THE CHARACTERISTICS OF INJURIES IN MOTORCYCLE TO BARRIER COLLISIONS IN MARYLAND

Allison Daniello

(corresponding author)

Research Engineer
Virginia Tech - Wake Forest University
School of Biomedical Engineering and Sciences
440 ICTAS Building, Stanger Street (MC 0194)
Blacksburg, VA, USA 24061
Phone: (908) 839-6828
Fax: (540) 231-9738
E-Mail: adaniell@vt.edu

Hampton C. Gabler, Ph.D.

Professor
Virginia Tech - Wake Forest University
School of Biomedical Engineering and Sciences
445 ICTAS Building, Stanger Street (MC 0194)
Blacksburg, VA, USA 24061
Phone: (540) 231-7190
Fax: (540) 231-9738
Email: gabler@vt.edu

Submission Date: November 15, 2011
Word Count: 3,733
Number of Tables: 5
Number of Figures: 5
Total Word Count Including Tables and Figures: 6,233

ABSTRACT

Motorcycle to barrier collisions are more serious than many other motorcycle crash modes, such as collisions with only the ground or passenger cars. In order to identify the potential need for design improvements to traffic barriers to reduce the severity of these crashes, the injuries incurred during these collisions must first be better understood. The objective of this study is to determine the type, relative frequency, and severity of injuries incurred in motorcycle to barrier crashes in Maryland. The Crash Outcome Data Evaluation System (CODES) was used to analyze motorcycle crashes in Maryland from 2006-2008. CODES links police-reported crashes to hospital data, providing detailed information about the injuries incurred during the collision. This study focused on four different crash modes for motorcyclists: single-vehicle barrier collisions, single-vehicle fixed object collisions, multi-vehicle collisions, and single-vehicle overturn collisions. The most commonly injured regions for all motorcycle crashes were the upper and lower extremities – over 70% of motorcyclists involved in the crashes analyzed suffered an injury to the upper and/or lower extremities. Motorcyclists involved in barrier collisions were 2.15 (95%CI: 1.17-3.92) times more likely to suffer a serious injury to the thorax than motorcyclists involved in overturn-only collisions. Additionally, severe lacerations were 2.26 (95% CI: 0.75-6.86) times more likely in motorcycle barrier collisions than overturn only collisions, though this was not found to be statistically significant.

INTRODUCTION

Motorcycle to barrier collisions are more serious than many other motorcycle crash modes, such as collisions with only the ground and collisions with passenger cars (*1-9*). Quddus et al. (2002) demonstrated that colliding with stationary objects increased the risk of severe injury in motorcycle crashes in Singapore (10). Likewise, Tung et al. (2009) demonstrated that the odds of serious or fatal injury in motorcycle-guardrail collisions were 1.7 times higher than those in motorcycle collisions that did not involve other objects (*4*). Rigid, sharp surfaces have been demonstrated to cause more severe injuries in motorcycle collisions (5).

Motorcyclists have a much higher fatality risk in collisions with traffic barriers than do other road users. Head injuries have been found to be the most common cause of fatality in all motorcycle crashes (*11-13*). Bambach et al. (2011) found that the most frequently injured region was the thorax, and the head was the second most commonly injured region (*13*). There are anecdotal reports that motorcycle to barrier crashes may result in a very different pattern of injuries, such as amputations or severe lacerations that are rarely observed in collisions with other objects. It is important to understand these injury patterns in order to identify the potential need for design improvements to traffic barriers.

Unlike passenger car crashes, there is currently no in-depth investigation database for motorcycle crashes in the United States. State crash databases do not include detailed injury information, making it difficult to determine how injury patterns differ across crash types. However, the Crash Outcome Data Evaluation System links police-reported crashes to hospital records. For this study, crashes in Maryland will be analyzed to determine differences in injury patterns across motorcycle collision types.

OBJECTIVE

The objective of this study was to determine the type, relative frequency, and severity of injuries incurred in motorcycle to barrier crashes. These injury distributions were compared to motorcyclist injury distributions in other crash modes to identify how barrier collisions differ from other collision modes.

METHODS

The Maryland Crash Outcome Data Evaluation System (CODES) was used to analyze three years of motorcycle collisions, from 2006-2008. Data sources for the Maryland CODES include, but are not limited to, police records, EMS, emergency department, and toxicology reports (*14*). The CODES data is the result of linking these datasets using a probabilistic method (*14*).

