MINOR REAR ALIGNED CRASHES IN THE UNITED STATES: A PILOT STUDY OF 98 CRASHES

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ABSTRACT

In the United States there are few available data regarding real world minor rear aligned crashes with struck vehicle delta-V less than 15 km/h. This study analyzed 98 such crashes in the US involving 258 occupants. Mean struck vehicle delta-V and acceleration were 6.4 km/h and 1.4 g, respectively. Within five weeks post-crash, 105 struck vehicle occupants had 695 ICD-9-CM diagnoses and 399 AIS codeable injuries (99.5% AIS1) attributed to the crashes. Diagnosis and injury distributions in these crashes did not match prior data from real world crashes. Transient AIS1 'whiplash' injuries during the post-crash medical treatment period were less prominent than anticipated. Transient complaints were frequently diagnosed to protected body regions. Prospects of litigation may have played a role in different occupant injuries reported in the current cohort when compared with prospectively collected data sets.

Keywords: Accident Reconstructions, Injury Severity, Rear Impacts, Spine, Whiplash

MINOR REAR 'WHIPLASH' CRASHES in the United States continue to be a societal burden. The National Highway Traffic Safety Administration (NHTSA) estimates that US occupants develop 'whiplash' symptoms in as many as 272,000 rear crashes each year (Kuppa, 2004). These crashes total $3.2 billion annually in economic and quality of life costs (Kuppa, 2004), exceeding the $2.4 billion in costs associated with all fatal rear crashes in the US (National Highway Traffic Safety Administration, 2006). Finally, while fatal US crashes have been steadily declining over the past several decades, rear 'whiplash' crashes have seen an increase since the 1960's (Kahane, 1982; Kuppa, 2004).

This study investigated the current availability of US real world mild rear aligned crash data published by NHTSA and compared this data with a newly gathered pilot data set of 98 real world minor crashes with struck vehicle delta-V less than 15 km/h. This analysis was done as a first step toward defining a threshold for onset of transient and chronic complaints for minor rear crashes in the US fleet. By relating occupant complaint diagnoses over one week and five week immediate post-crash periods to vehicle crash dynamics, it was hypothesized that minor rear crash transient and chronic 'whiplash' risk curves could be developed for these time periods. Ultimately, several factors prevented the development of these risk curves for the occupants in these crashes. Firstly, the current available data from NHTSA databases employed computer reconstruction methods for minor rear aligned crashes that have been shown to be unreliable (Niehoff and Gabler, 2006) and very few crashes were available where the rear crash resulted in no airbag deployment of the striking vehicle and where neither vehicle was towed from the scene. Secondly, data collected via the National Trauma Databank (NTDB) lacked specifics regarding impact direction or delta-V. With respect to the newly collected real world pilot data set, the presence of diagnoses related to degenerative/myelopathic conditions, a prevalence of non-'whiplash' diagnoses and the potential for litigation in each crash case precluded direct application of these results to current or proposed injury thresholds. Even though minor rear crash injury risk curves could not be developed, the crash dynamics and resulting occupant complaint diagnoses for the new data set of 98 real world crashes were analyzed in detail.

PREVIOUS WORK

In a previous US study by Tencer et al. (2001), a retrospective analysis of 432 struck vehicle litigants, who were previously diagnosed with 'whiplash', was performed. These occupants were included based on peak reconstructed delta-V and peak acceleration less than 11.3 km/h and 4.2 g, respectively. Additional requirements were use of a three-point harness, head restraints available in vehicle, no interior contact during the crash and occupants at least 18 years of age. Medical records were examined for immediate symptoms, but the time period between the crash and post-crash treatment visits was not reported. 174 occupants (104 female) had neck and low back pain diagnoses at mean delta-V of 7.7 km/h, 174 occupants (122 female) had neck and upper back pain diagnoses at mean delta-V of 8.0 km/h and 84 occupants (58 female) had neck and arm diagnoses at mean delta-V of 8.8 km/h. Every occupant reported neck pain, but no occupants reported head pain.

METHODS

A search of publicly available crash tests and query of real world crash files from a forensic engineering company were performed to gather real world minor rear US crashes. Inclusion criteria for the current study limited data to (1) rear crashes occurring on US roadways with non-volunteer occupants during the past 15 years, (2) during the crash there was only one impact between the front of the striking vehicle and rear of the struck vehicle, (3) the vehicles were aligned longitudinally and vertically during the crash, (4) there was full overlap contact with no offset between the two vehicles, (5) the striking vehicle airbags did not deploy during the crash, (6) each gross vehicle weight was less than 4,536 kg, (7) the crash occurred on a flat roadway, (8) the calculated struck vehicle speed change, or delta-V, was less than 15 km/h and (9) struck vehicle occupant medical records were available to document visits to a medical doctor (M.D.), osteopathic doctor (D.O.) or chiropractor within the first five weeks post-crash.

