The Importance of Vehicle Rollover as a Field Triage Criterion

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Background: The objective of this article was to review the importance of vehicle rollover as a field triage criterion. In 1987, field triage criteria were developed by the American College of Surgeons Committee on Trauma that have been propagated repeatedly over the subsequent 20+ years. The field triage decision scheme is based on abnormal physiology, obvious abnormal anatomy, mechanism of injury likely to result in severe injury, and other factors (age, etc.) and was supported by available science at that time. In 2005, the triage scheme was revised by a committee, and vehicle rollover as a crash scene triage criterion was dropped in 2006.

Methods: The medical literature and data from the Department of Transportation/National Highway Traffic Safety Administration (NHTSA) Fatal Accident Reporting System and the National Automotive Sampling System were analyzed to determine the contribution of rollover to morbidity and mortality.

Results: Vehicle rollovers represent a small but significant percentage of crashes; of the almost 12 million vehicle crashes reported by NHTSA in 2004, only 2.4% were rollovers, but these accounted for one-third of all crash-related occupant deaths and about 25,000 serious injuries every year. Rollovers are associated with the second highest number of vehicle occupant deaths by crash mode, three times the risk of injury when compared with other impact directions ($p < 0.0001$), specific types of injury such as head and spinal cord injuries, and a risk of death >15 times the risk in nonrollover crashes.

Conclusion: The data and literature unequivocally show a strong and disproportionate association between vehicle rollover and injury severity and death. Because it is difficult to devise simple, accurate decision rules for point of wounding and vehicle crash scene triage, simple, powerful relationships should be used when possible. Thus, the exclusion of rollover as a triage criterion seems to be ill advised.

Key Words: Field triage criteria, American College of Surgeons, Vehicle rollover, Vehicle crash, Injury, Death.

(*J Trauma.* 2009;67: 350–357)

In trauma systems, emergency medical services (EMS) dispatchers and scene providers must identify the more than 200,000 people with serious to fatal injuries among the 27 million vehicles in crashes each year (~1%).[1] They typically make their treatment and triage decisions with the aid of the American College of Surgeons (ACS) field triage decision scheme or modifications thereto. Designed to err on the side of patient safety by minimizing undertriage at the risk of overtriage, it provides a sequence of four steps to ascertain (1) whether vital signs are unstable and/or the patient is unconscious, (2) whether certain critical injuries (e.g., crush chest, amputations, proximal and multiple limb fractures, etc.) evident at the scene are present, (3) which known vehicle-related risk factors (e.g., high-delta velocity, ejection, pedestrian struck, rollover, etc.) are present, and (4) which other high-risk host factors (e.g., patient is a child, is pregnant, etc.) could be taken into account. This sequence enables dispatchers and providers to stratify the need for transport to a trauma center with some confidence.[2]

The ACS field triage decision scheme was a reflection of factors that the ACS Committee on Trauma considered to have associations with vehicle crash morbidity and mortality. It has been partially or wholly adopted as operating policy by EMS and healthcare systems; all levels of government throughout the world; and insurance companies and other payors.[3] It directly impacts how crash occupants are treated and where and how they are transported, may affect hospital/trauma center caseloads in some states, and affect reimbursement by third-party payors, and ultimately, public policy.

Submitted for publication October 15, 2008.
Accepted for publication April 17, 2009.

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Presented as a poster at the 67th Annual Meeting of the American Association for the Surgery of Trauma, September 24–27, 2008, Maui, Hawaii.
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DOI: 10.1097/TA.0b013e3181aabdc7

BACKGROUND

The ACS field triage decision scheme incorporated mechanisms of injury deemed likely to result in severe injury to the body in an effort to more completely identify patients at risk of serious injury not immediately apparent postincident who thus could require transport to a trauma center.[4] Early work determined which threshold velocities, change in velocity (delta velocity) and impact reconfigurations, and directions might best augment the physiologic variables to cumulatively predict injury[5] and identified factors (e.g., steering wheel deformation, 20+ inches of vehicle crush) suggestive of occult torso injury.[6,7] Preventable death rates in the range 7% to 21%[8–11] fueled additional research to facilitate more timely and effective use of crash severity information from the scene to improve the care of crash victims.[12] An important development stemming from this work was the URGENCY triage algorithm,[13–18] released as a software program in 1997 to improve computer-aided dispatch of rescue personnel using crash recorder data.[15] URGENCY comprised variables related to the vehicle, impact, and occupant characteristics. Several of these variables, including delta velocity, age, safety belt use and type, ejection, entrapment, intrusion, and rollover, were shown to have especially strong associations with probability of death and serious (Maximum Abbreviated Injury Scale ≥3) injury.[12]

Since its development by one of us (HRC) in the late 1980s, the basic construct of the ACS field triage decision scheme has stood the test of time but the content has been valuably refined and updated several times. The most recent revision, published in 2006, contained major changes from its predecessors, with the most notable being the removal of rollover from the vehicle-related risk factors. The purpose of this article is to determine whether the literature and data support exclusion of vehicle rollover as a field triage criterion.