Injury data is reported in CODES using the International Classification of Disease 9th Revision Clinical Modification (ICD-9-CM). The ICD-9-CM codes provide detailed injury information, but do not give a measure of injury severity, such as threat to life. The Abbreviated Injury Scale (AIS) is another coding metric used to describe injuries. AIS also reports injury severity in terms of threat to life (*15*), and is widely used in in-depth crash investigation databases. AIS codes rank injury severity from AIS=1 (minor) to AIS=6 (not survivable). In this study, the ICDMap-90 Program (Johns Hopkins and Tri-Analytics, 1998) was used to map the ICD-9-CM codes to the AIS-90 codes. In a small number of cases, ICD-9-CM codes did not map directly to AIS codes. When not enough information was provided in the ICD-9-CM code to identify a unique AIS code, the AIS code with the lowest potential severity was used (*16*).

Four categories of motorcycle crashes were analyzed in this study: crashes with traffic barriers, crashes with fixed objects, multi-vehicle crashes and overturn crashes. Traffic barrier crashes involved a collision with a guardrail, construction barrier, or crash attenuator. Fixed object crashes included collisions with bridges, buildings, culverts, embankments, fences, poles, and trees. Both the barrier and fixed object crashes included in this study were limited to single-vehicle crashes. If a motorcycle struck multiple objects, e.g., a guardrail followed by a tree, the object which caused the rider injury could not be determined. Multi-event collisions were therefore excluded from the barrier and fixed object analysis. The multi-vehicle crash category would include crashes between motorcycles and cars, but would exclude crashes where there was also a collision with a barrier or fixed object. Overturn crashes analyzed were likewise restricted to single-vehicle crashes. All motorcyclists included in this study were operators of the vehicle.

Severity of all crashes was analyzed using the maximum AIS severity score (MAIS). Serious injuries were defined as those with an AIS greater than or equal to 3. In addition, injuries were analyzed by body region to determine whether injury patterns of motorcyclists involved in barrier collisions differed from other collision types. Serious lacerations and amputations were tabulated separately to investigate concerns that the sharp edges of metal barrier posts and rail edges may lead to these types of cutting injuries. Lastly, the number of fatally injured riders in Maryland CODES was compared with the number of riders fatally injured in Maryland using the FARS database.

RESULTS

There were 5,586 motorcycle crashes of all severity in Maryland from 2006 – 2008. The CODES data linked 2,357 of these crashes with hospital inpatient or emergency department data. The injury data associated with all of these crashes was for the motorcycle operator. No motorcycle passengers were included in this study. Seven of the linked cases did not have any injury codes associated with them. There were 1,707 motorcyclists included in this study, which were divided into 4 crash categories: single vehicle barrier crashes, single-vehicle fixed objects crashes (excluding collisions with barriers), multi-vehicle crashes (excluding multi-vehicle collisions with barriers and fixed objects), and overturn only crashes. The number of crashes of each collision type is shown in TABLE 1. The 'Other' category includes all crashes not falling into the 4 analysis categories, such as multi-event collisions into barriers and fixed objects.

TABLE 1. Distribution of Crashes in Maryland (2006-2008)

Crash Type	MD CODES Composition		% Successfully Linked Crashes
	Linked Crashes	All Crashes	
Single Vehicle Barrier	107	242	44.2%
Single Vehicle Fixed Object[+]	260	654	39.8%
Multi-Vehicle	1,103	2,601	42.4%
Single Vehicle Overturn Only	242	452	53.5%
Other	645	1,637	39.4%
Total Crashes	*2,357*	*5,586*	42.2%

[+]Not including barrier collisions

Data linkage between two dissimilar datasets, e.g. police-reported crashes and hospital data, is seldom perfect. When using linked datasets, one question is how representative is the linked dataset of the overall dataset. TABLE 2 presents the distribution of police reported injury severity for all cases and for the linked subset of these cases. Only 42% (2,357 of 5,586) of police-reported crashes could be linked with hospital data. However, as the linked cases required hospital admission, we expected that the linked crashes would not include property damage only cases, most minor injury cases, and many fatal cases. TABLE 2 confirms that the linked cases are biased towards injury and disabled cases, and almost entirely exclude property damage only cases. Only 27.7% of the fatal cases were linked to hospital records. Indeed, a χ^2 test showed that there is a significant difference in the injury distributions of the linked and unlinked datasets ($p < 0.0001$).

