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New cars on the highways: Trends in injuries and outcomes following ejection

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ABSTRACT

Background: Although ejections from motor vehicles are considered a marker of a significant mechanism and a predictor of severe injuries and mortality, scant recent data exist to validate these outcomes. This study investigates whether ejections increase the mortality risk following a motor vehicle crash using data that reflect the introduction of new vehicles to the streets of a large city in the United States.
Methods: The Trauma and Emergency Medicine Information System of Los Angeles County was queried for patients ≥16 years old admitted following a motor vehicle crash between 2002 and 2012. Ejected patients were compared to nonejected. Primary outcome was mortality. A logistic regression model was used to identify predictors of mortality and severe trauma.
Results: A total of 9,742 (6.8%) met inclusion criteria. Of these, 449 (4.6%) were ejected; 368 (82.0%) were passengers and 81 (18.0%) were drivers. The rate of ejection decreased linearly (6.1% in 2002 to 3.4% in 2012). Compared to nonejected patients, ejected patients were more likely to require intensive care unit admission (43.7% vs 22.1%, $P < .01$), have critical injuries (Injury Severity Score > 25) (24.2% vs 7.3%, $P < .01$), require emergent surgery (16.3% vs 8.0%, $P < .01$), and expire in the emergency department (3.6% vs 1.2%, $P < .01$). Overall mortality was 3.6%: 9.6% for ejected and 3.3% for nonejected patients ($P < .01$). In a logistic regression model, ejection and extrication both predicted mortality (adjusted odds ratio: 1.83, $P < .01$ and 1.87, $P < .01$, respectively). Ejection also predicted critical injuries (Injury Severity Score > 25) with adjusted odds ratio of 2.48 ($P < .01$).
Conclusion: Ejections following motor vehicle crash have decreased throughout the years; however, they remain a marker of critical injuries and predictive of mortality.

Introduction

Ejection of an occupant from a motor vehicle occurs in only a small percentage of all motor vehicle crashes (MVCs) in the United States; however, the mechanism of ejection is a marker of severe trauma and a predictor of increased mortality [[3–6]3-6, 8–10]. Data from over 25 years ago suggest that individuals ejected from the vehicle during an MVC are up to 8 times more likely to die compared to those who are not, with a mortality rate between 7% and 11% for those ejected during an MVC [11–13]. The higher mortality is related to the higher probability of severe injuries in ejected victims. Individuals who are ejected typically have a higher Injury Severity Score (ISS), have a higher risk for closed head injuries, are more likely to require admission to the intensive care unit (ICU), and have a longer hospital length of stay [11,14]. The risk for severe injuries is mostly related to ejected subjects often lacking restraints during their collision and/or being involved in a rollover crash, increasing their potential injury burden and the associated mortality [9].

The large-scale production of motor vehicles, in association with the advancement in technology over the last decade, characterized by ample availability of safety features in these vehicles, has resulted in easier and cheaper accessibility of safer vehicles for drivers and passengers [15,16]. Recent data evaluating ejection as a marker of severe trauma and outcomes are lacking, and current triage criteria for trauma centers are based on studies published more than a decade ago [17,18]. We therefore sought to investigate the incidence of ejection during MVCs that are brought to a trauma center in an urban setting using recent data and to evaluate the associated injury burden and outcomes. We also aimed to determine whether factors reported from the scene could predict mortality in those patients successfully transported to a hospital. We hypothesized that despite the wider availability of safety features in newer production vehicles, ejections continue to occur at a similar rate and continue to be a marker of severe trauma and increased mortality risk.