Originally published in 1987,[19] the ACS field triage decision scheme was updated in 1990, 1993, 1999, and 2006. The most recent undertaking was rationalized because of changes that had taken place in trauma and EMS systems, disparities between rural and urban systems, economic concerns about overtriage and undertriage, concerns about surge capacity and resource utilization, and the potential impacts of the criteria upon industry and governmental entities.[3]

Reevaluation of the 1999 criteria by a multidisciplinary team resulted in substantial changes in the 2006 version.[20] Fine-tuning the thresholds for triage in the absence of decision thresholds being met in steps 1 and 2 has always been a challenge. Changes in the 2006 revision occurred primarily in steps 3 and 4. In step 3, three vehicle-related factors were deleted: (1) initial speed >40 mph (also related to rollover), (2) extrication time >20 minutes (extrication is often needed in rollover crashes), and (3) rollover (Fig. 1). In step 4, changes included deletion of several factors (cardiac and respiratory disease, diabetes, etc.) and addition of others (time-sensitive extremity injury, EMS provider judgment, etc.). Although each change and the quality of the supporting evidence could be examined here at length, it is the rollover component that we focus on here because of its historical and growing relationship with severe injury, long-term disability, economic impact, and death. Indeed, the deaths associated with rollover have risen so spectacularly that the National Highway Traffic Safety Administration (NHTSA) has, for the past several years, been engaged in a process of creating standards that will strengthen vehicle A and B pillars to prevent roof collapse and the consequent head and neck injuries.[21]

Rationale for removal of rollover from the triage criteria was given by Wang[3] and more recently in a Morbidity and Mortality Weekly Report issued by the Centers for Disease Control and Prevention.[22]The process focused on a minority of studies that showed minimal impact of rollover and avoided the preponderance of evidence to the contrary. Several primary assumptions upon which this effort was based, i.e., that rollover is only associated with increased injury severity when the occupant is partially or fully ejected[22] and that rollover-related injuries will be detected in steps 1 and 2,[23] can be seriously questioned and will be discussed here.

METHODS

The work represented here involved a review of both the medical literature on vehicle rollover and of national data published by the US Department of Transportation. A PubMed search using the search terms “vehicle” plus “rollover” yielded 146 studies between August 1978 and April 2009. The sole inclusion criterion for consideration was that the study examines the contribution of rollover to vehicle crash-related outcomes. Of the 146 studies, 118 were excluded because they dealt with biomechanics unrelated to rollover outcome (33), farm vehicles (29), or all-terrain vehicles (10); 9 were case reports (9); or were otherwise not applicable (37, e.g., dealt with stress/strain, safety belt use, general crash prevention, etc.). This left a total of 28 studies between 1989 and 2009 that were considered here.

Also considered were NHTSA reports containing national statistics. For these data, we predominantly relied upon the March 2007 NHTSA report, *An Analysis of Motor Vehicle Rollover Crashes and Injury Outcomes*,[24] and the Notice of Proposed Rulemaking (NPRM) for the federal motor vehicle safety standard (FMVSS), 216-Roof Crush Resistance.[21] Mortality data were culled from the NHTSA Fatality Analysis Reporting System (FARS) database (1978–2006), which contains more than 1.3 million US motor vehicle fatality records with ~100 data elements in each record that characterize the crash, the vehicle, and occupants.[25] Morbidity data were culled from NHTSA’s Crash Injury Research and Engineering Network and National Automotive Sampling System (NASS), a repository of crash data composed of Crashworthiness Data and General Estimates Systems (CDS and GES) data used for vehicle crash and injury analyses. Both CDS and GES are based on representative random crash data that include a spectrum of crash-related factors and severity of injury. Data used by NHTSA in FMVSS 216 and surrounding documentation were from FARS and CDS (1997–2002) for occupant fatalities and injuries (AIS 3–5) sustained in towaway crashes.

Definition of Vehicle Rollover

Rollover is defined as a vehicle overturned by at least one quarter turn, i.e., on its side (Fig. 2). Some rollovers involve many quarter turns and the final resting position may be on the vehicle’s side, roof, or back on its wheels. Factors that cause a vehicle to roll over include trajectory (i.e., turning vs. straight), vehicle type, and speed (precrash velocity may be the most predictive factor).[26]

RESULTS

Risk of Death

NHTSA data on crash fatalities (FARS), available from 1978 to 2006, reveal that during this 28-year-period, 1,275,932 people died from crash injuries, of whom 297,212 (23%) died in rollover crashes. In 2004, 31,693 occupant crash deaths occurred in the United States, of which 10,553 (33%) involved vehicle rollover (Table 1).[24] Rollovers are associated with the second highest number of vehicle occupant deaths by crash mode when compared with other impact directions ($p < 0.0001$).[21] NASS GES data (1994–2004) showed an average probability of death in a rollover crash of 2.58% compared with 0.15% in a nonrollover crash (Fig. 3, A)—approximately 15 times the risk—and a 17.5% increase in rollover crash deaths compared with a 3.6% decrease in