TABLE 2. Police Reported Injury Severity in MD CODES Data for the Entire Dataset

KABCO	Police Reported Injury Severity	% Linked Cases	% Un-Linked Cases
O	Not Injured	5.94	33.01
C	Possible Injury	18.16	16.01
B	Injured	48.88	30.54
A	Disabled	24.18	15.02
K	Fatal	2.84	5.42

However, when the seriously injured riders likely to have been hospitalized ('Disabled' and 'Injured') are compared as shown in TABLE 3, the linked and unlinked datasets are remarkably similar. A χ^2 test showed there was no significant difference in the injury distributions of the linked and unlinked datasets ($p = 0.908$) in the "Injured" and "Disabled" groups. We conclude that using the linked CODES data to analyze the injury distributions of the A+B crashes is representative of the serious injuries in the entire dataset.

TABLE 3. Seriously Injured Riders in MD CODES Data

KABCO	Police Reported Injury Severity	Number of Linked Cases	Number of Un-Linked Cases	% Linked Cases	% Un-Linked Cases
B	Injured	1,152	986	66.90	67.03
A	Disabled	570	485	33.10	32.97
A + B	Injured + Disabled	1,722	1,471	100	100

General characteristics of the crashes included in this analysis are given in TABLE 4. All injury severities were included for this analysis. The gender distributions were approximately the same for all collision types. Overall, 93% of motorcyclists included in this analysis were male. Maryland has a full helmet law which requires riders to wear a helmet at all times. Police reported that 81% of all motorcyclists were helmeted at the time of the crash. The distribution of helmet usage was approximately the same across all collision types.

TABLE 4. Composition of the Data Set

	Barrier Crashes	Fixed Object Crashes	Multi-Vehicle Crashes	Overturn Only Crashes	Total
Total Crashes	106	260	1,101	240	1,707
Gender					
Male	98	234	1,041	215	1,588
Female	8	26	58	25	117
Unknown	0	0	2	0	2
Helmet Usage					
Helmet Used	86	225	870	202	1,383
Eye Shield Used	1	1	6	2	10
None Used	7	16	71	15	109
Unknown	12	18	154	21	205

The vast majority of ICD-9-CM codes were successfully mapped onto AIS codes. The maximum injury severity could not be determined in fewer than 2% of cases (27 of 1,707). When mapping the ICD-9-CM scores to AIS scores, these 27 cases had at least one injury for which the severity could not be determined.

The most common body regions to be injured regardless of severity were the upper and lower extremities. Approximately 70% of all motorcyclists analyzed in this study suffered at least one injury to the upper and/or lower extremities. One in five riders (19.5%) suffered injuries to both the upper and lower extremities. For all collision modes analyzed, with the exception of overturn crashes, the lower extremities were most often the region of principal diagnosis (FIGURE 1). The region of principal diagnosis corresponds to the first ICD-9 code (*16*), but does not provide a measure of severity. The upper extremities were the second most frequent body region for the principal diagnosis for all collision modes analyzed except overturn crashes.

