Review Article

Epidemiology, Causes and Prevention of Car Rollover Crashes with Ejection

El-Hennawy HM[1], El-Menyar A[2,3], Al-Thani H[1], Tuma M[1], Parchani A[1], Abdulrahman H[1], Peralta R[1], Asim M[2], Zarour A[1], Latifi R[1,4]

[1]Department of Surgery, Trauma Surgery Section, Hamad General Hospital, [2]Clinical Research, Trauma Surgery, Hamad General Hospital, [3]Clinical Medicine, Weill Cornell Medical College, Doha, Qatar, [4]Department of Surgery, Arizona University, Tucson, AZ, USA

Address for correspondence:
Prof. Ayman El-Menyar,
Department of Surgery,
Trauma Surgery Section, Hamad
General Hospital, Doha, Qatar.
E-mail: aymanco65@yahoo.com

Abstract

Rollover crashes (ROCs) are responsible for almost a third of all highway vehicle occupant fatalities. Although ROCs are common and serious mechanism of injury, ROCs are under-reported. To analyze the causes, mechanism, impact and prevention of ROCs, we reviewed the literature between 1984 and 2013. By utilizing the search engines PubMed, MEDLINE and EMBASE by using key words “ROCs” “Ejection” and “vehicle” the initial search yielded 241 abstracts, of which 58 articles were relevant. Most of the articles were either retrospective or experimental studies funded by automobile companies. All vehicles are susceptible to rollovers to certain extents. Despite continuing innovation in vehicles’ safety, human factor is pivotal in prevention of ROCs. Distracted driving, speeding and drinking escalate the chances of rollover crashes. Wearing a seatbelt greatly improves the chances of surviving a ROC.

Keywords: Crashes, Ejection, Motor vehicle, Rollover

Introduction

Motor vehicle crashes (MVCs) are the major cause of morbidity and mortality among young population. Rollover crashes (ROCs) involves one of the most fatal type of MVCs.[1] It is referred to a crash in which vehicle rotation of ≥ 90° occurs about any longitudinal or lateral axis.[2] As the majority of ROCs take places in the highways, it poses serious road safety concerns.[3] Around 220,000 light motor vehicles sustain ROCs in the US annually involving 350,000 vehicle occupants. These crashes reported 9000 occupants deaths, 14,100 serious injuries whereas, minor to moderate injuries were reported in 224,000 victims of these crashes.[3] Despite the fact that ROCs constitute only 2.2% of all MVCs; it represents about 33% of the annual injury costs in the US (around $40 billion).[3] It has been reported that 50% and 10% of the harm due to ROCs is related to the head and neck and spines injuries, respectively.

Access this article online	
Quick Response Code:	Website: www.amhsr.org
	DOI: 10.4103/2141-9248.139279

Moreover, previous data showed that the annual incidence of ROCs-related mortality accounted for 3.4/100,000 person.[4] A high fatality rate is observed among the occupants of all vehicles which also includes light trucks and sports utility vehicles (SUVs; 50%) as well as the heavy trucks (60%).[4] Although the rollover is a serious event, the association of occupant’s ejection has the potential to add significantly to the resultant injuries. Furthermore, ejection from the vehicle is more serious when the occupant experiences contact either with the vehicle (on the way out) or the ground.[5] This is a review of the literature, to study the mechanism, classifications, severity and types of “ROCs” and “Ejection”.

Methods of Literature Search

To define the incidence, characteristics, mechanism, risk factors and preventive strategies for ROCs, we reviewed the literature between 1984 and 2013. We utilized the search engines PubMed, MEDLINE and EMBASE by using key words “ROCs” “Ejection” and “vehicle”. The initial search yielded 241 abstracts, of which 58 articles were relevant. Only relevant review articles and research studies (retrospective and prospective) were included in this review. The study design of the selected articles was mainly confined to relevant reviews articles and research studies either retrospective or experimental studies funded by automobile companies.

Studies addressing the car ROCs with or without ejection, impact of ROCs on safety measures, clinical presentation and outcome (mortality and hospital length of stay) were mainly considered. However, abstract, unpublished data and non-English manuscripts were excluded.

ROCs and Fatalities

MVCs are a significant source of major trauma among all age groups.[6] Fortunately, with the introduction of advanced safety features in motor vehicles (seat belt restraints and air bags); crash-related fatalities have been remarkably reduced.[7] Despite that, ROC remains a common cause of MVCs fatalities in all continents. In general, 35% of occupants fatalities are related to the rollover initiation speed at initiation and number of turns. Moreover, an increased association of fatality was observed with head injuries in restrained occupant.[8] In Australia ROC is responsible for about one in every five fatalities.[9] The estimated fatalities involving ROCs in Europe is around one in every 10 fatalities.[10] Studies from the US reported a relatively higher fatality rate by ROC which corresponds to one in every 3-4 fatalities.[11,12] Though, the intensity of collision and inadequacy of occupant protection in vehicles are associated with risk of severe injury in ROCs. Lack of standards for the assessment of ROCs resulted in overrepresentation of fatalities associated with ROCs in many countries.[13]