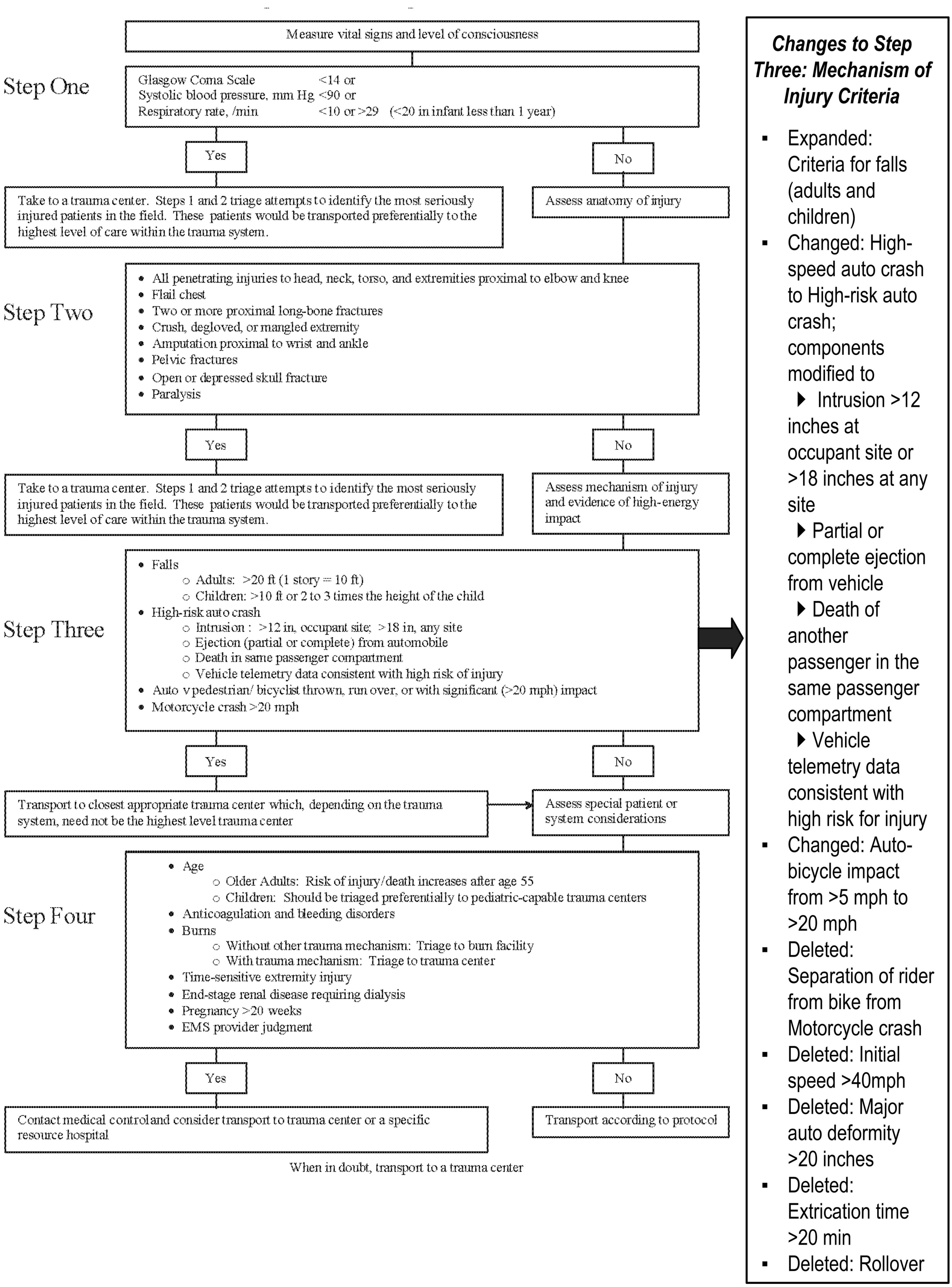

Figure 1. 2006 Field Triage Decision Scheme: mechanism of injury changes from 1999 version.[20]

Figure 2. Rollover crash photo.

TABLE 1. Rollover vs. Nonrollover Crash Injury and Death, 2004[24]

	Rollover		Nonrollover	
	No.	Percent	No.	Percent
All involved occupants*	393,000	100.0	13,700,000	100.00
Injured*	232,000	59.0	2,685,000	19.60
Killed†	10,553	2.7	21,140	0.15

* Data source: GES (sample of 50,000 police/accident reports).
† Data source: FARS (census and HS 810 741).

nonrollover crash deaths.[24] Rollover is an easily discernable and known factor that increases the risk of fatal outcome and severe injury in a motor vehicle crash.[27–30]

If the increased propensity for rollover of sport utility vehicles (SUVs)[31,32] is taken into account, the associated frequency and fatality rate increases substantially. SUV rollover frequency is approximately twice that of passenger cars, and the SUV rollover injury and fatality rates are 2 to 3 times that of passenger cars[33,34] SUVs had a rollover involvement rate of 34% in fatal crashes and of 10% in injury crashes, compared with 17% and 4% for passenger cars.[35] This is significant because almost 12% of the US vehicles in operation as of November 2008 were SUVs.[36]

Injury Severity

In the NPRM leading up to promulgation of the Roof Crush Resistance standard,[21] NHTSA estimated that 23,793 (8.7%) serious (AIS 3–5) injuries and 9,942 (3.6%) deaths occur in 272,925 rollover vehicle crashes each year—using 1997–2002 data on nonconvertible vehicles.[21] In their study of the serious injuries and deaths associated with rollover crashes reported in the NPRM, NHTSA concluded that rollover crashes present three times the risk of injury of other types of impacts (frontal, side, and rear).[21] Other NHTSA