During the crash database search, available NHTSA and NTDB crashes were investigated. NHTSA databases included the National Automotive Sampling System (NASS), Crash Injury Research Engineering Network (CIREN), Fatality Analysis and Reporting System (FARS) and Special Crash Investigations (SCI) while the NTDB crashes were from database version 6.2. In total, these six crash databases contained data from nearly two million US crashes of varying severity. However, these databases involved vehicles towed from the scene after higher energy crashes (NASS-Crashworthiness Data System), vehicle data taken solely from police reports, (NASS-General Estimates System) serious crashes (CIREN, SCI), fatal crashes (FARS) or lacked crash impact direction information (NTDB v6.2). Unfortunately, no minor crashes were gathered from these databases that met the inclusion criteria. While NASS had several crashes that could have been included in this analysis, the reconstruction delta-V was calculated from the computer reconstruction program called SMASH (NHTSA, Washington, D.C., USA). This program has been shown to be unreliable in reconstructing crashes below a delta-V of 15 km/h (Niehoff and Gabler, 2006) mainly because it utilizes post-crash residual crush measurements based on barrier crash testing in excess of 50 km/h delta-V. Additionally, some of the NASS crashes had borderline reconstruction confidence and recorded crush measurements of zero centimeters but still reported SMASH-calculated delta-V values. Because of these issues, the authors determined that the rear aligned NASS database crashes with struck vehicle delta-V less than 15 km/h should be excluded from this analysis.

During the search of the forensic engineering crashes, approximately 6,000 potential crash cases were identified. From these potential crashes, a set of 98 minor rear aligned crashes met the inclusion criteria where at least one occupant had medical complaints attributed to the crash. In these crashes there were 118 occupants in the striking vehicles and 140 occupants in the struck vehicles. Of the struck vehicle occupants, 105 (75%) sought medical treatment post-crash, had complaints attributed to the crash and were litigants or had the potential to pursue litigation in the US. None of the 118 striking vehicle occupants reported complaints attributed to the crash or sought medical treatment post-crash. Struck vehicle occupant medical records were examined and complaints for visits within five weeks post-crash were compiled. These medical records were obtained according to the US Health Insurance Portability and Accountability Act (HIPAA) requirements.(United States Department of

Health and Human Services, 1996) As a further precaution, any occupant specific identifiers in the medical records were redacted. Medical diagnoses were catalogued according to the International Classification of Diseases 9th Edition-Clinical Modification (ICD-9-CM) (U.S.Department of Health, 1979) and injuries were coded according to the Abbreviated Injury Scale (AIS) (Association for the Advancement of Automotive Medicine, 2005) requirements and were recorded in a double blind manner for the analysis. In order to avoid double-counting of any specific complaint diagnosis, occupants were restricted to having only unique ICD-9-CM diagnosis or AIS code recorded. For ICD-9-CM, a unique diagnosis was counted as the first instance of a diagnosis by a M.D., D.O. or chiropractor within the five week post-crash period. In cases where the same diagnosis was given to the occupant during multiple treatment visits over this five week period, the diagnosis was counted only for the first visit where it was diagnosed. Unique AIS injury codes were different than ICD-9-CM, as the AIS system only contains codes for acute injuries and does not provide codes for pre-existing syndromes or degenerative conditions. In cases where 'pain' was recorded as a diagnosis, this diagnosis was assigned an AIS1 minor injury code.

While compiling occupant medical complaints, the data required for crash reconstruction purposes were also collected. For each crash, a team of experienced professional automotive engineers and crash reconstructionists investigated and reconstructed the contact between the two vehicles. In the vast majority of these crashes, residual crush to either vehicle was minimal or completely absent and the only vehicle damage was minor scuffing or paint transfer to the exterior surfaces. This lack of residual vehicle damage resulted in the need to employ crash reconstruction methods that differed from those commonly used in higher energy crashes as well as in the NASS crash data collection system. A brief summary of the crash reconstruction methodology used in the current study follows.

ENGINEERING-BASED CRASH RECONSTRUCTION

In higher energy longitudinal crashes with appreciable residual crush, governing relationships involving balance of linear impulse and momentum, balance of work and energy and dynamic equations of motion can be used to analyze the impact between the two vehicles. These crashes can generally be assumed to be fully plastic and therefore restitution effects are ignored. Additionally, elastic deformation energy and impulsive tire forces are often neglected as these contributions are minimal when compared with the total energy and impulse in the two-vehicle system moving at higher velocities. Details on the reconstruction methodology in higher energy crashes, including the systems of equations used to solve for unknown crash velocities, is well established (Strother et al., 1986; Campbell, 1974).

While it would be desirable to simply input minor crash parameters into an existing computer crash reconstruction program validated to compute struck vehicle delta-V, this is not currently possible. Due to the wide range of contact restitution values, bumper system construction, vehicle misalignment, bumper height mismatch and dynamic energy dissipation, reconstructing a minor crash is a non-trivial task. Existing computer programs such as m-SMAC (McHenry Software, Cary, NC, USA), m-CRASH (McHenry Software, Cary, NC, USA), WinSMASH (NHTSA, Washington, D.C., USA), WinCRASH (AR Software, Edmonds, WA, USA), Crash3 (NHTSA, Washington, D.C., USA), and HVE-EDCRASH (Engineering Dynamics Corporation, Beaverton, OR, USA), use algorithms based on measurable residual crush from higher energy barrier crash test data in order to calculate vehicular dynamics and delta-V. These programs are not validated for minor crashes and the inaccuracy of computer crash reconstruction programs for crashes with minimal residual crush has been shown previously (Niehoff and Gabler, 2006). Another commercially available program known as PC-Crash (MEA Forensic Engineers & Scientists, Vancouver, Canada), utilizes momentum balance and restitution relationships to determine delta-V, but does not take into account energy considerations, impulsive tire forces or impact duration during the crash.