Mechanism of Injury in ROCs and Ejection

There are four main injury mechanisms involved in ROCs. First is roof intrusion, in which structural elements either penetrates the body of the occupants or crush them altogether due to massive structural deformations and loss of the residual space. Another mechanism is a projection in which uncontrolled movement of the occupants inside the vehicle resulted in occupants' body impact with the structural parts of the vehicle compartment.[14] In case of complete ejection, the passengers could be ejected from the vehicle during the rollover process. However, in partial ejection parts of the passenger's body come in contact with the outside surface and can be strongly crushed during rollover process.[14] Usually, the standard restraints equipped for frontal collisions are not beneficial in rollovers, particularly with roof intrusion. In addition, there is a high risk of severe head and spinal injuries in restrained occupant who were partially ejected.[13] A study by Rechnitzer *et al*.[15,16] demonstrated the ineffectiveness of restraints and impact of roof crush in the severity of injury.

Mechanism and Classification of ROCs

Rollover of vehicles involves two patterns. The first one is referred to lateral rollover in which the vehicle rotates around a longitudinal axis being parallel with the main longitudinal axis of the vehicle (i.e. bus). It is the most common way of rollover and about 98% of all vehicle ROCs represents this group.[14] In contrast, the second type of rollover vehicle crash involves rotation around an axis being perpendicular to the vertical longitudinal central plane of the vehicle. This type of ROCs is uncommon and observed only in 1-2% cases.[14]

ROCs categories based on different initiation scenarios

- Trip-over occurred when the vehicle is suddenly slowed or stopped inducing a rollover
- Flip-over: When the vehicle is rotated along its longitudinal axis by a ramp-like object such as a turned down guardrail
- Bounce-over: When a vehicle rebounds off a fixed object and consequently overturns
- Turn-over: When centrifugal forces from a sharp turn or vehicle rotation are resisted by normal surface friction
- Fall-over: When the surface on which the vehicle is traversing slopes downward in the direction of movement of the vehicle's center of gravity (COG) such that the COG becomes outboard of its wheels
- Climb-over: When the vehicle climbs up and over an object (e.g., guardrail, barrier) that is high enough to lift the vehicle completely off the ground
- Collision with another vehicle: When an impact with another vehicle causes the rollover
- End-over-end: When a vehicle rolls primarily about its lateral axis after crashing with a concrete barrier.[13]

ROCs of heavy vehicles based number of turns

- Turn on side (¼ rotation): The vehicle generally slips a certain distance on its side and finally stops
- Turn into a ditch: The rotation is somewhat between one-fourth and a half and the depth of the ditch is enough to stop further rotation.
- Rollover from the road: More than half rotation, but not more than two. The level difference between the road and the ground, where the vehicle finally stops is not more than 10 m
- Serious rollovers involve more than two rotations and the level difference between the road and the ground is more than 10 m, where the vehicle finally stops
- Combined rollover: The rollover followed by fire, or before the rollover a severe frontal collision occurred, or after the rollover, the vehicle falls into a water body. In general, more than 90% of all ROCs rotate about the longitudinal (roll) axis of the vehicle.[14]

Rollover of Heavy Vehicles

ROCs of heavy trucks are particularly serious and common subtype on highways. Unlike passenger vehicles, ROCs of heavy trucks are associated with significant damage to the vehicle and injuries to the occupants, even those who are restrained. It has been estimated that on an average 35% of incapacitating and fatal injuries occur during ROCs of heavy trucks annually in the US.[17]

Analysis of Rollover Injuries

Post-roll events are frequently (66%) associated with severe injury followed by pre-roll and under turn ROCs.[18] Moreover, the unrestrained occupants had severe injuries due to intrusion by rollover in the majority of cases. Complex injuries of head/neck and hemo/pneumothoraces were the most significant injuries sustained during serious rollover events.[18]

Impact: In light vehicle rollover event, the most common cause of injury for non-ejected occupants is the impact of the event rather than crushing. During a rollover, impact corresponds to relatively short duration and involves only the striking and the struck objects.

Crushing: Represents a slower process involving the object and two other surfaces between which the object is being crushed. Crushing can take all day; on the other hand, even a slow impact is still capable of quick bump or bang. The rollover event is largely governed by the upsetting force (depends upon geometry and weight of the vehicle) which should persist long enough, to rolls over the vehicle.[18]

Contributing factors determine the severity of ROCs

These factors include (1) Type of vehicle, (2) pre-crash speed, (3) restraints used, (4) number of turns, (5) intensity of the impact, (6) vehicle damage especially roof intrusion in relation to survival space (the physical envelope in which the motion of an occupant is contained during a crash), (7) single or multivehicle event, (8) type of rollover initiation, (9) vehicle design, (10) field triage models, (11) age of the occupant, (12) occupant size body mass index, (13) location of occupant in the vehicle and (14) whether occupant was ejected or confined.[13,19-21]

Furthermore, the roof impact and availability of survival space are important indicators of severity in a single vehicle crash and provides a uniform relationship between crash severity and injury risk.[19] For non-restraint occupants, the ejection risk increases with the number of quarter-turns. On the other hand, for non-ejected unbelted occupants, one quarter-turn is commonly associated with severe injuries in single vehicle crashes.[19] An increased injury risk was also observed in a crash with a stationary object (tree or wall) prior to rollover. Also, multivehicle rollover event possesses greater risk of injury compared with a single vehicle crash. The injury severity for children in a ROC was also significantly higher than for non-ROCs. In crashes involving children, a greater risk of rollover observed for pickups and SUVs compared with passenger cars and minivans.[22]