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Methods

Patient Selection. The Trauma and Emergency Medicine Information System was developed by the Department of Health Services of the Los Angeles County in 1984 to meet reporting, system management, monitoring, and evaluation requirements. A trauma registry portion of the system tracked the critically injured from dispatch of the 9-1-1 responding vehicle through discharge or death. Currently, 14 trauma centers from across the Los Angeles County contribute data to Trauma and Emergency Medicine Information System, including 4 Level I adult centers, 1 pediatric Level I center, and 9 level II trauma centers. This database was queried for all subjects involved in an MVC who were at least 16 years of age and were admitted to any of these trauma centers between January 1, 2002, to December 31, 2012. The selection of these subjects was based on the supplementary classification of external causes of injury and poisoning of the *International Classification of Diseases, Ninth Edition*, codes E810.*x* to E819.*x*. Demographics and clinical data, including admission systolic blood pressure (SBP) and Glasgow Coma Scale (GCS) score on admission, were abstracted. The location of these subjects within the vehicle (driver or passenger) during the crash was determined based on the E-code reported. Additionally, these E-codes provided other details regarding these incidents, including whether there was loss of control of the vehicle, whether it occurred on a highway, and the type of vehicle the collision occurred against. Injury characteristics, including ISS, were reviewed. Disposition from the emergency department and operative interventions including craniotomy, exploratory laparotomy, exploratory thoracotomy, upper or lower extremity amputations, spinal procedures, and vascular interventions were all included in the final database. The primary outcome was mortality, and secondary outcomes included ICU and hospital length of stay.

Statistical Analysis. Included subjects were classified into 2 groups based on whether they were ejected during the incident or not. The 2 groups were compared using standard statistical tools, including χ^2 or Fisher exact test for categorical variables and *t* test or Mann-Whitney test for continuous variables. Differences in primary and secondary outcomes between the 2 groups were obtained from logistic regression models incorporating all variables that were different between the 2 groups at a $P < .050$ level, providing adjusted odds ratio (AOR) and adjusted mean difference (AMD) with 95% confidence intervals (CIs) and adjusted *P* values. A bivariate analysis was then carried out to identify factors reported from the scene that could potentially be associated with mortality. A separate bivariate analysis was also performed to identify factors potentially associated with critical injuries, defined as ISS > 25. These factors included passenger space intrusion (PSI), need for extrication, ejection, the type of vehicle the collision occurred against, the location of the subject within the vehicle during the incident, and whether the incident occurred on a highway or small street. All factors that were different between survivors and casualties and between patients who had critical injuries and those who did not at a $P < .200$ were entered into 2 separate forward logistic regression models to identify independent predictors of mortality and of critical injuries, respectively. All analyses were performed using the IBM SPSS Statistics for Windows, Version 24.0 (IBM Corp, Armonk, NY). Given that the data used were deidentified, approval from the institutional review board was waived.

Results

Patient Characteristics. Over the 11-year study period, 9,742 subjects older than 16 years were admitted to trauma centers as occupants in a vehicle involved in an MVC. The median age was 28 years, and 46.4% were male, with a median ISS of 5. The trauma team was activated in 85.5% of these incidents. A total of 449 (4.6%) of the 9,742 subjects admitted to a trauma center were ejected from their vehicle during the incident. The proportion of ejected patients decreased progressively with time from 6.1% in 2002 to 3.4% in 2012 (Fig 1). When compared to nonejected patients, those who were ejected were significantly more likely to be younger (median age 23 vs 28, $P < .001$) and be male (55.2% vs 46.0%, $P < .001$) (Table 1). The trauma team was activated almost universally for those who were ejected (98.0% vs 84.9%, $P < .001$). In addition, compared to their nonejected counterparts, those who were ejected had a higher ISS (median 12 vs 5, $P < .001$), and were more likely to be admitted hypotensive with an SBP < 90 mm Hg (5.6% vs 2.7%, $P < .001$) and in a coma with a GCS ≤ 8 (18.6% vs 5.2%, $P < .001$) (Table 1). They were also more likely to require blood transfusion (10.7% vs 5.7%, $P < .001$), ICU admission (43.7% vs 22.1%, $P < .001$), and mechanical ventilation (9.6% vs 3.3%, $P < .001$) (Table 1).