When two vehicles collide resulting in little or no residual crush, as is often the case in minor crashes, higher energy crash assumptions, including those incorporated into existing computer reconstruction programs, are no longer valid. Restitution effects, elastic deformation energy and impulsive tire forces can become significant contributors to the governing collision relationships involving balance of linear momentum, balance of energy and normal force restitution. The methods used to compute vehicle velocities in the current study incorporated engineering elastic deformation assumptions involving estimates of normal force restitution, elastic energy absorption and contact duration between the two vehicles based on published testing and literature. The specific system of equations used to calculate struck vehicle delta-V, via the momentum-energy-restitution (MER) method, will not be presented in detail but this methodology has been shown to accurately reproduce or slightly overestimate delta-V values (Happer et al., 2003). Some of the variables used in these reconstruction calculations required various parameters from published testing such as impact duration, restitution, dynamic crush energy and vehicle damage information. Whenever these parameters had a range of values, the more liberal value was applied. This allowed for assurance of a slight overestimation of the struck vehicle delta-V. Additionally, the impulsive tire force contributions during the minor crashes were ignored in order to further provide a cautious calculation of struck vehicle delta-V. Thus, the delta-V values presented in the current study are liberal calculations of the struck vehicle crash severity and will tend to mildly overestimate the true struck vehicle delta-V. However, this approach does not as significantly overestimate delta-V as assuming finite residual crush when crush is actually absent (Cipriani et al., 2002). If more detailed descriptions of the minor crash reconstruction methods presented here are desired, the reader is encouraged to review several publications on this topic (Bailey et al., 1995; Happer et al., 2003; Siegmund et al., 1996).

RESULTS

CRASH RECONSTRUCTION RESULTS: Since the query of publicly available crash databases returned no crashes that met the inclusion criteria, the results presented here are from the pilot set of 98 reconstructed, rear aligned mild crashes. These crashes involved passenger or light truck/SUV vehicles of gross vehicle weight less than 4,536 kg in a single, aligned, rear crash with full overlap on a US roadway. Of the 98 crashes, one crash resulted in both the striking and struck vehicles being towed from the scene. In six other crashes the struck vehicle was towed from the scene. A total of 118 occupants were in the striking vehicles and 140 occupants were in the struck vehicles at the time of the crash. Of these occupants, 92 struck vehicle and 70 striking vehicle occupants had documented belt restraint information. A total of 86 struck vehicle and 68 striking vehicle occupants reported use of a three-point harness system, 4 struck vehicle and one striking vehicle occupant reported use of a lap belt only and 2 struck vehicle and one striking vehicle occupant reported no use of available belt restraint. There was no airbag deployment for the striking vehicles in any of these crashes. While 105 of the struck vehicle occupants were diagnosed by a M.D., D.O. or chiropractor within five weeks post-crash with medical complaints attributed to the crash or pre-existing conditions, none of the 118 striking occupants sought medical treatment during the same time period. A summary of the 105 struck vehicle occupants with ICD-9-CM diagnoses attributed to the crash is shown in Table 1. The engineering reconstruction results are shown in Table 2.

Table 1. Summary for 105 struck vehicle occupants

<table>
<tr><td rowspan="2">Male
(29 drivers, 5 passengers)</td><td>mean age ± s.d. (years)</td><td>mean weight ± s.d. (kg)</td><td>mean height ± s.d. (m)</td></tr>
<tr><td>39.5 ± 12.2</td><td>92.2 ± 13.1</td><td>1.75 ± 0.080</td></tr>
<tr><td rowspan="2">Female
(59 drivers, 15 passengers)</td><td>mean age ± s.d. (years)</td><td>mean weight ± s.d. (kg)</td><td>mean height ± s.d. (m)</td></tr>
<tr><td>40.4 ± 11.7</td><td>78.8 ± 23.3</td><td>1.62 ± 0.071</td></tr>
</table>

Table 2. Struck vehicle reconstruction summary

Delta-V (km/h)		Mean acceleration (g)		Impact duration (sec)	
mean ± s.d.	6.4 ± 2.2	mean ± s.d.	1.4 ± 0.5	mean ± s.d.	0.137 ± 0.023
min/max	0.8/13.7	min/max	0.3/3.3	min/max	0.091/0.200