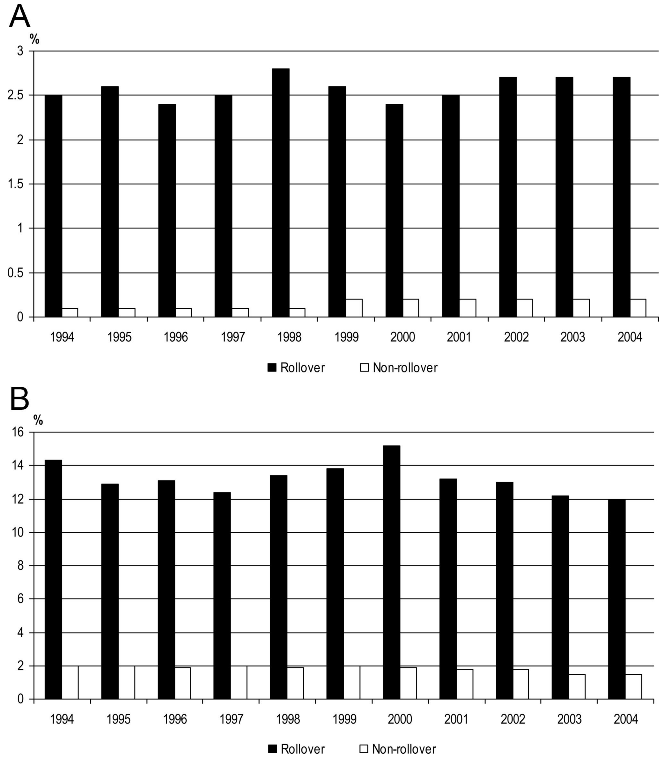

Figure 3. Rollover versus nonrollover occupant crashes, 1994–2004. (*A*) Fatalities per year. (*B*). Incapacitating injuries per year.[24]

data show the consistent disparity in rollover and nonrollover injury data through time (Fig. 3, B).[24]

The medical literature shows that rollover crashes are associated with increased injury severity compared with nonrollovers,[37] and rollover has been associated with specific types of injuries including severe whiplash[38] and injuries to the torso,[39] spleen,[40] and especially spinal cord.[41–43] With the exception of one early study that showed no additional contribution of rollover to spinal cord injury in 30 cases,[44] the predominant current view is that there is a clear correlation. Data from a state (Utah) spinal cord injury registry indicate that almost half (49%) of spinal cord injuries result from motor vehicle crashes, of which 70% involve vehicle rollover.[45] Most recently, among the 2% of 17,208 patients in the Canadian C-Spine Rule study with cervical spine fracture, rollover was definitively demonstrated to be a significant risk factor among those whose injuries were sustained during motor vehicle collisions.[42]

Analysis of severely injured motor vehicle crash occupants has shown that rollovers are associated with a statistically significant increased risk of spinal cord injury over nonrollover crashes that varies by vehicle type.[41] Analysis of Australian Spinal Cord Injury Register data indicated that the age-adjusted rate of spinal cord injury in Australia was 14.5 per million people, of which 43% were due to motor vehicle crashes that primarily involved rollover.[46] Aggregated case reports from this database indicated that the likelihood of spinal cord injury was especially high in non-sedan-type cars involved in rollover crashes.[47]

In children, risk of injury and death associated with rollover has also been shown to be greater than that for nonrollover crashes.[48–50] A 1993–1998 study of CDS data on the US children under the age of 16 showed an adjusted relative risk of rollover-associated injury and death of 2.1 (95% CI, 1.1–3.8) and 1.8 (95% CI, 1.1–2.8), respectively, compared with nonrollover.[51] NASS GES and FARS data for two centers in Canada showed a rollover frequency of 2.2% that was associated with 28% of child passenger deaths.[52] Rollover also raises the index of suspicion for injuries in the unborn. According to a survey of clinical directors of emergency medicine teaching programs, fetal monitoring in patients with a viable fetus and no abdominal pain is routinely used 46% of the time after falls and 92% of the time after a strike to the abdomen or vehicle rollover.[53]

Ejection

Factors that impact injury severity in a rollover crash include roof crush, entrapment, ejection, intrusion (especially that of the roof rail or B-pillar), seat belt use/failure, and low vehicle stability factors.[5,54,55] Ejection increases the risk of death by a factor of five[56] and has been associated with approximately two-thirds of rollover crash deaths.[57,58] The notion (propagated by those responsible for removal of rollover from the triage criteria) that rollover only increases risk of injury and death when ejection is a factor, however, is not supported by data and is directly contradicted by recent federal initiatives. These include the recent proposal of federal roof crush standards[21,59] and enactment of FMVSS No. 126 mandating use of Electronic Stability Control systems on most US vehicles[60] by 2012 "as part of a comprehensive plan for reducing the serious risk of rollover crashes and the risk of death and serious injury in those crashes"[60] primarily related to roof collapse. In the NPRM published in the *Federal Register* in August 2005, only nonejected occupants were considered in the analysis, which concluded that a sufficient risk of injury and death existed to move forward with promulgation of the roof crush resistance standards.[21]