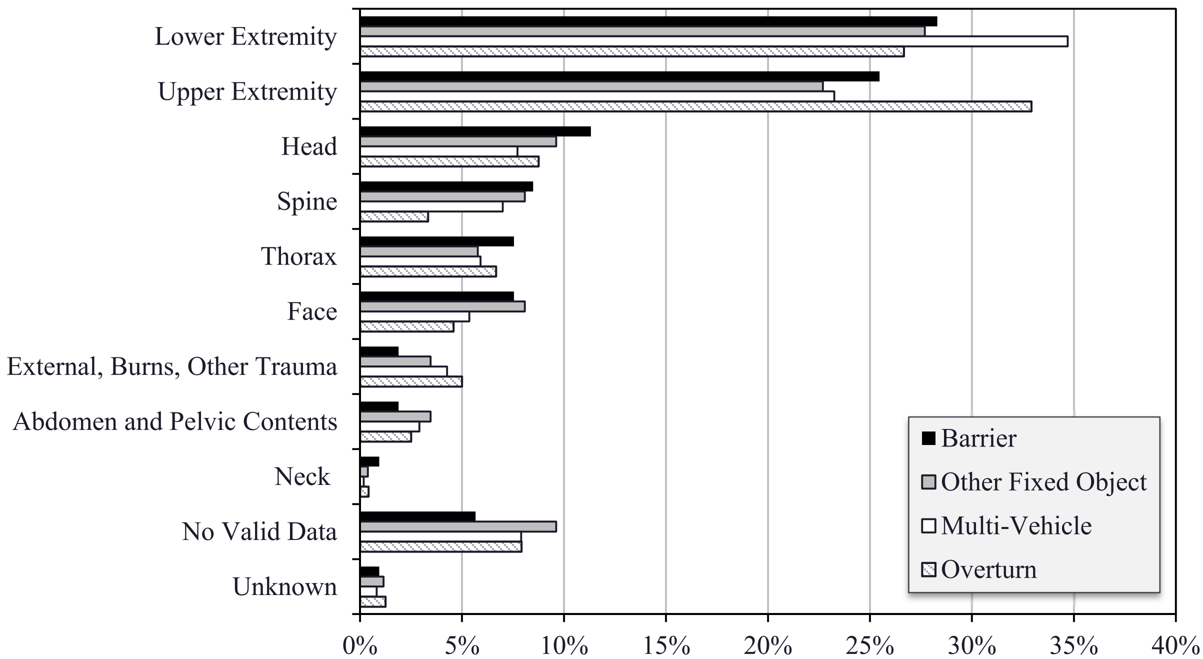

FIGURE 1. Region of Principal Diagnosis

FIGURE 2 presents the distribution of MAIS 3+ injuries by body region. For all crash modes analyzed except multi-vehicle crashes, the thorax was the most common region for an AIS 3+ injury. For multi-vehicle crashes, the lower extremities suffered AIS 3+ injuries most often.

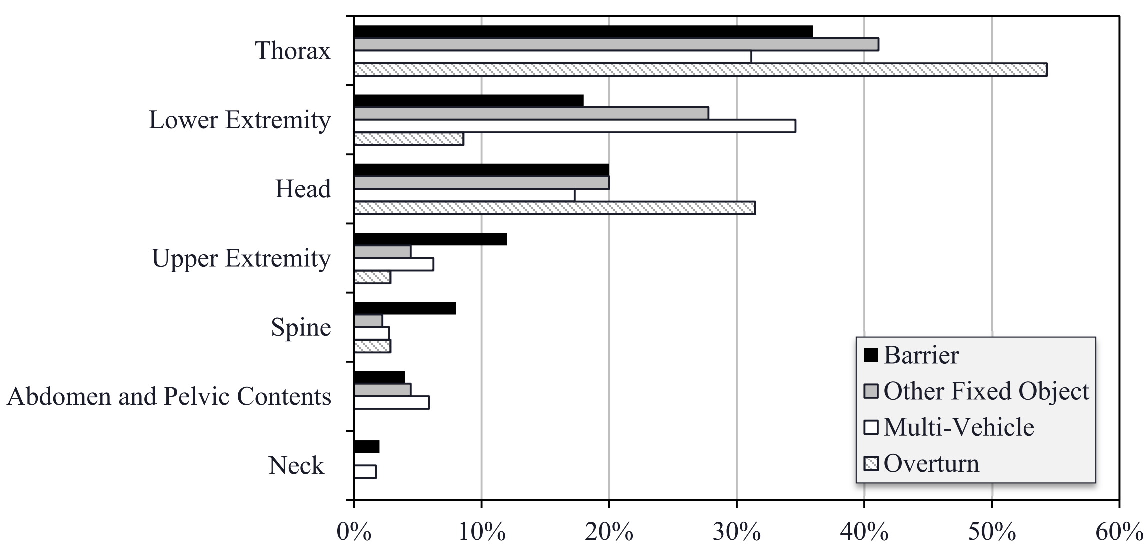

FIGURE 2. Distribution of AIS 3+ Injuries by Body Region

Extremity Injuries and Amputations

There were 1,206 motorcyclists who suffered an upper or lower extremity injury from the crashes analyzed for this study. As noted above, the extremities were the most frequently injured body regions. To investigate reports of amputations in barrier crashes, the CODES dataset was searched for this type of injury. In our dataset, only 4 motorcyclists suffered an amputation. None of these motorcyclists collided with a barrier. The amputations were incurred either in a collision with another type of fixed object or in a collision with another vehicle. However, this dataset excludes many of the fatal crashes; therefore, any amputations suffered during these crashes could not be determined based on this dataset.

Lacerations

One concern about collisions with guardrail is that the sharp edges of the guardrail posts and the upper and lower rail edges might pose a serious laceration hazard to motorcyclists. The MD CODES dataset was examined for this type of injury. Over half of the motorcyclists (55.7%) involved in barrier collisions included for analysis suffered at least one laceration injury. In contrast, only approximately one-third of riders in fixed object and multi-vehicle collisions (33.8% and 30.9%, respectively) and 22.9% of riders in overturn collisions suffered at least one laceration injury.