The crash configuration for the 98 vehicle crashes is presented in Figure 1. Passenger vehicles are denoted by 'P' and light truck/SUV by 'L'. For these vehicles, 16 struck vehicles and 20 striking vehicles, respectively, were manufactured before 1990. The various bumper constructions for the 98 striking and 98 struck vehicles is presented in Figure **2** with the frequencies of rigid, piston, lattice/plastic, foam or deformable box bumper systems. Figure 3 shows the results of a Student's t-Test comparison of the mean striking and struck vehicle weights with the +1 s.d. bounds. This figure illustrates that striking vehicles were significant for being more massive than struck vehicles. It is also apparent that the vehicles studied were well under the weight limit of 4,536 kg that generally delineates light truck, SUV and passenger vehicles from heavier transport vehicles. The Insurance Institute for Highway Safety (IIHS) geometric head restraint rating (Insurance Institute for Highway Safety, 2008) for 64 of the struck vehicle front seats is shown in Figure 4. The data in Figures 1-4 are presented here as mainly as a reference for future studies, as this data has never been published before for US minor rear crashes.

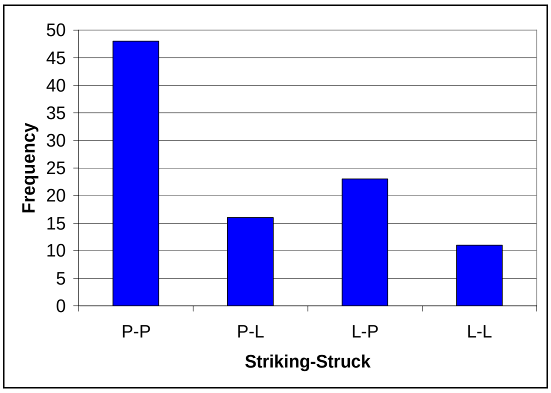

Figure 1. Vehicle crash configuration

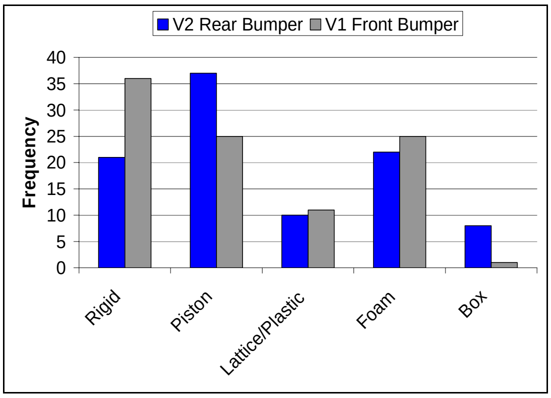

Figure 2. Vehicle bumper constructs

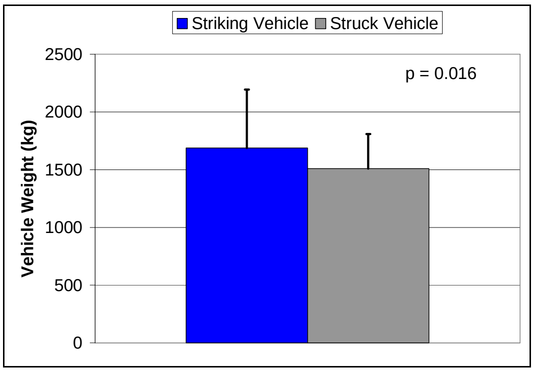

Figure 3. Vehicle weight comparison

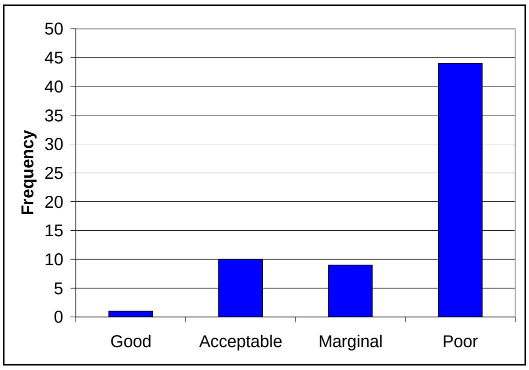

Figure 4. IIHS geometric rating

MEDICAL TREATMENT RESULTS: Post-crash, 105 struck vehicle occupants first sought medical treatment at emergency room/urgent care or medical office facilities. One occupant made both an emergency room and medical office visit the same day as the crash. The distribution of male versus female initial medical facility visits post-crash is shown in Figure 5. The time period between the crash and this first treatment visit for males and females is shown in Figure 6. Occupants that visited a medical facility the same day as the crash were recorded as zero days between the crash and first treatment visit.