As described by Eigen,[61,62] unejected occupants comprise the majority (93%) of those injured in rollover collisions, and 58% of those with severe (defined as Maximum AIS [MAIS] 3+) injuries. Additionally, acknowledgment that "the need for extrication is caused most often by intrusion into the passenger compartment"[22] is further evidence of the risks faced by nonejected occupants in rollover crashes, whose "most severe injury was associated with roof contact."[21] Matchboxing, and header and pillar collapse are some forms of roof crush that are associated with injuries that include brain injuries, as well as spinal injuries (most frequently, paralysis) from neck fractures, axial neck compression, and hyperextension in nonejected occupants in rollover crashes.[63]

Costs

Because they are disproportionately deadly and incapacitating, the costs of rollover injuries are substantial. In 2005, crash fatalities resulted in an estimated comprehensive cost of about $36 billion.[64] Adding costs for serious but nonfatal injuries (e.g., paralysis, brain injury) brings estimates to about $50 billion incurred each year.[64]

DISCUSSION

On average, >450,000 occupants are involved in a rollover crash each year and 59% of the time there will be injured occupants.[21] What is not immediately known is which of the injured will be among the 14% with serious to fatal injuries such as asphyxiation, brain, and spinal cord injuries, limb amputations, and burns, and which may require extrication rescue teams. What is known, as shown by the data and literature, is that occupants of vehicles involved in rollover crashes are much more likely to be injured or killed than if their vehicle does not roll. The rollover criterion helps dispatchers expedite EMS and extrication resources to the scene to provide timely optimal care to the people involved in these relatively rare, but dangerous crashes. Further, it has implications for EMS notification, resource allocation, transport, and hospital choice and readiness. A significant shortcoming of the current revision process was failure to consider the fact that 911 dispatchers also rely upon the criteria.

Overtriage

As noted in the most recent edition of *Prehospital Trauma Care: Resources for Optimal Care of the Injured Patient*,[20] in which the revised field triage decision scheme appears, "Prehospital personnel should be trained to recognize mechanisms of energy transfer that could lead to severe injury. The successful management of patients requires the identification of specific injuries or mechanisms likely to cause severe injury to allow correct triage to an appropriate facility." Point-of-wounding triage in close temporal proximity to the time of injury, particularly in diffuse blunt trauma such as automobile crashes, inevitably results in inaccuracies in matching patient need with timely available healthcare resources. In recognition of this fact, the ACS deemed that an undertriage rate of 5% to 10% was necessary despite being associated with a 30% to 50% overtriage rate because the patient population affected, i.e., the most severely injured, was quite small (~1% of all crash-related injuries).[65,66]

The purpose of the triage guideline is to accumulate a variety of observable data points that have an established relationship with injury severity, resource requirements, or outcome and create a decision scheme within which there is a threshold for determining trauma center need. Ideally, such a decision scheme should involve trend analysis or sequential observations on the pathophysiological consequences of injuries that are not anatomically obvious at the scene. Such deterministic relationships necessarily produce a probabilistic tool when used to predict outcomes of individual patients. One consequence of a probabilistic decision scheme is a significant error in selection. However, the scheme must be founded to err on the side of patient safety, and, thus, sensitivity/specificity assessments and tradeoffs are not necessarily the best tools for judging appropriateness of field triage decision schemes.

Use of Mechanism of Injury in Triage

Injury, in its essence, is about energy coupling to human tissue. Mechanism of injury (MOI) was added to the triage criteria to provide a guide to high-energy transfer, particularly to the torso and axial skeleton in patients without obvious anatomic derangement or abnormal vital signs at the scene but who are at risk of liver, lung, spleen, or other internal injury. The study of MOI in triage has produced a variety of results (e.g., not predictive,[67] not very predictive,[68] less predictive than physiologic variables in children,[69] MOI alone not indicative of abdominal injury,[70] variously predictive of injury depending on specific mechanism[71–73]). Other studies show positive associations,[74,75] including the role of MOI in identifying patients who have normal physiology in conjunction with anatomic injuries that may rapidly deteriorate.[5] Most recently, a relationship between MOI—including rollover—and elevated risk of cervical spine fracture was quantitatively demonstrated.[42]

The predictive value of the MOI component of the ACS field triage criteria is currently being examined in a study of 15,000 patients admitted to three Level I trauma centers. The goal of the study is to gain more information about the use of MOI as a guide to triage decisions when the physiologic/anatomic criteria are not met.[76] A recent attempt to refine the criteria, in which 10 prehospital variables seen in 4,326 injured persons across the United States and Canada were examined, yielded a simplified decision rule that included field intubation, Glasgow Coma Scale score <8, age ≥ 70 years, and MOI.[77] Although the rule was lacking in specificity, the ongoing research demonstrates that MOI is still widely held to be of value in identifying patients at risk of serious but not immediately apparent injury.

CONCLUSION

The data and review of the literature show that vehicle rollover is a clear contributor to injury and death that is easily discernable at the scene. Because it is difficult to devise straightforward, accurate decision rules for point of wounding and vehicle crash scene triage, simple, powerful relationships should be used when possible. Thus, the exclusion of rollover as a triage criterion seems to be ill advised.