Focusing on higher severity lacerations, riders in barrier collisions were 2.26 (95% CI: 0.75-6.86) times more likely to suffer at least one AIS 2+ laceration injury than those in overturn collisions. However, this higher risk was not statistically significant. Similarly, motorcyclists involved in fixed object collisions and those involved in multi-vehicle crashes were 1.54 (95% CI: 0.57-4.17) and 1.60 (95% CI: 0.69-3.71) times more likely to suffer an AIS 2+ laceration than motorcyclists in overturn collisions, respectively. Again, the risk of laceration in these types of collisions was not found to be significantly different than the risk of laceration in overturn collisions.

For barrier collisions, the most common body regions to suffer a laceration were the face and the lower extremities (FIGURE 3). In overturn collisions, motorcyclists were more likely to have lacerations on the upper extremities. For lacerating injuries of all crash modes analyzed, the majority of these injuries were incurred to either the face or extremities.

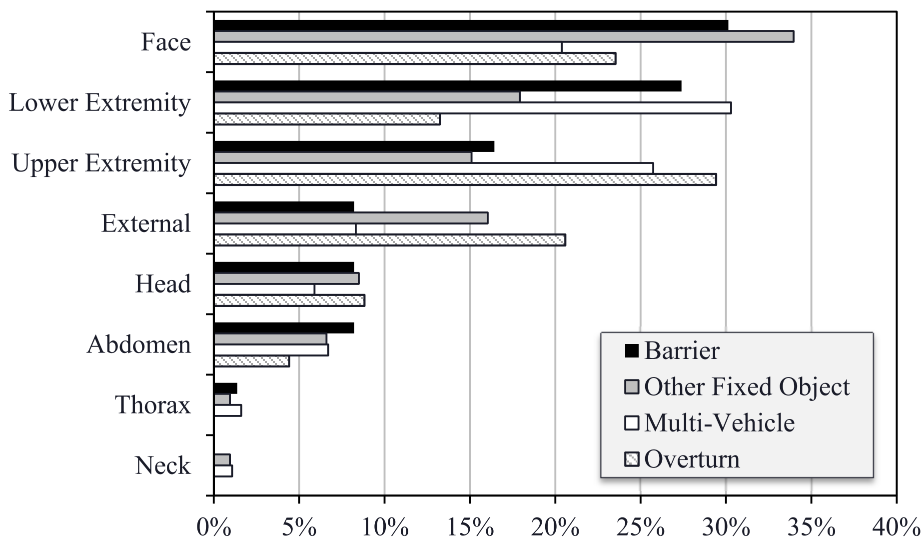

FIGURE 3. Distribution of Lacerations by Body Region

However, barrier type could not be determined from the information in the database. Different barrier post and rail designs exist that may affect the risk of laceration. FIGURE 4 shows some common cross sections for W-beam guardrail post designs and a cable barrier post design. These are representative of posts used in the United States. As shown, all these posts have small faces, which may increase the risk of laceration. However, not all barriers included in this study had posts and there was no way to differentiate between barriers with posts and barriers without posts, e.g. concrete barriers.