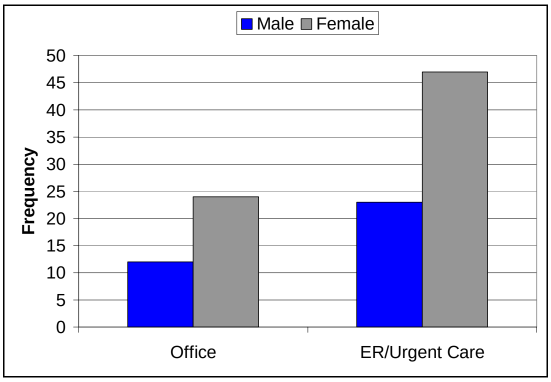

Figure 5. First medical facility visits

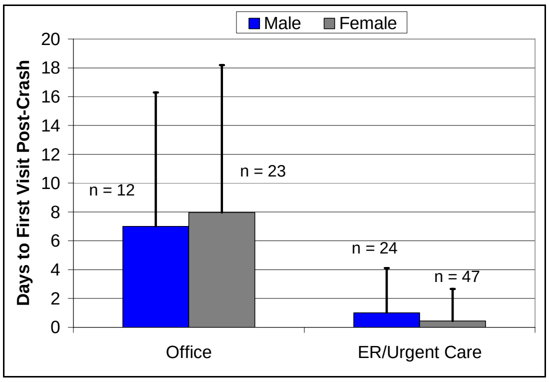

Figure 6. Time between crash and first visit

For these first medical treatment visits, the complaint diagnoses were compiled using ICD-9-CM diagnosis and AIS coding systems. Figure 7 shows the results from the initial medical treatment visit diagnoses using ICD-9-CM. 372 unique ICD-9-CM diagnoses were given to the 105 struck vehicle occupants in the first visit. Figure 8 shows the results from initial visit AIS coding. 231 unique AIS injury codes were assigned from the initial visit diagnoses and all codes were of minor severity, or AIS1.

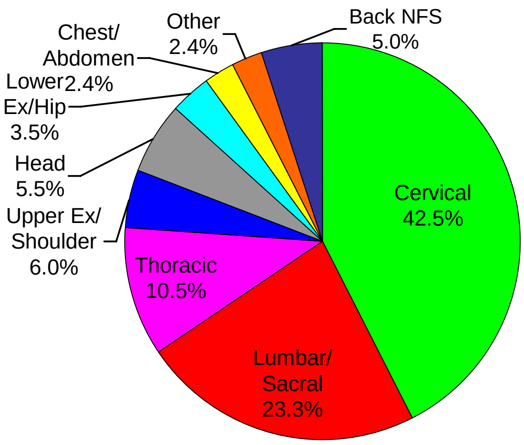

Figure 7. ICD-9-CM diagnoses in first visit

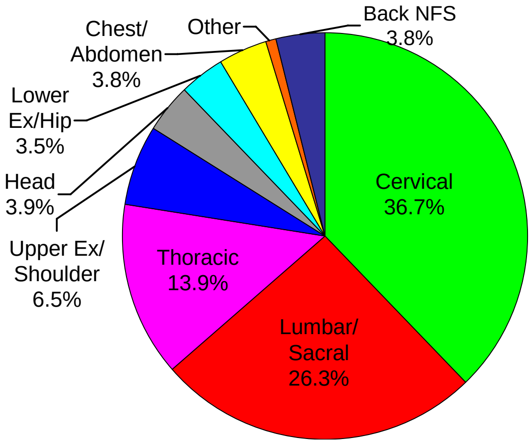

Figure 8. AIS1 codes from first visit

In addition to compiling the first visit ICD-9-CM diagnoses and AIS codes, the struck occupant medical records were analyzed to capture all unique complaints with both systems over the five week period post-crash. This was done to examine any differences in complaint distribution as the post-crash time period progressed. Figure 9 shows the five week diagnosis summary from ICD-9-CM and Figure 10 shows a similar summary for AIS codes. A total of 695 unique ICD-9-CM diagnoses were made and 399 AIS injury codes were assigned based on these complaints. For the AIS codes, 397 were of AIS1 severity. The other two injuries were of moderate severity, or AIS2, and included one lumbar vertebral body fracture and one meniscus tear. While it was debatable whether the occupants with these diagnoses sustained forces of sufficient magnitude and direction in the crashes to cause the AIS2 injuries, these injuries were ultimately included in the analyses of diagnoses during the five week post-crash period.