REFERENCES

1. U.S. Department of Transportation, NHTSA. Economic impact of motor vehicle crashes 2000. Available at: http://www.nhtsa.dot.gov/staticfiles/DOT/NHTSA/Communication%20&%20Consumer%20Information/Articles/Associated%20Files/EconomicImpact2000.pdf. Accessed September 12, 2008.
2. National Highway Traffic Safety Administration. National EMS Research Agenda. EMS update. Fall, 2006. Available at: http://www.nhtsa.dot.gov/people/injury/ems/EMSUpdateFall/pages/page4.htm. Accessed August 19, 2008.
3. Wang SC. Upcoming revisions to field triage criteria. Presented at the CIREN Public Meeting, Milwaukee, WI, September 2006. Available at: http://www.nhtsa.dot.gov/portal/nhtsa_static_file_downloader.jsp?file=/staticfiles/DOT/NHTSA/NRD/Featured%20Services/CIREN/2006%20Presentations/Michigan0906.pdf. Accessed August 27, 2008.
4. Knudson P, Frecceri CA, DeLateur SA. Improving the field triage of major trauma victims. *J Trauma.* 1988;28:602–606.
5. Jones IS, Champion HR. Trauma triage: vehicle damage as an estimate of injury severity. *J Trauma.* 1989;29:646–653.
6. Lombardo LV, Ryan SD. *Detection of Internal Injuries in Drivers Protected by Air Bags*. Washington, DC: US DOT, Office of Crashworthiness Research, Research and Development; 1993.
7. Augenstein JS, Digges KH, Lombardo LV, et al. Occult abdominal injuries to airbag-protected crash victims: a challenge to trauma systems. *J Trauma.* 1995;38:502–508.
8. Esposito TJ, Reynolds SA, Sanddal ND, et al. Rural preventable mortality study. NHTSA Report DOT HS 807 973. Washington, DC: US Department of Transportation, NHTSA; 1992.
9. Maio RF, Burney RE, Gregor MA, Baranski M, Welch KB, Rothman ED. Michigan rural preventable mortality study. NHTSA Report DOT HS 808 341. Washington, DC: US Department of Transportation, NHTSA; 1995.
10. Cunningham PRG. North Carolina preventable mortality study with inter-rater reliability modifications. NHTSA Report DOT HS 808 345. Washington, DC: US Department of Transportation, NHTSA; 1995.
11. Center for Transportation Injury Research. Occult Injury Database. Available at: http://www.cubrc.org/centir/docs/Occult.pdf. Accessed September 4, 2008.
12. Malliaris AC, Digges KH, DeBlois JH. Relationships between crash casualties and crash attributes. SAE Technical Paper Series 970393. Warrendale, PA: Society of Automotive Engineers; 1997.
13. National Highway Traffic Safety Administration (NHTSA). Crash Injury Research and Engineering Network (CIREN) program report, 2001. DOT HS 809 377. Washington, DC: US Department of Transportation, NHTSA; 2001.
14. Champion HR, Augenstein, JS, Blatt AJ, et al. New tools to reduce deaths and disabilities by improving emergency care: URGENCY software, occult injury warnings, and air medical services database. NHTSA Paper No. 05-0191. Washington, DC: US Department of Transportation, NHTSA; 2005. Available at: www.cubrc.org/centir/docs/new_tools.pdf. Accessed July 12, 2007.
15. Champion HR, Augenstein JS, Cushing B, et al. Reducing highway deaths and disabilities with automatic wireless transmission of serious injury probability ratings from crash recorders to EMS providers. In: *Proceedings of the International Symposium on Transportation Recorders*. Arlington, VA: National Transportation Safety Board; 1999:67–84. Available at: http://www.ntsb.gov/events/symp_rec/proceedings/authors/champion.htm. Accessed October 7, 2006.
16. William Lehman Injury Research Center at the University of Miami School of Medicine. CIREN Program Report, October 2002. Available at: http://www-nrd.nhtsa.dot.gov/departments/nrd-50/ciren/networkreport/Miami.html. Accessed July 12, 2007.
17. Augenstein JS, Digges KH, Ogata S, et al. Development and validation of the Urgency algorithm to predict compelling injuries (DOT HS 809 220). Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles, Amsterdam, June 4–7, 2001.
18. Validation of the URGENCY algorithm for near side crashes. In: *46th Annual Proceedings of the Association for the Advancement of Automotive Medicine*; 2002:305–314.
19. American College of Surgeons (ACS). Hospital and Prehospital Resources for Optimal Care of the Injured Patient. Chicago, IL: ACS; 1987.
20. American College of Surgeons (ACS). *Resources for Optimal Care of the Injured Patient: 2006*. Chicago, IL: ACS; 2006.
21. Federal Motor Vehicle Safety Standards; Roof Crush Resistance. Notice of proposed rulemaking. *Federal Register*. 2005;70:49223.
22. Morbidity and Mortality Weekly Report. Guidelines for field triage of injured patients. Recommendations of the national expert panel on field triage. January 23, 2009. Available at: www.cdc.gov/mmwr/pdf/rr/rr5801.pdf. Accessed February 3, 2009.
23. CDC and national expert panel promote revised field triage guidelines of trauma patients. Conference call with Hunt RC, Sasser SM (CDC, Division of Injury Response, National Center for Injury Prevention and Control), January 28, 2009, 3 pm.
24. NHTSA, Center for Statistics and Analysis. An analysis of motor vehicle rollover crashes and injury outcomes. DOT HS 810 741. Washington, DC: NHTSA, Center for Statistics and Analysis; 2007.
25. NHTSA, Fatality Analysis Reporting System (FARS). Available at: http://www.nhtsa.dot.gov/people/ncsa/fars.html. Accessed September 3, 2008.