Roof strength as risk of injury in ROCs

Though, some studies on crash analyzes have not established a strong association between roof deformation and injury of occupant.[23] Vast majority of studies suggested that maintenance of "survival space" in the vehicle is an important factor for crash outcome. Earlier studies have demonstrated a significant correlation between roof intrusion (>10 cm) and increased injury severity.[24-27] Moreover, single unit increase in roof strength-to-weight ratio demonstrated 20-25% reduction in serious injury during rollovers. A study by Mandell *et al*.[28] showed that the risk of mortality and severe head/spinal injuries increases significantly with an increasing degree of roof crush during ROCs. The risk of mortality was twice with a roof crush of >15 cm which increases to six-fold for roof crush of >30 cm. Similarly, the risk of traumatic brain injury increases more than three-times and spinal injuries more than two-fold for roof crush of above 30 cm.[28] Burns *et al*.,[29] demonstrated that by controlling the severe roof intrusion, it is possible to minimize the spinal cord injuries and in turn can reduce substantial direct cost. Therefore, improving the roof strength of a vehicle might help in minimizing the severity of injury. In addition, Inamasu and Guiot[30] have emphasized the efficacy of seatbelt use in minimizing the severity of rollover-induced thoracolumbar junction injury. About one-third of the contained and restrained occupants suffered serious thoracic injuries in single-vehicle ROCs.

Vehicle design as risk of injury in ROCs

It is shown that the fatality rates vary significantly based on vehicle types and makes and are largely associated with the vehicle stability, which shows the importance of vehicle design role in minimizing the morbidity and mortality, resultant from rollovers.[31] Most crashes have a high velocity at the initial rollovers and the occupants had high impact with the roof and doors due to massive displacement. There is a significant risk of severe injuries in absence of roof integrity particularly seen in vehicles equipped with four wheel drive.[31] Some seatbelt designs may be deficient and unlatched during the rollover or provides little restraint against partial ejection.[31] Moreover, earlier studies have demonstrated that some occupants were died due to front airbags in low-severity crashes which was supposed to impact minor or no injuries.[32,33] Furthermore, improper padding of roof structures and framing results in severe head injuries, mainly involving scalp lacerations, fractures of skull and brain injury.[31]

Vehicle design-related factors such as mechanistics, arising from vertical and lateral roof intrusion and impact loading of the head with the ledge formed by the underside of the roof and door frame leads to severe head and spinal injuries.[31] In general, roof crush together with deformation of other vehicle structures indicates the severity of rollovers. However, only roof crush without other structural deformities reflects defect in vehicle design. O'Neill[34] showed that newer vehicles designed for crash avoidance (with electronic stability control [ESC]) have the potential in reducing casualties in single-vehicle crashes.

Rechnitzer and Lane have recommended certain modification in vehicle design for improved safety.[31] To prevent partial ejection from the vehicle, plastic glazing should be used to maintain the integrity of side window. Minimum standard for roof integrity should be maintained by increasing roof framing and A and B pillar strength.[31] To avoid head contact, interior energy absorbing padding over the roof should be used. Modify the design of door/roof to avoid the risk of head stuck against the frame. Improve the performance of seat belts to reduce vertical movements of occupants. Enhance the integrity of doors together with energy absorbing side padding. Figures 1 and 2 show types of roof deformation.[13,35]

ROCs among Children and the Relation to Vehicle Type

Children involved in MVCs with rollover events have two-fold increased risk of morbidity or mortality.[4] Furthermore, MVCs particularly involving SUVs have 11 times increased risk of rolling over compared to the passenger cars. In a study by Rivara *et al*.[4] observed that around 60% of children involved in ROCs were travelling in SUVs. However, Evans and Frick[36] demonstrated an inverse relationship between mass of the vehicle and fatality risk. Hence, SUVs being heavier vehicles compared to passenger cars possess a lower risk of mortality in rollover events.[4] Hence, the overall risk of mortality for children undergone SUVs rollover may not increase in comparison to the passenger cars and may in fact be lower;[4] this might be due to better safety measures, separate protected seats for children and stronger frames. Rasouli *et al*.[37] observed MVCs to be the major cause of traumatic spinal injuries (29%) in children. Moreover, single vehicle crashes, rollover event and ejection from the motor vehicle are the major risk factors for MVC-related spinal injuries in children. Olsen *et al*.[38] showed that the driver seatbelt use was associated with child restraint compliance and reduced risk of ROCs and head-on collisions.