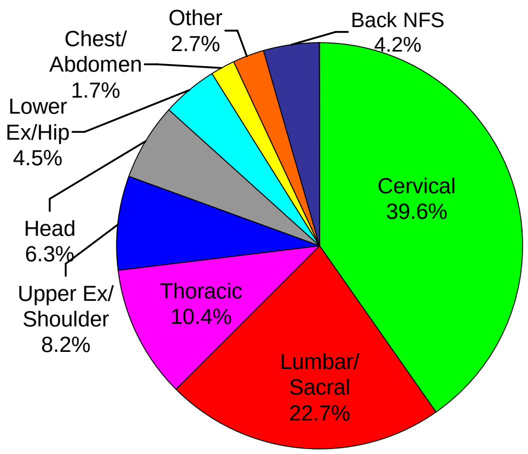

Figure 9. ICD-9-CM 5 weeks post-crash

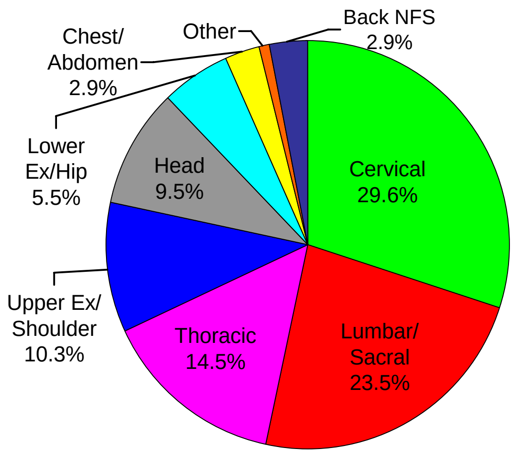

Figure 10. AIS injury 5 weeks post-crash

'Whiplash' complaints were also analyzed in these crashes. For this study, 'whiplash' complaints were based on the Quebec Task Force (Spitzer et al., 1995) grade I, II or III 'whiplash associated disorders' but related to transient head or neck AIS1 injuries only and obviously did not include pre-existing degenerative myelopathic or neurological conditions. Therefore, any AIS1 code applicable to head or cervical spine diagnoses from the first post-crash visit qualified as an acute 'whiplash' injury for that occupant. To avoid spurious contributions of complaint diagnoses occurring outside of the transient injury post-crash time period, 'whiplash' diagnoses were only considered for the first medical treatment visit within seven days post-crash. Occupants were thusly split into one of three groups based on their diagnoses and corresponding AIS codes during the first medical treatment visit within this seven day post-crash treatment period: (1) a 'whiplash' only diagnosis group, (2) a 'whiplash' in addition to 'other' diagnoses group and (3) a group with solely 'other' diagnoses. A total of 13 occupants made their first medical treatment visit over seven days post-crash and these occupants were not considered for this portion of the analysis. For each of the three occupant groups examined, AIS1 injury codes were collected for the entire five week post-crash treatment period to examine injury distribution among these groups. Any nonspecific diagnoses without corresponding AIS codes were ignored for this analysis. Table 3 illustrates the struck vehicle occupant distribution for the three groups.

Table 3. Struck vehicle 'whiplash' AIS codes from first treatment visit

'Whiplash' only		'Whiplash' + 'other'		'Other' only	
male	7	male	13	male	10
female	13	female	35	female	14
total	20	total	48	total	24
mean age (yr)	40.1	mean age (yr)	40.3	mean age (yr)	40.7
mean # days to first visit	0.2	mean # days to first visit	0.9	mean # days to first visit	0.6
total AIS1 diagnoses	50	total AIS1 diagnoses	189	total AIS1 diagnoses	89

Figure 11, Figure 12 and Figure 13 show the AIS injury distribution for these three groups over the five week treatment period.