The most common required interventions in the entire studied population were vascular procedures (4.2%), craniotomy/craniectomy (2.3%), and exploratory laparotomy (2.9%) (Table 2). In the ejected group, 7.8% required craniotomy/craniectomy compared to only 2.0% in the nonejected group ($P < .001$). Additionally, there was a significant difference between the groups in those requiring spine operations (2.9% ejected vs 1.5% not ejected, $P = .015$) and vascular interventions (6.5% ejected vs 4.1% nonejected, $P = .015$). No significant differences were

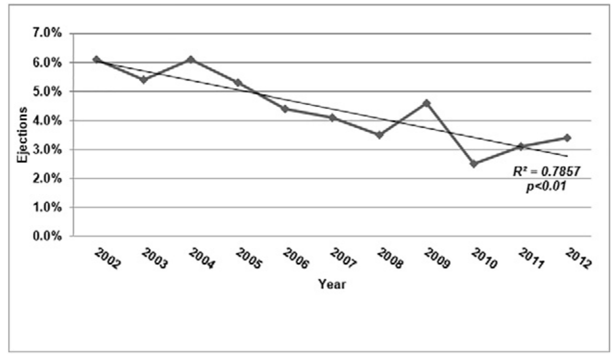

Fig 1. Ejection rate of victims involved in MVC: percent of motor vehicle collisions resulting in ejection of an occupant between 2002 and 2012. Line of best fit with corresponding R^2 of 0.7857.

Table 1
Comparison of basic demographics and clinical data between ejected and nonejected victims of motor vehicle collisions

	Ejected (*n* = 449)	Not ejected (*n* = 9293)	*P* value
Age (y) mean ± SD [median]	28.1 ± 12.9 [23.0]	35.0 ± 18.2 [28.0]	<.001
Age > 65 y	2.4% (11/449)	9.0% (836/9293)	<.001
Male	55.2% (248/449)	46.0% (4271/9293)	<.001
Trauma team activation	98.0% (434/443)	84.9% (7846/9238)	<.001
ISS mean ± SD [median]	16.7 ± 14.5 [12.0]	9.0 ± 10.2 [5.0]	<.001
ISS ≤ 16	56.4% (252/447)	82.2% (7524/9156)	<.001
ISS 17–25	19.5% (87/447)	10.5% (963/9156)	
ISS > 25	24.2% (108/447)	7.3% (669/9156)	
SBP < 90 mm Hg	5.6% (25/443)	2.7% (247/9219)	<.001
GCS ≤ 8	18.6% (82/442)	5.2% (472/9134)	<.001
ED disposition			
ICU	28.9% (128/443)	15.3% (1418/9247)	<.001
OR	16.3% (72/443)	8.0% (743/9247)	<.001
Morgue	3.6% (16/449)	1.2% (109/9290)	<.001
Home	17.2% (76/443)	30.8% (2846/9248)	<.001
Blood transfusion	10.7% (48/449)	5.7% (533/9293)	<.001
ICU admission	43.7% (196/449)	22.1% (2050/9293)	<.001
Mechanical ventilation	7.1% (32/449)	2.7% (247/9293)	<.001

P values were extracted from χ^2 or Fisher exact test for categorical variables and from *t* test or Mann-Whitney test for continuous variables.
ISS, Injury Severity Score; *SBP*, systolic blood pressure; *GCS*, Glasgow Coma Scale; *ED*, emergency department; *ICU*, intensive care unit; *OR*, operating room.

Table 2
Comparison of required surgical interventions between ejected and nonejected victims of motor vehicle collisions

	Ejected	Not ejected	*P* value
	($n = 449$)	($n = 9293$)	
Craniotomy/craniectomy	7.8% (35)	2.0% (185)	<.001
Exploratory laparotomy	3.8% (17)	2.9% (267)	.261
Thoracotomy	0.9% (4)	0.4% (33)	.089
Amputation/disarticulation upper extremity	0.0% (0)	0.0% (2)	1
Amputation/disarticulation lower extremity	0.0% (0)	0.1% (5)	1
Spine procedure	2.9% (13)	1.5% (135)	.015
Vascular procedure	6.5% (29)	4.1% (381)	.015

P values were extracted from χ^2 or Fisher exact test.

seen with respect to exploratory laparotomy, thoracotomy, or amputations.