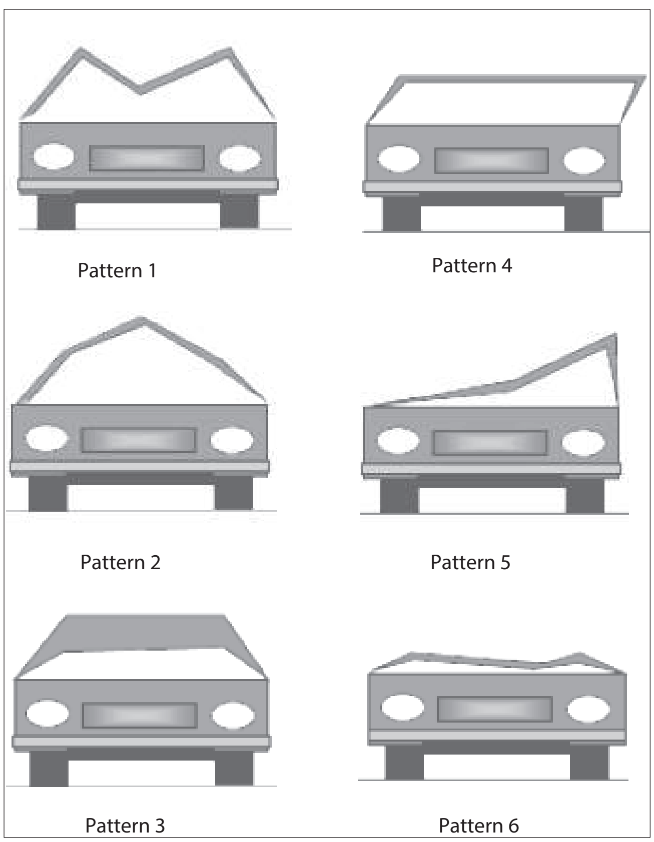

Figure 1: Types of roof deformations: Front and rear view[13,35]

Ejection and Confinement and Rollovers

Ejection is the process in which an occupant is either partially or fully thrown away from a vehicle resulted in ground contact and other surfaces exterior to the vehicle.[13] Serious injuries occur due to entrapment of the occupant between the road surface and the vehicle structure. Berg *et al*.[35] in their study have reported that occupants who were ejected had torso and head injuries mainly due to secondary impact with the ground or by entrapment.

Whereas, the non-ejected occupants experiences head, spine and extremities injuries primarily by roof crush or impact of the interior on the occupant. Sustaining an intact survival space (minimal roof crush) together with proper seatbelt restraint would be the beneficial in controlling occupant movement and subsequent ejection.[39] Non-compliance of vehicle restraints is the major cause of ejection. An earlier study, observed 70% compliance of seat belts among injured non-ejected occupants. On the other hand, 51% of the partially ejected and only 3% of completely-ejected occupants used restraints.[40] Table 1 shows comparison between rollover with and without ejection.[3,35,40]

Ejection and Fatalities

In a rollover, there is a five-fold increased risk of mortality, if the occupant ejected during the crash. It was also suggested that the fatality rate could be reduced by 70% by effective controlling of ejection in rollover.[19] Another study reported that even in less severe ROCs, two-thirds of the mortalities were attributed to occupant ejection from the vehicle.[41] Deutermann[42] also found ejection as the primary cause of mortality (62%) in severe ROCs. According to the Advanced Glazing Project of National Highway Traffic Safety Administration, which analyzed ejection ROCs, a relative risk of fatality for ejected to non-ejected occupants was found to be 3.55 for drivers and 3.15 for front seat passengers. So, controlling ejection of drivers significantly helps in reducing the rate of morbidity by 58% and mortality by 72%, respectively.[43] Howard *et al*.[44] in their study have reported that ejection from the vehicle is frequently associated with mortality (29%) among young children. Similarly, Scheidler *et al*.[45] found ejection to be associated with increased morbidity and mortality among children of all age groups. Further, infants and young children (0-4 years) had the highest fatality rate and were mostly found to be either unrestrained or improperly restrained. Therefore, factors involving increased risk of ejection needs to be analyzed for controlling significant risk of injury and mortality in ROCs with ejection. The relative risk of mortality