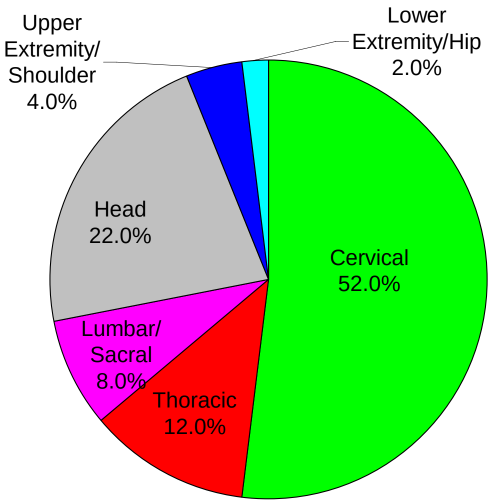

Figure 11. AIS1 for 'whiplash' group

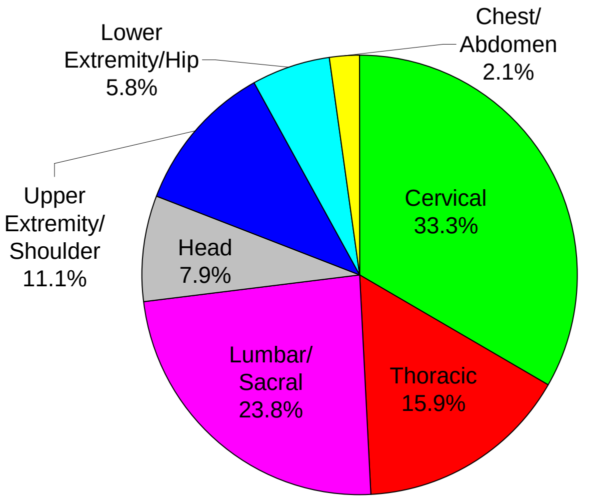

Figure 12. AIS1 for 'whiplash' + 'other' group

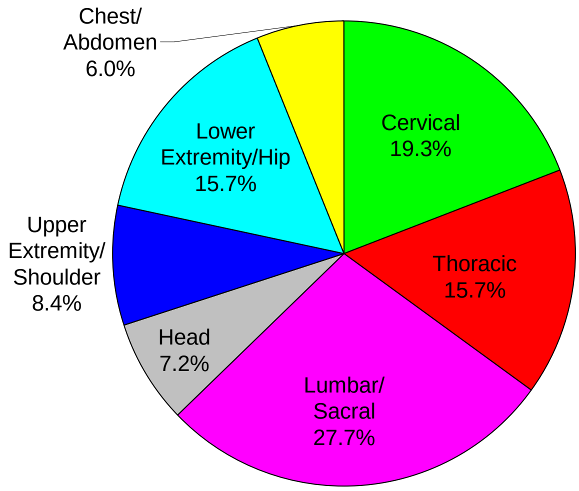

Figure 13. AIS1 for 'other' group

DISCUSSION

Even though current US crash databases could not provide minor rear crashes to include for comparison with this pilot study sample of 98 crashes, much information was derived from this pilot data set. A total of 118 occupants were in the striking vehicles and 140 occupants were in the struck vehicles at the time of the crash. A relatively high percentage of occupants, 95% of struck vehicle and 97% of striking vehicle occupants, reported use of a three-point harness system. None of these crashes were severe enough to reach airbag deployment thresholds in the striking vehicles. A total of 105 of the struck vehicle occupants were diagnosed within five weeks post-crash with complaints attributed to the crash, while none of the 118 striking occupants sought medical treatment during the same time period.

The mean delta-V of 6.4 km/h and mean acceleration of 1.4 g appear to be low when compared with the frequency of complaints or medical diagnoses for all occupants and when compared to previous testing (Howard et al., 1998; McConnell et al., 1995; Siegmund et al., 2004; Szabo et al., 1994). Of all the crashes studied, 88% of the crashes were at or below the previously proposed 8 km/h threshold for onset of transient head or cervical spine complaints in rear crashes from published live volunteer rear crash tests (Szabo et al., 1994; McConnell et al., 1995). To date, no study has been presented to illustrate the transient and/or minor AIS1 injury threshold to the thoracic/lumbosacral spine or extremities for US struck vehicle occupants. This study highlights the potential need for further research in this area if these structures are truly at risk during a minor rear aligned crash.

Most crashes occurred between two passenger vehicles or with a light truck/SUV striking the rear of a passenger vehicle. The majority of the bumper systems for both the striking and struck vehicles were rigid, piston or foam. Striking vehicles were seen to be significantly heavier than struck vehicles. IIHS geometric head restraint ratings for the struck vehicle front seats were poor or marginal for 83% of vehicles that had ratings available. This precluded any analytical comparison of outcomes for struck occupants with acceptable or good ratings due to the small sample size in this group.

A total of 67% of struck vehicle occupants who sought treatment post-crash initially sought treatment at an emergency room or urgent care facility as opposed to the 33% who visited medical offices. And occupants that went to emergency room or urgent care facilities on average went less than one day post-crash as opposed to more than seven days post-crash for occupants who first sought treatment at medical office locations.

When examining diagnosis frequency it was observed that for the same occupant, more ICD-9-CM diagnoses were made by the treating medical M.D., D.O. or chiropractor than could be coded with AIS. The presence of large numbers of pre-existing condition diagnoses such as degenerative spine conditions, myelopathic symptoms or radicular indications in the ICD-9-CM codes were responsible for this disparity. Future work will explore any potential relationship between pre-existing degenerative conditions and injury risk in these minor crashes.

Several trends were observed when transient AIS1 injury codes were compared to ICD-9-CM diagnoses. The percentage of head and cervical complaints during the first post-crash treatment visit differed between the two systems as 48.0% of total ICD-9-CM diagnoses compared with 40.6% of AIS1 injuries. When expanding the analysis to all visits within five weeks post-crash, it was seen that the portion of head and cervical complaints with respect to ICD-9-CM decreased to 45.9% of total diagnoses and for AIS to 39.1% of total coded injuries.

When examining diagnoses to body regions other than the head and cervical spine during the first treatment visit, clinicians diagnosed many complaints attributed to the crash that would not normally be expected in rear impacts or in impacts of such low severity. With respect to ICD-9-CM diagnoses in the first treatment visit, there were 33.8% thoracic and lumbosacral spine diagnoses along with 9.4% of diagnoses to the extremities. As a comparison, in the first visit AIS1 thoracic/lumbosacral spine codes constituted 40.2% of the total and the extremities had 10.0% of the total codes. When expanded to the entire five week treatment period, for ICD-9-CM, the thoracic/lumbosacral spine diagnoses remained relatively constant at 33.1% but the proportion of extremity diagnoses increased to 12.7%. For AIS1 injury codes over this same five week period, thoracic/lumbosacral codes fell to 38.0% of the total while extremity codes increased to 15.8% of the total. A large number of thoracic, lumbosacral and extremity complaints persisted weeks after the crash. The reasons as to why such a large portion of complaints remained up to five weeks post-crash are unknown as prior testing (Kaneoka et al., 1999; Siegmund et al., 2004; McConnell et al., 2003; Dehner et al., 2007; Croft et al., 2002) has shown that body regions caudal to the cervical spine are within their normal physiologic limits during crashes of these severities. Furthermore, the most comprehensive studies on real world crash injury data from other countries fails to corroborate the proportion of complaints to these well-supported and/or less at-risk body regions (Krafft et al., 2005; Schuller et al., 2000; Eis et al., 2005). It is a possibility that the retrospectively selected cohort of litigation crash cases may have had some bearing on the differences in occupant complaints and complaint rates when compared with prior studies.