Mortality. The overall mortality was 3.6% but nearly 3-fold higher for ejected patients who survived the MVA and were transported to a trauma center (9.6% vs 3.3%, $P < .01$). After adjusting for all significant differences between the 2 groups, using a multivariate logistic regression model, the AOR for mortality was 1.22 (95% CI: 0.74–1.98, $P = .434$). In addition, there were no significant differences noted with respect to ICU stay (mean days 6.6 vs 8.8; AMD 2.20; 95% CI: 0.81–3.59; adjusted $P = .908$), ventilator days (mean days 9.1 vs 9.7; AMD 0.65; 95% CI: −6.71 to 5.41; adjusted $P = .362$), and overall hospital length of stay (mean days 8.8 vs 5.2; AMD 3.63; 95% CI: 2.66–4.60; adjusted $P = .862$).

Predictors of Mortality and Significant Trauma. In a forward logistic regression model, incorporating all available covariates from the scene of the incident, 4 variables were found to predict mortality: being a passenger in an MVC on a highway, requirement for extrication, PSI, and ejection. Of all these variables, ejection was associated with the highest AOR for mortality (AOR: 4.07; 95% CI: 2.88–5.75; adjusted $P < .001$) (Table 3). Table 4 outlines the variables obtained from another forward logistic regression to identify predictors of critical injuries, defined as ISS > 25. Ejection was again associated with the highest AOR for these injuries (AOR: 5.29; 95% CI: 4.14–6.75, adjusted $P < .001$) (Table 4).

Discussion

In the present analysis that spans a period of 11 years, 4.6% of subjects involved in an MVC in Los Angeles County were ejected from their vehicles, and the proportion of ejected patients decreased by almost half by the end of the study period. Compared to nonejected patients, those ejected who were transported to a trauma center were more likely to be younger; have a higher injury burden; and require more transfusion of blood products, operative intervention, admission to the ICU, and mechanical ventilation. The significantly high percentage of trauma team activations for ejected subjects who survived to hospital admission resulted in similar outcomes to patients who were not ejected. Nonetheless, when accounting only for variables from the scene of injury, ejection, along with other factors, including PSI and need for extrication, was an independent predictor of critical injuries and mortality.

Table 3
Scene variables predictors of mortality

	Adjusted* odds ratio (95% CI)	Adjusted* *P* value
MVC on highway; passenger	2.00 (1.39–2.90)	<.001
Required extrication	3.56 (2.72–4.67)	<.001
PSI	1.32 (1.04–1.67)	.022
Ejected	4.07 (2.88–5.75)	<.001

CI, confidence interval; *MVC*, motor vehicle collision; *PSI*, passenger space intrusion.
* Variables in the equation: train versus auto (driver, passenger), reentry MVC (driver, passenger), auto versus auto (driver, passenger), auto versus other type vehicle (driver, passenger), auto versus pedestrian with occupant injured (driver, passenger), MVC on highway (driver, passenger), MVC due to loss of control (driver, passenger), MVC alighting/boarding (driver, passenger), MVC other (driver, passenger), required extrication, PSI, and ejected.