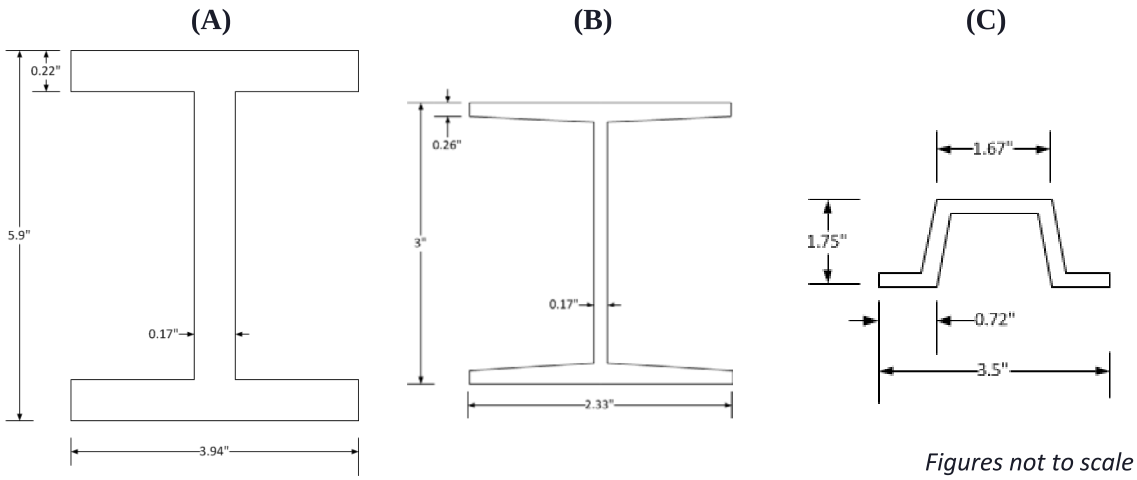

FIGURE 4. Various Post Designs
(A) Strong-Steel Post for W-Beam Guardrail (B) Weak-Steel Post for W-Beam Guardrail
(C) Flanged-Channel Post for Cable Barrier. Dimensions based on Task Force 13 Guidelines.

Injuries to the Thoracic Region

The thoracic region was next analyzed in further detail due to the large risk in thoracic injury in the event of a barrier collision. Of the motorcyclists included in this study, 23.5% involved in barrier collisions and 16.7% involved in overturn collisions suffered at least one injury to the thorax. TABLE 5 shows the distribution of the number of injuries to the thoracic region. In addition, 39% of riders with a thoracic injury suffered multiple thoracic injuries. Motorcyclists involved in a barrier collision were 2.15 (95%CI: 1.17-3.92) times more likely to suffer a serious thoracic injury than riders in overturn collisions, which was found to be significant at the 0.05 level. There were elevated relative risks of serious thoracic injury for motorcyclists involved in fixed object and multi vehicle collisions as compared to overturn collisions; however, these risks were not found to be significant.

TABLE 5. Distribution of People Injured in the Thoracic Region

Number of Thoracic Injuries	Barrier	Fixed Object	Multi-Vehicle	Ground	All
1	13	26	105	27	171
2	7	18	36	10	71
3	3	11	17	2	33
4	2	0	2	1	5
5	0	0	1	0	1
6	0	1	0	0	1
Total People Injured	*25*	*56*	*161*	*40*	*282*
Total Injuries	*44*	*101*	*241*	*57*	*443*
% People with 1+ Thoracic Injuries	*23.6%*	*21.5%*	*14.6%*	*16.7%*	*16.1%*

FIGURE 5 presents the types of thoracic injuries occurring in motorcycle crashes. The most common type of thoracic injury for motorcyclists who collided with a barrier was a lung contusion. The risk of lung contusion for those involved in barrier collisions was 1.87 (95% CI: 1.04 - 3.36) times higher than that in overturn collisions for motorcyclists who suffered at least one thoracic injury. Chest wall contusions were the most common injury for riders involved in an overturn collision. The most common injury for motorcyclists involved in a fixed object or multi-vehicle collision was a hemothorax or pneumothorax (blood or air in the pleural cavity, i.e., the space between the chest wall and the lung).