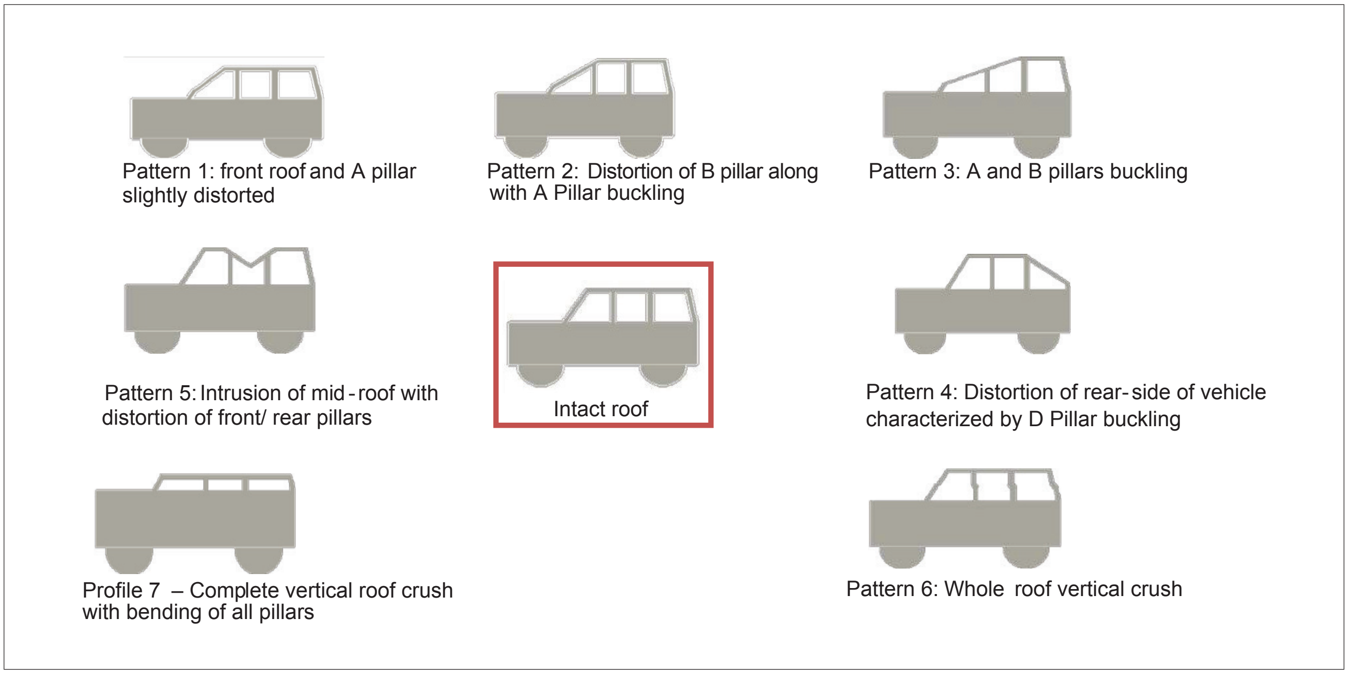

Figure 2: Types of roof deformations: Side view[13,35]

Table 1: Comparison between rollover with and without ejection

Variable	Ejected	Non-ejected
Severely injured cases[35]* (%)	50	5
Seatbelt use[40] (%)	3	70
Relative HARM (injury cost×number of accident)[3]	6.2	0.5

*The severity of injury was assessed by the abbreviated injury severity score of more than 5, HARM: To assess the cost of management: The sum of each injury cost multiplied by its respective frequency of occurrence. Data were from references 3, 35, 40

in ejected occupants ranged from about 1.5 to 8 depending upon the crash mode or type. In addition, single-vehicle ROCs with ejection have the highest increased risk of mortality.[46] Table 2 shows studies of ROC and outcomes.[2,22,30,44,45]

Significance of Rollover Direction on Ejection and Injury Risk

The kinematics of vehicle occupants is considerable affected by the direction of the rollover, magnitude of forces and position of the occupant.[47] Rollovers involving more numbers of quarter turn and far-side occupants had increased risk of serious injuries and fatality for unrestrained ejected occupants.[48] An earlier study observed that irrespective of the restraint use, the potential risk of severe head and thorax injury was high for crashes involving two and more complete rolls.[49]

Parenteau *et al.*[48] have reported that occupants of far-side sustained serious injury compared to near-side occupants. They also concluded that head injury was more common in drivers of far-side than near-side. Head, lower extremity, thorax and upper extremity injuries were frequently observed in near-side drivers. In contrast, occupants of far-side sustained spine, head and thorax injuries. Drivers of near-side rollovers were mainly through the driver's door window opening. On the other hand, drivers in far-side rollovers were ejected either from the driver's door window opening or through opening of glass roof.[49]

Safety Belt Use and Ejection

Use of seatbelt potentially reduces the risk of complete ejection during a ROC. Moreover, the risk of partial ejection is also substantially minimized by restraints.[50] For unbelted occupants, the relative risk of severe injury increases by 20 times whereas; in restraint occupants the injury risk increases to 77-folds for complete ejection in comparison to non-ejected occupants.[51]

Prevention of ROCs

Every year, MVCs cause significant mortality and morbidity with 40,000 deaths and 4.3 million non-fatal injuries world-wide.[52] Several epidemiological studies have proposed effective strategies to address these preventable deaths and injuries which are mainly associated with socio-economic factors. However, occupant ejection remains a critical issue in ROCs. The important factors that play a crucial role in ejection prevention involves seatbelt use, lesser roof inversions, vehicle design, curtain airbag deployment, near-side seating position and small occupant size.[53]

Based on preliminary data, side-curtain airbag deployment appears to be a promising ejection mitigation counter measure. Further reductions in ejection could potentially be achieved

Table 2: Studies of rollover with and without ejection

Authors	Age (years)	Type of study	ROC cases	Ejection/ unrestrained %	Mortality %	Findings
Aldaghlas *et al*.[2]	>16	Retrospective	257	-/40	-	Use of seatbelt and physiometric data could be useful for triage of non-critically injured rollover occupants which save the cost of trauma center
Kallan *et al*.[22]	≤15	Retrospective	2461	-/2.3	-	The risk of injury to the child occupants in rollovers was significantly higher than in non-rollover crashes
Scheidler *et al*.[45]	0-16	Retrospective	2298	8.2/88	14.8	Most children ejected from MVCs were either unrestrained or improperly restrained. Head injuries were the most common cause of death in all age groups
Howard *et al*.[44]	0-16	Retrospective	1832	29/81	64	Ejection from the vehicle is common among fatally injured children. Shoulder straps alone may not prevent the ejection of toddlers during rollovers
Inamasu and Guiot[30]	17-64	Retrospective	22	55/55	-	Seatbelt helps in reducing the severity of rollover-induced thoracolumbar junction injury

ROC: Rollover crashes, MVCs: Motor vehicle crashes

by blocking ejection portals in the roof.[53] Currently, cars are equipped with ESC which poses pressure to individual wheel brakes during the situation of no response from the driver's steering (a precursor to rollovers).