Table 4
Scene variables predictors of critical injuries defined as ISS > 25

	Adjusted* odds ratio (95% CI)	Adjusted* *P* value
Auto versus auto; passenger	1.42 (1.17–1.72)	<.001
MVC on highway; passenger	2.17 (1.59–2.97)	<.001
MVC due to loss of control; passenger	1.82 (1.44–2.30)	<.001
Required extrication	3.57 (2.94–4.33)	<.001
PSI	1.53 (1.30–1.80)	<.001
Survived a fatal crash	1.47 (1.00–2.16)	.050
Ejected	5.29 (4.14–6.75)	<.001

CI, confidence interval; *MVC*, motor vehicle collision; *PSI*, passenger space intrusion.
* Variables in the equation: train versus auto (driver, passenger), reentry MVC (driver, passenger), auto versus auto (driver, passenger), auto versus other type vehicle (driver, passenger), auto versus pedestrian with occupant injured (driver, passenger), MVC on highway (driver, passenger), MVC due to loss of control (driver, passenger), MVC alighting/boarding (driver, passenger), MVC other (driver, passenger), required extrication, PSI, and ejected.

Ejection during MVC continues to be a significant source of morbidity and mortality among crash victims. Factors previously identified to increase the risk of ejection from the vehicle include lack of restraints, rollover collisions, and older-model vehicles [16]. Furthermore, individuals ejected during MVC have been reported to be from 2 to 8 times more likely to be fatally injured compared to nonejected victims, which is comparable to our data showing that ejected patients had more than 4 times increased odds for death compared to those who were not ejected when only variables from the scene were accounted for [13,16]. In addition, previous data indicate an increased likelihood of closed head and spinal injuries [8,11,19], again in line with our findings.

Góngora et al reported that ejections remained constant between 1990 and 1999 even in the setting of increased use of restraints [11]. Data reports from the National Highway Traffic Safety Administration (NHTSA) also indicate a constant rate of ejection events between 2003 and 2007 (13.4%–14.0%) [16]. In contrast to these findings, our data indicate that, in Los Angeles County, there was an almost linear reduction in the percentage of ejections from 6.1% to 3.4% between 2002 and 2012. Possible reasons for this include the implementation and more effective enforcement of seat belt laws over the study period and better safety features of newer model vehicles [15,20–23]. This concept is further supported by NHTSA data which show that collisions involving newer-model vehicles have lower rates of ejection [16]. According to the NHTSA, a driver in a model year vehicle 2003–2007 was 20% more likely to be fatally injured compared to a driver in a model year vehicle 2008–2012 [24]. Another study based on data from the National Automotive Sampling System from 2000 to 2010 found that certain motor vehicle engineering characteristics such as curtain airbag deployment might be protective for ejections; however, this did not reach statistical significance [25]. Other factors that appeared to be protective include fewer number of roof inversions, passenger body type, and near side seating position.

We found that ejection was significantly higher in single-vehicle collisions (loss of control), whereas nonejected victims were more often involved in auto versus auto/other vehicle collisions. This observation is supported by previous data showing that front, rear, or side impact collisions have lower rates of ejection than rollover or underside collisions, which are both more frequent in single-vehicle collisions [9,14,26]. Given these findings, a higher index of suspicion for injuries and a lower threshold for trauma activation may be warranted when single-vehicle collisions occur, a concept not generally applied to activation criteria.

Our data showed that a significantly higher percentage of ejection victims required cranial or spinal procedures, which coincides with previous studies identifying increased head and neck injuries in ejected victims [27,28]. Therefore, a high index of suspicion should be maintained when evaluating ejected patients in the acute setting, and liberal imaging for early identification of these injuries is warranted.

Interestingly, after controlling for differences between ejected and nonejected subjects transported to a trauma center, there was no significant difference in ICU days, ventilator days, and hospital days. Furthermore, there was no identifiable difference in the overall mortality between ejected and nonejected victims that made it to the hospital. Possible factors that contribute to this finding are improved critical and trauma care, improved trauma triage and activation protocols, and improved in-field identification of critical injuries requiring trauma level care. This finding may also reflect that given the high percentage of on-scene mortality for ejected victims, only those with survivable injuries are transported to trauma centers; however, based on the data we are evaluating, we are not able to discern this finding. Trauma team activation in 98% of these cases might have resulted in early identification and treatment of severe injuries, resulting in improved outcomes. This finding continues to support activation of resources for all ejected victims following an MVC.