26. Malliaris AC, DeBlois JH. Pivotal characterization of car rollovers. In: *Proceedings of the International Technical Conference on Experimental Safety Vehicles, Vol. II*. Washington, DC: NHTSA; 1991:721–728.
27. Awadzi KD, Classen S, Hall A, Duncan RP, Garvan CW. Predictors of injury among younger and older adults in fatal motor vehicle crashes. *Accid Anal Prev.* 2008;40:1804–1810.
28. Gonzales MM, Dickinson LM, DiGuiseppi C, Lowenstein SR. Student drivers: a study of fatal motor vehicle crashes involving 16-year-old drivers. *Ann Emerg Med.* 2005;45:140–146.
29. Treacy PJ, Jones K, Mansfield C. Flipped out of control: single-vehicle rollover accidents in the Northern Territory. *Med J Aust.* 2002;176:260–263.
30. Lane PL, McClafferty KJ, Green RN, Nowak ES. A study of injury-producing crashes on median divided highways in southwestern Ontario. *Accid Anal Prev.* 1995;27:175–184.
31. Keall M, Newstead S. Induced exposure estimates of rollover risk for different types of passenger vehicles. *Traffic Inj Prev.* 2009;10:30–36.
32. Kweon YJ, Kockelman KM. Overall injury risk to different drivers: combining exposure, frequency, and severity models. *Accid Anal Prev.* 2003;35:441–450.
33. Jehle D, Kuebler J, Auinger P. Risk of injury and fatality in single vehicle rollover crashes: danger for the front seat occupant in the "outside arc." *Acad Emerg Med.* 2007;14:899–902.
34. Deutermann W. Characteristics of fatal rollover crashes. DOT HS 809 438. Washington, DC: National Highway Traffic Safety Administration, National Center for Statistics and Analysis; 2002. Available at: http://www.citizen.org/documents/NCSAReport.pdf. Accessed December 10, 2008.
35. NHTSA, National Center for Statistics and Analysis. Traffic safety facts, 2007 data. DOT HS 810 993. Available at: http://www-nrd.nhtsa.dot.gov/cats/listpublications.aspx?Id=24&ShowBy=Category. Accessed February 2, 2009.
36. Number of SUVs, pickup trucks on the road holds strong, according to Experian Automotive. November 4, 2008. Data from Experian Automotive's AutoCount Vehicles in Operation database. Available at: http://www.aftermarketnews.com/Item/37214/number_of_suvs_pickup_trucks_on_the_road_holds_strong_according_to_experian_automotive.aspx. Accessed December 10, 2008.
37. Singleton M, Qin H, Luan J. Factors associated with higher levels of injury severity in occupants of motor vehicles that were severely damaged in traffic crashes in Kentucky, 2000–2001. *Traffic Inj Prev.* 2004;5:144–150.
38. Holm LW, Carroll LJ, David Cassidy J, Ahlbom A. Factors influencing neck pain intensity in whiplash-associated disorders in Sweden. *Clin J Pain.* 2007;23:591–597.
39. Nirula R, Talmor D, Brasel K. Predicting significant torso trauma. *J Trauma.* 2005;59:132–135.
40. Al-Qahtani MS. The pattern and management outcomes of splenic injuries in the Assir region of Saudi Arabia. *West Afr J Med.* 2004;23:1–6.
41. O'Connor PJ, Brown D. Relative risk of spinal cord injury in road crashes involving seriously injured occupants of light passenger vehicles. *Accid Anal Prev.* 2006;38:1081–1086.
42. Thompson WL, Stiell IG, Clement CM, Brison RJ; Canadian C-Spine Rule Study Group. Association of injury mechanism with the risk of cervical spine fractures. *CJEM*. 2009;11:14–22.
43. O'Connor P. Work related spinal cord injury, Australia 1986–97. *Inj Prev.* 2001;7:29–34.
44. Cushman LA, Good RG, States JD. Characteristics of motor vehicle accidents resulting in spinal cord injury. *Accid Anal Prev.* 1991;23:557–560.
45. Thurman DJ, Burnett CL, Beaudoin DE, et al. Risk factors and mechanisms of occurrence in motor vehicle-related spinal cord injuries: Utah. *Accid Anal Prev.* 1995;27:411–415.
46. O'Connor P. Incidence and patterns of spinal cord injury in Australia. *Accid Anal Prev.* 2002;34:405–415.
47. O'Connor P. Injury to the spinal cord in motor vehicle traffic crashes. *Accid Anal Prev.* 2002;34:477–485.
48. 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;50:171–184.
49. Daly L, Kallan MJ, Arbogast KB, Durbin DR. Risk of injury to child passengers in sport utility vehicles. *Pediatrics.* 2006;117:9–14.
50. Viano DC, Parenteau CS. Fatalities of children 0–7 years old in the second row. *Traffic Inj Prev.* 2008;9:231–237.
51. 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.
52. Howard A, McKeag AM, Rothman L, Comeau JL, Monk B, German A. Ejections of young children in motor vehicle crashes. *J Trauma.* 2003;55:126–129.
