehicle" as a covariate. This could lead to confounding if, for example, the death was of a pedestrian or cyclist struck by the vehicle, which sustained little damage and

TABLE 4 Multivariable logistic regression showing adjusted odds ratios for covariates predicting major injury (vehicle rollover classified as either present or absent)

Predictor	Adjusted OR	95% CI	*P*
Rollover versus none	1.10	0.78–1.53	0.589
Entrapment versus none	6.89	4.38–10.85	<0.001
Encapsulation versus none	3.53	2.35–5.31	<0.001
Ejection from vehicle versus none	3.47	1.95–6.17	<0.001
Death on scene versus none	3.05	1.54–6.04	0.001
High speed versus not high speed[c]	2.34	1.69–3.23	<0.001
Seat belt not worn versus worn	2.29	1.42–3.70	0.001
Airbag not deployed versus deployed	1.93	1.41–2.65	<0.001
Trauma respond versus not trauma respond	22.0	12.70–38.24	<0.001
Test			
Goodness of fit			
Hosmer-Lemeshow test χ^2 (9) test			$P = 0.276$[a]
Full model versus nested model without rollover			
Likelihood ratio χ^2 test			$P = 0.590$[b]

CI, confidence interval; OR, odds ratio.
[a]The Hosmer-Lemeshow statistic tests the null hypothesis that the predicted frequency from the model and observed frequency are no different. With a non-significant *P* value (>0.05) the null hypothesis is not rejected.
[b]The Likelihood ratio chi-square statistic tests the hypothesis that the nested model without rollover is not different from the full model with rollover. With a non-significant *P* value (>0.05) the null hypothesis is not rejected.
[c]High speed is defined as >60 kilometers (37 miles) per hour.

TABLE 5 Multivariable logistic regression showing adjusted odds ratios for covariates predicting major injury (vehicle rollover classified as either "none," "isolated," or "mixed mechanism")

Predictor	OR	95% CI	*P*	OR	95% CI	*P*
Rollover						
None	1			1.72	0.99–3.00	0.055
Isolated[a]	0.58	0.33–1.01	0.055	1		
Mixed mechanism[b]	2.04	1.41–2.96	<0.001	3.52	1.87–6.60	<0.001
Death on scene versus none	3.72	1.94–7.16	<0.001			
Seat belt not worn versus worn	2.84	1.84–4.38	<0.001			
High speed versus not high speed[c]	2.54	1.86–3.47	<0.001			
Airbag not deployed versus deployed	1.87	1.38–2.54	<0.001			
Trauma respond versus trauma alert or none	32.9	18.4–55.8	<0.001			
Test						
Goodness of fit						
Hosmer-Lemeshow test χ^2 (9) test					$P = 0.855$[d]	

CI, confidence interval; OR, odds ratio.
[a]Rollover without planar impact, ejection, entrapment, or encapsulation.
[b]Rollover with planar impact/ejection/entrapment/encapsulation.
[c]High speed is defined as >60 kilometers (37 miles) per hour.
[d]The Hosmer-Lemeshow statistic tests the null hypothesis that the predicted frequency from the model and observed frequency are no different. With a non-significant *P* value (>0.05) the null hypothesis is not rejected.

its occupants were uninjured. However, the percentage of death on scene was (2%), and its odds for major injury when compared with no deaths remained high (3.7) relative to other covariates. Death on scene is classed as a high-risk predictor for major injury by the US National Expert Panel on Field Triage.[5]

The associations between motor vehicle crash characteristics and major injury are complex. The covariates (predictors) included in this study are not mutually exclusive. The causal pathway from rollover to major injury might be interposed by planar impact, ejection, and other covariates, which act as mediators rather than confounders of the association between rollover and major injury. The inclusion mediators in the model may overadjust the model so the unconfounded association between rollover and major injury is not made evident.[21]

The lack of collinearity between predictors was surprising. The statistical methods may not have been able to portray and separate the interrelationships between the variables. The number of patients in the same vehicle was unable to be determined from the trauma registry data set. This could have threatened the independence of the observations in the regression models. The study was conducted in a single center with a sole EMS agency, which may limit its external validity. A strength of our study is that we not only compared rollover with and without planar impact as in the study by Bose et al[15] but also compared non-rollovers with isolated and mixed-mechanism rollovers.

5 | DISCUSSION

When considered as a whole, vehicle rollover does not appear to be a useful predictor of major injury. Rollover is associated with but is not an independent predictor of major injury. Rollovers appear to be 2 distinct entities: isolated and mixed mechanism. The odds of major injury were lower for isolated rollovers than for non-rollovers, although this finding was not statistically significant. The odds were certainly not greater. In an isolated rollover, there is no planar impact or collision, no ejection, and no entrapment or encapsulation by definition. In a crash without rollover, planar impact is typical, whereas ejection, entrapment, and encapsulation are all possible. When comparing isolated rollover with non-rollover, the smaller odds for major injury is plausibly because there was no collision and no ejection despite the rollover.