Rollover prevention technology also provides a method for estimating the COG position in real time.[54] The timely and accurate estimation of COG is critical for triggering the appropriate vehicle safety mechanisms.

Apart from technological advancement, safety measures such as seatbelt compliance, avoidance of panic maneuvers and loading too much gear onto a roof rack, excessive speed around ramps/curves in the highway and excessive speed in slippery conditions would help in preventing ROCs.

Moreover, public awareness through educational programs has enormous potential to reduce these serious crashes. Driving while engaged in other activities which include using a cell phone, texting, eating, or reading, compromise the safety of the vehicle occupants and other individuals on the road.[55] According to the United States Department of Transportation, text messaging while driving had 23 times higher risk of crash than driving without distraction.[56] Despite these statistics, 37% of drivers in the USA have sent or received text messages while driving and 18% admit doing so regularly.[57] Distraction while driving is broad and multidimensional concept and we just hinted on this issue as it is very common in our region and world-wide as it is one of the major causes of ROC.

Conclusion

Though, it is difficult to determine the exact correlation between the injury severity and ejection and whether the injuries sustained were before or after the ejection. Studies showed that vehicle ROCs with ejection are particularly associated with higher rate of morbidity and mortality. The major causes of occupant ejection include lack of seat-belt restraints, average speed and age of driver and occurrence of rollover. So, seatbelt use, lesser roof inversions, vehicle design, near-side seating position and small occupant size are the important factors for ejection prevention. Furthermore, the majority of vehicle ROCs is lateral and the frequent injury mechanisms are roofing intrusion, projection, complete and partial ejection. It is noteworthy that the roof impact and availability of survival space are important indicators of severity in a single vehicle crash. Despite continuing innovation in vehicles' safety, human behavior (distracted driving, speeding and drinking) is an important factor that increases the chances of ROCs. Furthermore, the risk of fatality in ROCs largely depends upon the intensity of collision, occupant protection and ejection status. In order to minimize ROC with ejection, all the aspects should be addressed including car design, driver behavior, the occupants and road. Therefore, public awareness through educational programs has enormous potential to reduce these serious crashes. The current review addresses all these issues in a simplified language that can be easily available for the concerned physicians.

References

1. National Highway Traffic Safety Administration, Traffic Safety Facts 2010, FINAL Edition. Available from: http://www-nrd.nhtsa.dot.gov/Pubs/811659.pdf. [Last accessed on 2013 Sep 05].
2. Aldaghlas T, Burke C, Sheridan MJ, Stadter GW, Hanfling D, Griffen M, *et al*. Are trauma team activations essential and cost effective for rollover crashes? SAE Int J Passeng Cars- Mech Syst 2010;3:481-7. doi:10.4271/2010-01-0519.
3. Digges KH. Summary Report of Rollover Crashes. FHWA/NHTSA National Crash Analysis Center; 2002. Available from: http://www.ncac.gwu.edu/research/Rollover%20Summary%20Report%20-%20Digges%202002.pdf. [Last accessed on 2013 Sep 05].
4. Rivara FP, Cummings P, Mock C. Injuries and death of children in rollover motor vehicle crashes in the United States. Inj Prev 2003;9:76-80.
5. Eichler RC. The causes of injury in rollover accidents. Accid Reconstr J 2003;2:1-17. http://www.e-z.net/~ts/web-6-1-06/~docs/The%20Causes%20of%20%20Injury%20in%20Rollover%20Accidents3.pdf. [Last accessed on 2013 Sep 05].
6. Funk JR, Cormier JM, Manoogian SJ. Comparison of risk

factors for cervical spine, head, serious, and fatal injury in rollover crashes. Accid Anal Prev 2012;45:67-74.