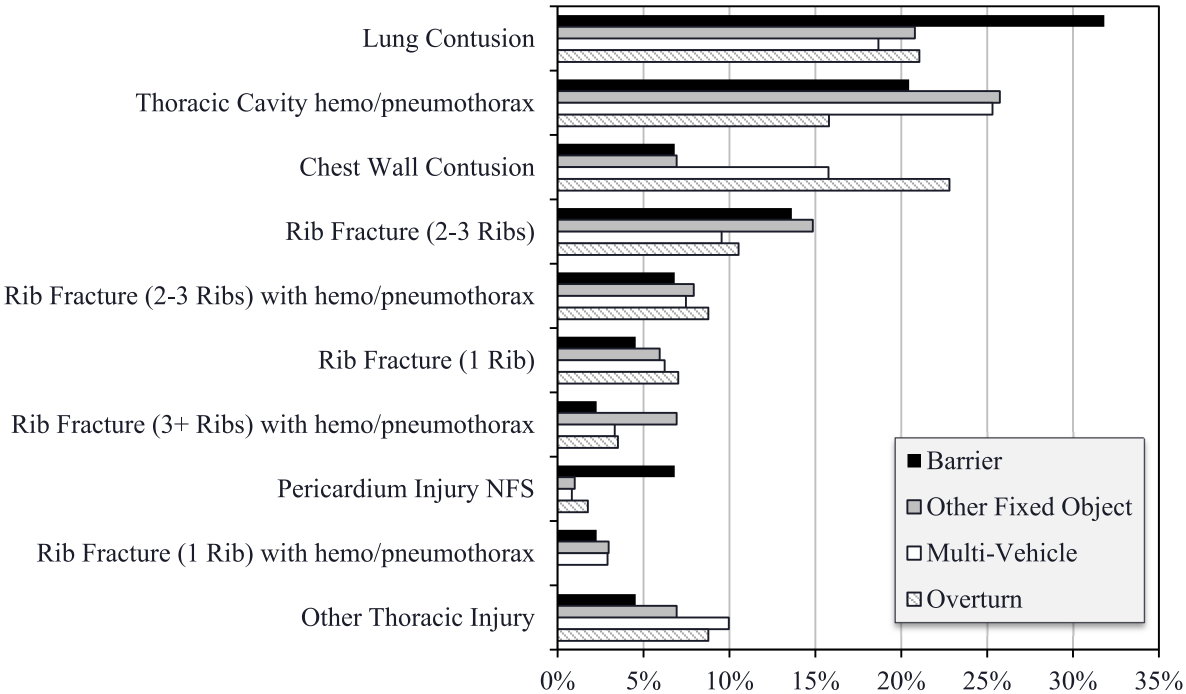

FIGURE 5. Distribution of Injuries to the Thoracic Region

Nearly one-third (31%) of riders involved in a barrier collision suffered a lung contusion. In contrast, only 18% of riders who did not strike a barrier suffered a lung contusion. In addition, 33% of the motorcyclists analyzed suffered at least one rib fracture, 43% of whom also suffered a hemothorax or pneumothorax associated with the fracture.

LIMITATIONS

There are several limitations associated with this study. First, the CODES data only lists the injuries incurred by the rider. Hospital teams however have no way to determine the either the injury mechanism or the component which caused the injury. Second, the Maryland CODES data does not record the type of the barrier struck by the rider. Daniello and Gabler (2011) showed that fatality risk is a function of barrier type (*17*), and findings from Berg et al. (2005) suggest the same conclusion (*18*). Our hypothesis is that injury risk is likewise a function of barrier type. However, there was not enough detail in the dataset to determine the barrier type. Additionally, the sequence of events typically describes what happened to the vehicle during the crash, not the people in the crash. Therefore, we assumed that the rider follows the same path as the vehicle, having the same sequence of events.

Lastly, the data set is limited to those crashes that could be linked to the injury information, and is not necessarily representative of all motorcycle crashes in Maryland. The data set did not include most property damage only crashes, minor non-hospitalized riders, and many fatally injured riders, and showed a significantly different distribution of police-reported injury severity than all Maryland motorcycle crashes. The injury distributions of those fatally injured may be different than those who suffered serious injuries. The dataset is therefore most appropriately used to compare the types of injuries suffered by riders who were admitted to a hospital after a crash.

DISCUSSION AND CONCLUSIONS

This study has examined the risk of injury by body region in motorcycle-barrier crashes. The study was based upon linked police accident reports and hospital data from Maryland from 2006-2008. The most commonly injured regions for all motorcycle crashes were the upper and lower extremities. Over 70% of motorcyclists involved in the crashes analyzed suffered an injury to the upper and/or lower extremities. This finding is consistent with that of Lin and Kraus (*11*), who found that lower-extremity injuries most commonly occur in motorcycle crashes, and Hefny et al. (*12*), who found that upper and lower limbs were the two most common cause of injury in motorcycle collisions in the United Arab Emirates. Extremities were the most commonly injured region, but not the most commonly seriously injured body region.

The thorax was the most frequently seriously injured body region. This is consistent with the findings of Bambach et al. who examined fatal crashes (*13*). Motorcyclists involved in barrier crashes were 2.15 (95%CI: 1.17-3.92) times more likely to suffer a serious injury to the thoracic region that motorcyclists not involved in barrier collisions. The most common injury for motorcyclists involved in barrier collisions was a lung contusion, whereas the most common injury for motorcyclists not involved in barrier collisions was a hemothorax or pneumothorax.

Riders impacting barrier had a higher risk of AIS 2+ laceration than riders in other types of collisions based on the point estimate, though this was not found to be significant. One hypothesis is that the lacerations are caused by rider impact with the edges of the guardrail posts and the upper and lower edges of the w-beam. However, the contact source for these lacerations cannot be determined from the CODES data. When practical, further information about the crash should be acquired and retained so that retrospective studies can be conducted more thoroughly.