53. Kolb JC, Carlton FB, Cox RD, Summers RL. Blunt trauma in the obstetric patient: monitoring practices in the ED. *Am J Emerg Med.* 2002;20:524–527.
54. Conroy C, Hoyt DB, Eastman AB, et al. Rollover crashes: predicting serious injury based on occupant, vehicle, and crash characteristics. *Accid Anal Prev.* 2006;38:835–842.
55. Esterlitz JR. Relative risk of death from ejection by crash type and crash mode. *Accid Anal Prev.* 1989;21:459–468.
56. Malliaris A, Digges K. Crash protection offered by safety belts. In: *Proceedings of the 11th ESV Conference*; 1987;242–252.
57. 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, DC: NHTSA; 1989.
58. Deutermann W. Characteristics of fatal rollover crashes. DOT HS 809 438. Washington, DC: NHTSA; 2002.
59. Crash Network. FMVSS standards related to crash testing. Available at: http://www.crash-network.com/Regulations/FMVSS/fmvss.html. Accessed September 5, 2008.
60. US Department of Transportation, National Highway Traffic Safety Administration (NHTSA). Final regulatory impact analysis, FMVSS No. 126: electronic stability control systems, 2007. Available at: http://www.nhtsa.dot.gov/portal/site/nhtsa/menuitem. 012c081c5966f0ca3253ab10cba046a0/. Accessed August 29, 2008.
61. Eigen A. *Characterization of Attributes Applicable to a Rollover Crash Severity Metric*. Ashburn, VA: The George Washington University/NHTSA; 2004.
62. Eigen AM. Rollover crash mechanisms and injury outcomes for restrained occupants. NHTSA Technical Report HS 809 894. Washington, DC: NHTSA; 2005. Available at: http://www-nrd.nhtsa.dot.gov/Pubs/809894.pdf. Accessed April 2, 2009.
63. Roof crush. Available at: http://www.safetyforum.com/roofcrush/. Accessed February 4, 2009.
64. Chang J, Cohen D, Blincoe L, Subramanian R, Lombardo L. CICAS-V research on comprehensive costs of intersection crashes. Proceedings of the ESV Conference, Lyon, France, June 2007. Available at: http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv20/07-0016-O.pdf. Accessed September 7, 2008.
65. American College of Surgeons (ACS). *Resources for Optimal Care of the Injured Patient*. Chicago, IL: ACS; 1993.
66. Garthe E, Mango N. Scene triage criteria associated with fatal crashes and potential for use of event data recorder (EDR) data. DOT HS 809 823. Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicles, No. 05-0445, Washington, DC, 2005. Available at: http://www_nrd.nhtsa.dot.gov/pdf/nrd_01/esv/esv19/05_0445_O.pdf. Accessed December 5, 2008.
67. Santaniello JM, Esposito TJ, Luchette FA, Atkian DK, Davis KA, Gamelli RL. Mechanism of injury does not predict acuity or level of service need: field triage criteria revisited. *Surgery.* 2003;134:698–704.
68. Esposito TJ, Offner PJ, Jurkovich GJ, Griffith J, Maier RV. Do prehospital trauma center triage criteria identify major trauma victims? *Arch Surg.* 1995;130:171–176.
69. Engum SA, Mitchell MK, Scherer LR, et al. Prehospital triage in the injured pediatric patient. *J Pediatr Surg.* 2000;35:82–87.
70. Brasel KJ, Nirula R. What mechanism justifies abdominal evaluation in motor vehicle crashes? *J Trauma.* 2005;59:1057–1061.
71. Palanca S, Taylor DM, Bailey M, Cameron PA. Mechanisms of motor vehicle accidents that predict major injury. *Emerg Med (Fremantle).* 2003;15:423–428.
72. Kohn MA, Hammel JM, Bretz SW, Stangby A. Trauma team activation criteria as predictors of patient disposition from the emergency department. *Acad Emerg Med.* 2004;11:1–9.

73. Henry MC, Hollander JE, Alicandro JM, Cassara G, O'Malley S, Thode HC Jr. Incremental benefit of individual American College of Surgeons trauma triage criteria. *Acad Emerg Med.* 1996;3:992–1000.
74. Long WB, Bachulis BL, Hynes GD. Accuracy and relationship of mechanisms of injury, Trauma Score, and Injury Severity Score in identifying major trauma. *Am J Surg.* 1986;151:581–584.
75. Lowe DK, Oh GR, Neely KW, Peterson CG. Evaluation of injury mechanism as a criterion in trauma triage. *Am J Surg.* 1986;152:6–10.
76. Evaluation of the mechanism of injury component of the trauma triage criteria. Available at: http://www.mcw.edu/emergencymed/SelectedResearch/EvaluationoftheMechanismofInjuryComponentofTraumaTriageCriteria.htm. Accessed December 5, 2008.
77. Newgard CD, Rudser K, Hedges JR, et al. Abstract 70: Improving the prehospital trauma triage guidelines for physiologic derangement: can we do better? *Circulation*. 2007;116:II_938. Available at: http://circ.ahajournals.org/cgi/content/meeting_abstract/116/16_MeetingAbstracts/II_938-a. Accessed December 9, 2008.