7. Hazarika S, Willcox N, Porter K. Patterns of injury sustained by car occupants with relation to the direction of impact with motor vehicle trauma – Evidence based review. Trauma 2007;9:145-50.
8. Fréchède B, McIntosh AS, Grzebieta R, Bambach MR. Characteristics of single vehicle rollover fatalities in three Australian states (2000-2007). Accid Anal Prev 2011;43:804-12.
9. Richardson SA, Rechnitzer G, Grzebieta RH, Hoareau E. An advanced methodology for estimating vehicle rollover propensity. Int J Crashworthiness 2002;8:63-72.
10. Gugler J, Steffan H, Lutter G, Fleischer S. Improvement of rollover safety for passenger vehicles, European Community-R and TD-Project-5" Framework-Programme "Growth", Rollover Scenarios in Europe, Paper on Results of Work Package "In Depth Accident Analysis".
11. Insurance Institute for Highway Safety (IIHS) Fatality Facts 2004: Passenger vehicle Occupants2005. Available from: http://www.iihs.org/iihs/topics/t/general-statistics/fatalityfacts/passenger-vehicles/2005. [Last accessed on 2013 Sep 05].
12. National Highway Traffic Safety Administration. Traffic Safety Facts 2004, National Centre for Statistics and Analysis. Washington, DC: U.S. Department of Transportation; 2004. p. 20590.
13. Young D, Grzebieta RH, Rechnitzer G, Bambach M, Richardson S. Rollover crash safety: Characteristics and issues. Available from: http://www.accidentreconstruction.com/newsletter/jul08/RolloverCrashSafety_CharecteristicsandIssues.pdf. [Last accessed on 2013 Jan 15}.
14. Matolcsy M. The severity of bus rollover accidents. Scientific Society of Mechanical Engineers. Paper Number: 07 0989. Available from: http://www-nrd.nhtsa.dot.gov/pdf/esv/esv20/07-0152-O.pdf. [Last accessed on 2013 Sep 05].
15. Rechnitzer G, Lane J. Rollover Crash Study-Vehicle Design and Occupant Injuries. Australia: Monash University Accident Research Centre; 1994. p. 56.
16. Rechnitzer G, Lane J, McIntosh AS, Scott G. Serious neck injury in rollovers– is roof crush a factor? Int J Crashworthiness 1998;3:286-94.
17. Evans JL, Batzer SA, Andrews SB. Evaluation of heavy truck rollover accidents. NHTSA. Paper Number 05-0140. Available from: http://www-nrd.nhtsa.dot.gov/pdf/esv/esv19/Other/Print%2015.pdf. [Last accessed on 2013 Sep 05].
18. Brooks J. Analysis of turn rollover population of MAIS 3+, non-ejected and unrestrained passengers in single vehicle accidents. National Crash Analysis Center. Available from: http://www.ncac.gwu.edu/research/Janet_Brooks_tip_over.pdf. [Last accessed on 2013 Sep 05].
19. Digges KH, Eigen AM. Crash attributes that influence the severity of rollover crashes. The National Crash Analysis Center, Paper Number 231. Available from: http://www-nrd.nhtsa.dot.gov/pdf/esv/esv18/CD/Files/18ESV-000231.pdf. [Last accessed on 2013 Sep 05].
20. Malliaris A, DeBlois J. Pivotal Characterization of Car Rollovers Proceedings of 13th ESV Conference, November; 1991.
21. Digges K, Klisch S. Analysis of Factors which Influence Rollover Crash Severity. Proceedings of 13th ESV Conference, November; 1991.
22. Kallan MJ, Arbogast KB, Durbin DR. Effect of model year and vehicle type on rollover crashes and associated injuries to children. Annu Proc Assoc Adv Automot Med 2006;50:171-84.
23. Heller MF, Newberry WN, Smedley JE, Eswaran SK, Croteau JJ, Carhart MR. Occupant kinematics and injury mechanisms during rollover in a high strength-to-weight ratio vehicle. SAE 2010 World Congress and Exhibition, April 13, 2010, Detroit, Michigan, United States. Available from: http://www.papers.sae.org/2010-01-0516/.[Last accessed on 2013 Sep 05].
24. Paine M. Physics of rollover crashes, 1998. Available from: http://www1.tpgi.com.au/users/mpaine/rollover.html. [Last cited on 2006 Feb 03].
25. Austin R, Hicks M, Summers S. The Role of Post-Crash Headroom in Predicting Roof Contact Injuries to the Head, Neck or Face During FMVSS No. 216 Rollovers. Springfield, Virginia: National Highway Traffic Safety Administration; 2001. p. 22.
26. Herbst B, Forrest S, Orton T, Meyer SE, Sances A Jr, Kumaresan S. The effect of roof strength on reducing occupant injury in rollovers. Biomed Sci Instrum 2005;41:97-103.
27. Brumbelow ML, Teoh ER. Roof strength and injury risk in rollover crashes of passenger cars. Traffic Inj Prev 2009;10:584-92.
28. Mandell SP, Kaufman R, Mack CD, Bulger EM. Mortality and injury patterns associated with roof crush in rollover crashes. Accid Anal Prev 2010;42:1326-31.
29. Burns SP, Kaufman RP, Mack CD, Bulger E. Cost of spinal cord injuries caused by rollover automobile crashes. Inj Prev 2010;16:74-8.
30. Inamasu J, Guiot BH. Thoracolumbar junction injuries after rollover crashes: Difference between belted and unbelted front seat occupants. Eur Spine J 2009;18:1464-8.
31. Rechnitzer G, Lane J. Rollover Crash Study-Vehicle Design and Occupant Injuries. Monash University Accident Research Centre-Report #65, 1994. Available from: http://www.monash.edu.au/miri/research/reports/muarc065.pdf. Last accessed on 2013 Sep 05].
32. National Highway Traffic Safety Administration. Third Report to Congress: Effectiveness of Occupant Protection Systems and Their Use. Report DOT HS-809-442. Washington, DC: U.S. Department of Transportation; 1996. Available from: http://www.nhtsa.dot.gov/people/injury/airbags/208con2e.html. Last accessed on 2013 Sep 05].
33. Werner JV, Robertson SF, Ferguson SA, Digges KH. Injury Risks in Cars with Different Air Bag Deployment Rates. SAE 970491. Warrendale, PA: Society of Automotive Engineers; 1997.
34. O'Neill B. Preventing passenger vehicle occupant injuries by vehicle design – A historical perspective from IIHS. Traffic Inj Prev 2009;10:113-26.
35. Berg A, Krehl M, Behling R, Helbig M. Rollover crashes-Real world studies, tests and safety systems. In: 18th International Conference on the Enhanced Safety of Vehicles. Nagoya, Japan; 2003.
36. Evans L, Frick MC. Car mass and fatality risk: Has the relationship changed? Am J Public Health 1994;84:33-6.
37. Rasouli MR, Rahimi-Movaghar V, Maheronnaghsh R, Yousefian A, Vaccaro AR. Preventing motor vehicle crashes related spine injuries in children. World J Pediatr 2011;7:311-7.
38. Olsen CS, Cook LJ, Keenan HT, Olson LM. Driver seat belt