The odds of major injury are 3.5 times greater for mixed-mechanism rollovers than for isolated rollovers. In a mixed-mechanism rollover, there is a planar impact, ejection, entrapment, or encapsulation unlike an isolated rollover. When comparing mixed-mechanism rollover with isolated rollover, the larger odds for major injury is conceivably related to the collision or ejection. This finding is consistent with that reported by Bose et al.[15] In their comparison of rollover with and without planar impact, the former was more likely to result in occupant fatality and major injuries.

Planar impact can result in intrusion, which is a more commonly described indicator of major injury. Intrusion can be measured more precisely than planar impact. The US National Expert Panel on Field Triage quantified the extent of intrusion (>12 inches occupant site, >18 inches any site) and included roof intrusion for high-risk automobile crashes.

Intrusion was considered as a surrogate for extrication time, which is poorly standardized in the literature.[5] Stuke et al reported an extrication time >20 minutes as a predictor of major injury while intrusion was not in their multivariable model.[18] Planar impact, intrusion, and extrication time are undoubtedly related. We used entrapment and encapsulation rather than intrusion because that is that is what is used in our EMS. We also used "death on scene" rather than "death in same vehicle" as a predictor because that is what is reported locally.

Although it is common for major injury to be clinically defined as ISS >15, in research, definitions that include ISS plus 1 or more other factors are often used.[17,18,22,23] Such factors may include the need for blood transfusion, surgery within 24 hours, t2 or more proximal long bone fractures, and ICU admission of more than 24 hours or requiring ventilation.[17,18,22,23] However, there is no standardized definition of "major injury." Our definition included ISS >15, major surgery on the day of or day following the crash, ICU admission, and in-hospital death. Despite variations in the definition, our findings are consistent with the literature that show vehicle rollover to be associated with but not an independent predictor of major injury.[12,17,18,22,23]

The US National Expert Panel on Field Triage removed rollover from their 2006 guidelines, which was reaffirmed in the 2011 update.[5] Rollover as a standalone criterion was considered insufficient to meet their requirement of a 20% positive predictive value for ISS >15. Champion et al questioned the removal of rollover as a field triage criterion in the 2006 guidelines because rollover is a simple indicator with a strong association with injury severity and death.[11] On the contrary, Haan et al found that patients involved in rollovers could be safely evaluated and treated at non-trauma centers or referred later.[12] Other investigators have reported that rollover is not an independent predictor of the need for trauma center care or major injury.[17,18,23]

In a recent US study examining factors that predict high injury severity, Leichtle et al reported that only high speed (>55 miles per hour) and abnormal shock index (heart rate/systolic blood pressure >0.9) were independent predictors of ISS >15.[22] Other commonly reported crash characteristics were not. Their study included vital signs and GCS in their multivariable model. Other authors excluded patients who had abnormal vital signs and thus met the US National Expert Panel on Field Triage step 1 (physiological) criteria.[17,18,24] We used activation of an ED "trauma respond" as the surrogate for abnormal vital signs because that was more consistently documented than prehospital vital signs. In contrast to Attia et al, we used a composite outcome rather than ISS alone and found that the mechanism of the crash can be predictive of major injury, although rollover is not. The predictor variables are undoubtedly interrelated. Future research could use directed acyclic graphs to identify out which variables should be modeled.[21]

The inclusion of rollover in prehospital trauma triage guidelines is controversial. In systems that use rollover (both isolated and mixed mechanism) as a criterion for local hospital bypass and transport to a level 1 trauma center, the removal of isolated rollover as a triage criterion has the potential to reduce over triage rates. Questions remain, however, as to whether isolated rollover can be easily determined by emergency care workers. Furthermore, does the identification of mixed-mechanism rollovers in the triage scheme add to the sensitivity for identifying major injury when ejection and entrapment are already included in the scheme? The answers await further research.

Besides prehospital triage, the use of vehicle rollover as a mechanism of major injury has implications for the provision of ED resources. Trauma team activation may not be needed for patients from isolated rollover crashes if other mechanisms of injury criteria have not been met.[25] The activation may unnecessarily divert trauma, surgical, radiological, and blood bank services to patients at low risk of major injuries.

Vehicle rollover is a dramatic and unmistakable crash characteristic, but not all rollovers are equal. Patients from isolated rollover crashes without other mechanisms of injury may not need to be transported to a trauma center as they carry a lower risk of injury.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Sunayana Moriarty conceived the study, obtained ethics and governance approvals, and acquired the data. Nathan Brown contributed to the study design. Michael Waller supervised the data analysis. Kevin Chu analyzed the data and drafted the manuscript. All authors contributed to the interpretation of the results and revision of the draft and approved the final manuscript.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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