For the ‘whiplash’ analysis, several more trends were observed. While ‘whiplash’ head and cervical spine complaints have been attributed by others to real world (Krafft et al., 2005; Schuller et al., 2000; Eis et al., 2005; Ono and Kanno, 1996) and volunteer (Howard et al., 1998; Kaneoka et al., 1999; Linder et al., 1999; Matsushita et al., 1994; McConnell et al., 1995; Ono et al., 1997; Siegmund et al., 2004; Szabo et al., 1994; Hell et al., 2002) rear crashes at similar or increased severities as these 98 crashes, the current data set did not possess an overwhelming majority of ‘whiplash’ complaints while including many complaints to body regions caudal to the cervical spine. Specifically, in the ‘whiplash’ only group that was coded with AIS1 injury within one week post-crash, thoracic/lumbosacral and extremity AIS1 injuries constituted 26.0% of the total injuries coded during the five week treatment period. When the ‘whiplash’ in addition to ‘other’ codes and ‘other’ codes groups were considered, the proportion of non-‘whiplash’ AIS1 coded injuries increased to 58.8% and 73.5% of the total respectively. Thus, while the minor crashes studied here have been indicated by many as having high risk of ‘whiplash’ trauma, occupants in this pilot set had comparatively low risk of ‘whiplash’. This is in contrast with very high rates of AIS1 injury diagnoses other than ‘whiplash’ during the five week post-crash period. The injury mechanisms for the prevalence of non-‘whiplash’ AIS1 coded injuries need to be elucidated in the future as they defy common biomechanical and medical theories regarding the head and cervical spine being the most at-risk body structures in minor rear crashes; this has been noted previously (Schuller et al., 2000). Again, the effects of litigation bias on the current study cohort are unknown. In order to verify these findings, a prospectively gathered, unbiased minor rear crash study cohort is needed.

CONCLUSIONS

The lack of publicly available US minor rear crash data to include in the current study is unfortunate. For minor rear NASS crashes, if the reconstruction methodology could be modified from a SMASH-based residual crush model to a validated momentum-energy-restitution model, these minor crash reconstructions in the NASS database would be a rich data source for ‘whiplash’ rear crash research. Another modification to these databases that would aid minor crash researchers would be to incorporate more crashes where vehicles were driven from the scene. When utilizing tow-away crashes as an inclusion criterion for a given database, the vast majority of crashes presented here would be excluded. Even without the comparative crash database information, the current pilot set of 98 crashes provided some interesting results. Large numbers of ICD-9-CM diagnoses and AIS1 injury codes were documented at these minor crash severities. The ICD-9-CM diagnosis and AIS injury frequencies seemed to be high when considering the magnitude of each crash and when compared with published volunteer crash testing and real world data collection. The vehicle and occupant dynamics necessary to cause the large proportion of complaints to regions other than the head and cervical spine during these minor crashes is unknown and requires further investigation.

The current study had weaknesses. The 98 real world crashes were potentially biased by litigation or prospects of litigation. As these crashes involved litigants or potential litigants, crashes reconstructed by the forensic engineering company could not be selectively included and separated into control and experimental groups. The NHTSA databases were one potential source of comparison for US real world crashes, but these databases contained higher energy crashes and had uncertain reconstruction results based on residual crush when examining minor crashes. Without a comparative set of real world minor rear crash reconstructions, collected prospectively via well established programs such as CIREN or NASS, the current minor crash pilot data set remains to be verified against real world crashes without involvement of litigants or potential litigants. Additionally, the crash reconstruction methodology used here would have ideally been validated against a large series of vehicle crash tests. But this crash testing was deemed too costly when compared with the relative increase in delta-V and acceleration calculation accuracy. Even without a rigorous crash test validation of each reconstruction in the current study, the minor crash reconstruction methodology used here has been shown to mildly overestimates struck vehicle delta-V (Happer et al., 2003). Therefore, the authors accepted the amount of calculation error in each reconstruction, given that any error present in the struck vehicle delta-V resulted in a more liberal estimate of crash severity and increased occupant exposure risk.

While this initial pilot set of 98 crashes might seem fairly small, when compared with the most recent results of 150 crashes taken from a comprehensive study of 60,000 event data recorder equipped vehicles in Sweden (Krafft et al., 2005), this pilot set compares favorably. The pilot data set presented here illustrates that much can determined when comparing crash severity with actual occupant diagnosis and much data exists in sources other than US crash databases. An effort to prospectively expand this data set could use methods presented here, in combination with existing NHTSA crash collection techniques, to aid minor rear crash researchers in elucidating the relationship between crash dynamics and occupant complaint risk. Finally, the confounding presence of non-'whiplash' diagnoses in the current data set is a new phenomenon that has only had limited mention in the US literature (Tencer et al., 2001; Smith, 1999). To truly determine the proportion of occupant complaints seen in the US fleet due to minor rear crashes, additional research is needed in the US. In this regard, US auto safety experts can look to the examples set by Germany, (Schuller et al., 2000; Eis et al., 2005) Japan (Ono and Kanno, 1996) and Sweden (Krafft et al., 2005) for the collection and analysis of crash data that could help reduce the minor rear crash 'whiplash' burden in the US.

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