The NHTSA reports a nearly 70% mortality of ejected victims during MVC; however, this accounts for all ejections including those dead on-scene who are not transferred to the hospital. Our mortality rate for ejected victims reaching the hospital was 9.6%, which is consistent with previously reported mortality rates [11,12]. These data compared to those of the NHTSA demonstrate the lethality of ejection events but also further support the idea that transport to a trauma center may be a lifesaving decision for an ejected victim.

In analyzing variables observed at the scene, ejection from the vehicle remained the highest predictor of mortality and critical injury. Consistent with prior data, victims ejected from the vehicle were at a 4 times increased risk of death and were more than 5 times more likely to sustain a critical injury compared to those who were not ejected [14,27]. Other predictors of death and significant injury in our study included PSI and extrication but neither at the level of ejection. Our data contrast with those reported by Matsushima et al where PSI alone was not found to be a strong predictor of injuries requiring trauma center resources [29]. All 3 of these factors indicate a significant MVC, and these remain important in-field factors in activating the trauma team. Identifying and reporting these predictors by the response team and appropriately triaging the patient to a dedicated trauma center are important and may lead to improved outcomes in this particular group.

There is a lot of promise in future advances and their incorporation in automotive technology and autonomous driving. Based on artificial intelligence, deep learning has the ability to recognize pedestrian traffic, the presence of other vehicles, and traffic patterns, which in turn executes an algorithm in response. The development of automotive technology is still in evolution, however, and its efficacy is yet to be established [30]. However, we believe that autonomous driving will ultimately lead to decreased mortality in the years to come by at least mitigating the effect of human error, especially in the face of distracted driving [31].

Limitations of the study include its retrospective nature, with all the possible misreporting and missing data. Ejection data are frequently linked to and compared to restraint use; however, restraint information was missing from most patients, not allowing for further analysis. Additionally, given the deidentified nature of these data, we are unable to link specific vehicle model years or safety features to particular MVCs. This information may have been useful in identifying factors contributing to ejection in MVC. The distance that the subject was found away from the vehicle, in addition to the speed of the vehicle at the time of the incident, was also not available. Lastly, interventions and procedures performed at the scene by paramedics or bystanders, in addition to the transport time, were also missing. That information could have allowed for identification of a subset of ejected patients who may have a higher risk for mortality and critical injuries. Despite these limitations, our study provides recent overview of the incidence and outcomes of ejected victims of MVC that are successfully transported to a trauma center in a large metropolitan area, and highlights the importance of maintaining a high index of suspicion for severe injuries in this subpopulation of trauma patients.

Conclusion

Although the incidence of occupant ejection during MVC is decreasing, when accounting only for variables from the scene of injury, ejection from a motor vehicle remains a significant predictor of mortality and severe trauma. With the advancement in critical care, transport of these patients to high-level trauma centers, and almost universal trauma team activation, in-hospital outcomes remain similar to patients who are not ejected. Nonetheless, in evaluating variables obtained from the scene of the incident, ejection remains the most important predictor of both mortality and severe trauma.

Author Contributions

Study conception and design: DR Margulies, MD; G Barmparas, MD; N Manguso, MD. Acquisition of data: G Barmparas, MD; N Manguso, MD; NK Dhillon, MD; R Huang, MD. Analysis and interpretation of data: G Barmparas, MD; N Manguso, MD; R Huang MD. Literature review: N Manguso, MD; G Barmparas, MD; NK Dhillon, MD; R Huang, MD. Drafting of manuscript: N Manguso, MD; G Barmparas, MD; NK Dhillon, MD; DR Margulies, MD. Critical revision: DR Margulies, MD; N Melo, MD; EJ Ley, MD; RF Alban, MD.

Conflict of Interest

All authors report no conflict of interest.

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None.

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