Our dataset showed no evidence of amputations in barrier crashes, which has been a concern to riders. However, fatal injuries are underrepresented in the dataset since only hospital data is available to describe injuries. Injury data for fatal crashes is crucial in understanding many severe crashes. There is a need to document fatal injuries in motorcycle crashes, as is done for passenger vehicle crashes through the National Automotive Sampling System Crashworthiness Data System. These data would provide useful insight into the most severe motorcycle crashes.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the Transportation Research Board for their sponsorship of this research under NCHRP Project 22-26. The authors would also like to acknowledge the Maryland Crash Outcome Data Evaluation System, Maryland Health Services Cost Review Commission, and the Maryland Automated Accident Reporting System for providing the data used for this study. Lastly, we would like to acknowledge the Virginia Tech Laboratory for Interdisciplinary Statistical Analysis for their assistance on the statistics.

REFERENCES

1. Daniello, A. and Gabler, H.C. Fatality Risk in motorcycle collisions with roadside objects in the United States. *Accident Analysis and Prevention*, Vol. 43, No. 3, 2011, pp. 1167-1170.
2. Gabler, H.C. The Risk of Fatality in Motorcycle Crashes with Roadside Barriers. Proceedings of the Twentieth International Conference on Enhanced Safety of Vehicles, Lyons, France, June, 2007.
3. Jama, H.H., Grzebieta, R.H., Friswell, R., McIntosh, A.S. Characteristics of fatal motorcycle crashes into roadside safety barriers in Australia and New Zealand, *Accident Analysis and Prevention*, Vol. 43, 2011, pp. 652–660.
4. Tung, S.H., Wong, S.V., Law, T.H., and Umar, R.S. Crashes with roadside objects along motorcycle lanes in Malaysia. *International Journal of Crashworthiness*, Vol. 12, 2009, pp. 205-210.

5. Ouellet, J.V., "Environmental Hazards in Motorcycle Accidents", Proceedings of the 26th Annual Meeting of the American Association for Automotive Medicine, Ottawa, Ontario, Canada , 1982.
6. Domham, M. "Crash Barriers and Passive Safety for Motorcyclists", Proceedings of the Stapp Car Crash Conference, SAE Paper No. 870242, 1987.
7. Quincy, R., Vulin, D., and Mounier, B., "Motorcycle Impacts with Guardrails", Transportation Research Circular, No. 341, pp. 23-28, 1988.
8. Gibson, T. and Benetatos, E., Motorcycles and Crash Barriers, NSW Motorcycle Council Report, 2000.
9. Hurt, H., Ouellet, J.V., and Thom, D., Motorcycle Accident Cause Factors and Identification of Countermeasures, Volume I, DOT Technical Report, Contract No. DOT HS-5-01160, Washington DC, 1981.
10. Quddus, M.A., Noland, R.B., and Chin, H.C. An analysis of motorcycle injury and vehicle damage severity using ordered probit models. *Journal of Safety Research*, 2002
11. Lin, M.R., and Kraus, J.F. A review of risk factors and patterns of motorcycle injuries. *Accident Analysis and Prevention*, Vol. 41, 2009, pp. 710-722.
12. Hefny, A.F., Barss, P., Eid, H.O., and Abu-Zidan, F.M. Motorcycle-related injuries in the United Arab Emirates. *Accident Analysis and Prevention*, 2011, doi: 10.1016/j.aap.2011.05.003.
13. Bambach, M.R. Grzebieta, R.H. McIntosh, A.S. Injury typology of fatal motorcycle collisions with roadside barriers in Australia and New Zealand, *Accident Analysis and Prevention*, accepted for publication, 2011, Ref. No.: AAP-D-10-00443R1.
14. NHTSA, *The Crash Outcome Data Evaluation System (CODES) and Applications to Improve Traffic Safety Decision-Making*. Publication DOT HS 811 181, U.S. Department of Transportation, 2010.
15. AAAM. The Abbreviated Injury Scale: 1990 Revision, Update 98. Association for the Advancement of Automotive Medicine, 2001.
16. *ICDMap-90 User's Guide*, Johns Hopkins University and Tri-Analytics, 1998.
17. Daniello, A. and Gabler, H.C. The Effect of Barrier Type on Injury Severity in Motorcycle to Barrier Collisions in North Carolina, Texas, and New Jersey. Proceedings of the 90th Annual Meeting of the Transportation Research Board, Washington, D.C., January, 2011.
18. Berg, F.A., Rucker, P., Gartner, M., Konig, J., Grzebieta, R., and Zou, R., Motorcycle Impacts into Roadside Barriers – Real Word Accident Studies, Crash Tests, and Simulations Carried Out in Germany and Australia", Proceedings of the Nineteenth International Conference on Enhanced Safety of Vehicles, Washington, DC, 2005.