use indicates decreased risk for child passengers in a motor vehicle crash. Accid Anal Prev 2010;42:771-7.

39. Richardson S, Grzebieta RH, Rechnitzer G. Proposal for dynamic rollover protective system test. Int J Crashworthiness 2002;8:133-41.
40. Eigen AM. Examination of Rollover Crash Mechanisms and Occupant Outcomes. Washington: National Crash Centre for Statistical Analysis; 2003.
41. Kahane CJ. An Evaluation of Door Locks and Roof Crush Resistance of Passenger Cars. Federal Motor Vehicle Safety Standards 206 and 216, DOT HS 807 489. Washington, D.C: NHTSA; 1989.
42. Deutermann W. Characteristics of Fatal Rollover Crashes, DOT HS 809 438, 2002. Washington, D.C: NHTSA; 2001.
43. Winnicki J. Estimating the injury-reducing benefits of ejection-mitigating glazing. Available from: http://www.ntl.bts.gov/lib/000/200/266/00266.pdf. [Last accessed on 2013 Sep 05].
44. Howard A, McKeag AM, Rothman L, Comeau JL, Monk B, German A. Ejections of young children in motor vehicle crashes. J Trauma 2003;55:126-9.
45. Scheidler MG, Shultz BL, Schall L, Ford HR. Risk factors and predictors of mortality in children after ejection from motor vehicle crashes. J Trauma 2000;49:864-8.
46. Esterlitz JR. Relative risk of death from ejection by crash type and crash mode. Accid Anal Prev 1989;21:459-68.
47. Gloeckner DC, Moore TL, Steffey D, Le-Resnick H, Bare C, Corrigan CF. Implications of vehicle roll direction on occupant ejection and injury risk. Annu Proc Assoc Adv Automot Med 2006;50:155-70.
48. Moore TL, Vijayakumar V, Steffey DL, Ramachandran K, Corrigan CF. Biomechanical factors and injury risk in high-severity rollovers. 49th Annual Proceedings of the Association for the Advancement of Medicine; 2005.
49. Parenteau C, Gopal M, Viano D. Near-and far-side adult front passenger kinematics in a vehicle rollover. Society of Automotive Engineers 2001-01-0176; 2001.
50. Parenteau CS, Shah M. Driver Injuries in U.S. Single-Event Rollovers. Society of Automotive Engineers Paper 2000-01-0633; 2000.
51. Viano DC, Parenteau CS. Ejection and severe injury risks by crash type and belt use with a focus on rear impacts. Traffic Inj Prev 2010;11:79-86.
52. WHO. World Report on Road Traffic Injury Prevention. Available from: http://www.who.int/violence_injury_prevention/publications/road_traffic/world_report/en/index.html. Last accessed on 2013 Sep 05].
53. Funk JR, Cormier JM, Bain CE, Wirth JL, Bonugli EB, Watson RA. Factors affecting ejection risk in rollover crashes. Ann Adv Automot Med 2012;56:203-11.
54. Improved rollover prevention technology for automotive vehicles community research and development information service. Available from: http://www.cordis.europa.eu/fetch?CALLER=MSS_IE_RESU_EN and ACTION=D and DOC=31 and CAT=RESU and QUERY=013cce6a7a5e:7443:217deb11 and RCN=40126. Last accessed on 2013 Sep 05].
55. What is distracted driving. U.S. Department of Transportation. Available from: http://www.distraction.gov/. [Last retrieved on 2012 Apr 26].
56. Driver Distraction in Commercial Vehicle Operations. U.S. Department of Transportation. Available from: http://www.distraction.gov/download/research-pdf/Driver-Distraction-Commercial-Vehicle-Operations.pdf. [Last retrieved on 2012 Apr 26].
57. Cell phone and texting accident statistics. Edgar Snyder and Associates. Available from: http://www.edgarsnyder.com/car-accident/cell-phone/cell-phone-statistics.html. [Last retrieved on 2012 Apr 26].

How to cite this article: El-Hennawy HM, El-Menyar A, Al-Thani H, Tuma M, Parchani A, Abdulrahman H, *et al*. Epidemiology, causes and prevention of car rollover crashes with ejection. Ann Med Health Sci Res 2014;4:495-502.

Source of Support: Nil. **Conflict of Interest:** None declared.