Applications of Occupant and Injury Biomechanics Data Available in the CIREN Public Data Set

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Abstract The National Highway Traffic Safety Administration's (NHTSA) Crash Injury Research and Engineering Network (CIREN) program collects crash and injury data from seriously injured occupants of motor vehicle crashes in the United States. While vehicle and scene data are collected using standard NHTSA field crash investigation protocols, the multi-disciplinary CIREN case review process establishes detailed injury causation scenarios according to a formalised procedure referred to as BioTab. Case data are available for public use via an Internet-based case viewer and in tabular data sets. The objectives of this paper are to introduce and demonstrate the capabilities of the tabular data sets. In addition to high-level examination of the public data set, several in-depth analyses, made possible by the case viewer, will be presented as examples of how the data can be used for occupant protection research.

Keywords Crash data, Biomechanics, Injury causation, Field data, BioTab.

I. INTRODUCTION

The Crash Injury Research and Engineering Network (CIREN) has its roots in hospital-based studies of motor vehicle crash victims in the early 1990s. Based on a recommendation from the National Academy of Sciences to conduct multidisciplinary injury studies, the National Highway Traffic Safety Administration (NHTSA) began funding studies to better understand the engineering aspects of injury causation to humans in real-world motor vehicle crashes, and the CIREN program was formally established in 1996 [1]. At that time, there were seven centres performing crash injury data collection and analysis, and efforts began to build an electronic data system.

CIREN's mission is to improve the prevention, treatment, and rehabilitation of motor vehicle crash injuries in order to reduce deaths, disabilities, and human and economic costs. This mission joins engineering and medical expertise from industry, academia, and government to determine the causation of injuries in motor vehicle crashes, creating a field crash database and expanding the knowledgebase of those involved. CIREN also serves as a sentinel to detect emerging safety problems and acts as a catalyst for crash safety research. While the program's inclusion criteria have evolved over time, the general theme has been to enroll seriously injured occupants of newer vehicles. This focus provides the clinicians and researchers with valuable data to understand the performance of the most advanced automotive safety technologies. The case selection process qualifies CIREN as a purposive sample that cannot be considered representative of all crashes in the USA. The CIREN program attempts to constrain case enrollment to restrained occupants who sustained serious injury in non-catastrophic crashes of newer vehicles. The realities of the CIREN model sometimes lead to inclusion of cases that do not fully meet the stated criteria. A simplified version of the target inclusion criteria are outlined in Table A-I of the Appendix. Some inclusion options have been added or removed over time with the goal of improving case count in response to shifting research interests. These additional options have yielded relatively few cases, and are not detailed in this context. The value of CIREN case data is the enhanced injury documentation and analysis.

The CIREN process begins with identification of eligible case subjects at one of the participating trauma centres. Centre personnel gain informed consent from the injured subjects and determine whether the case fits within the inclusion criteria. Once it has been determined that a case meets the inclusion criteria, medical and crash data collection begins and the enrolling team enters data into the electronic database. Crash and scene data conform to standard NHTSA field crash investigation protocols. Case subject medical records are de-identified and injuries are coded according to the Abbreviated Injury Scale (AIS). Once medical and crash data are

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complete, the case undergoes a review process in which the teams determine injury causation through collaborative discussion. Finalised case data are then checked for quality prior to being released to the public.

To more comprehensively characterise the nature of injury causation in the enrolled crashes, the engineering talent in the CIREN program undertook development of new methodologies for analysing and documenting injury causation. The formalised coding of injury causation data, identified as BioTab, is more thoroughly explained by Schneider *et al.* [2] and its development will not be discussed at length here. This approach overcame some of the limitations in other field data collection programs at the time. Since its inception in 2005, the BioTab coding approach has been a primary focus of CIREN case reviews, encouraging a more disciplined discussion of case evidence and its relationship to injury causation. Identification and documentation of the constituent factors and salient case evidence follow guidelines aimed at providing end-users with a comprehensive scenario for how the injury occurred. A scaled-down version of the BioTab coding scheme has been adopted for NHTSA's other field crash investigation programs (Crash Investigation Sampling System (CISS) and Special Crash Investigations (SCI)) as part of the recent Data Modernization effort [3].

There are two ways for the public to view published CIREN case data. NHTSA has provided public access to published CIREN cases via an Internet-based case viewer interface since 2001 [4]. The interface facilitates viewing individual case data, including crash and scene photography, and cases can be searched by crash and/or occupant parameters. This interface currently includes cases enrolled from calendar years 2004 to 2016 [5]. In 2013, the first CIREN tabulated data files and data dictionary were generated and released [6]. These SAS-readable files were structured like the annual files released from NHTSA's National Automotive Sampling System Crashworthiness Data System (NASS-CDS) and contained many of the same variables and attributes. Similarities in crash-, vehicle-, and occupant-level coding permit queries written for the NASS-CDS data set to be applied to the CIREN data set with minimal alteration. Unlike the NASS-CDS files, which were released one year at a time, the CIREN files are cumulative and include all data years in a single release. The tabulated files include only cases enrolled after June 1, 2005 when the CIREN program began using a new injury documentation protocol.

The objective of this paper was to heighten awareness of and highlight some of the unique analyses made possible by the publicly available CIREN data collected between 2005 and 2016. With the tabulated data and the case viewer interface, interested parties have multiple options for exploring cases collected and reviewed by the CIREN program. Used alone or in conjunction with other field data, CIREN case data provide the crash safety community with a rich source of real-world occupant injury biomechanics data.

II. METHODS

The analysis presented in this paper focuses on the tabular public data sets generated for CIREN cases enrolled between 2005 and 2016, which are accessible on the NHTSA Internet site [5]. The individual case viewer was also used to support in-depth review of selected cases [4]. Analysis of tabulated data was performed using SAS 9.3 (SAS Institute, Cary, NC, USA) and Microsoft Excel (Microsoft, Redmond, WA). Descriptive statistics are provided for the entire data set to provide a general overview of occupant and crash characteristics available for examination. Several focused analyses are performed based on some of the data elements unique to CIREN, such as injury mechanism, and the specific implicated event associated with injury causation.

Tabular Data Structure/Overview

CIREN data are presented in ten data files, where six are derived using the same variable names, definitions, and attributes as NASS-CDS (*Event, GV, VE, VI, OA, Acc_desc*). The four CIREN-unique files (*Case, Injuryanalysis, Injury, Scenario*) contain occupant-specific case data, injuries, and injury causation details for the CIREN case subject. The *Injuryanalysis* table contains a narrative summary of the occupant and crash details, occupant kinematics, and injury causation for the CIREN case subject.

The CIREN Data Dictionary, provided with the downloadable tabulated data set [6], provides guidance on the contents and linkages within the tables. The NASS-CDS Analytical User's Manual also serves as a valuable reference for analysis of tabulated CIREN data and provides information on year-to-year variable applicability for the tables and variables that mimic NASS-CDS [7].

A CIREN case is occupant-centric, and the highest-level record in the CIREN *Case* table is uniquely identified by its CIRENID. Figure 1 displays a schematic of the data tables, with key and linkage variables listed. CIREN-specific tables are all linked by a case subject's CIRENID. Linking to the NASS-level crash and occupant tables requires the use of CASENO, VEHNO, and OCCNO variables as multiple CIREN case subjects may be tied to the same crash or vehicle. Additional details are provided in Table A-II of the Appendix.

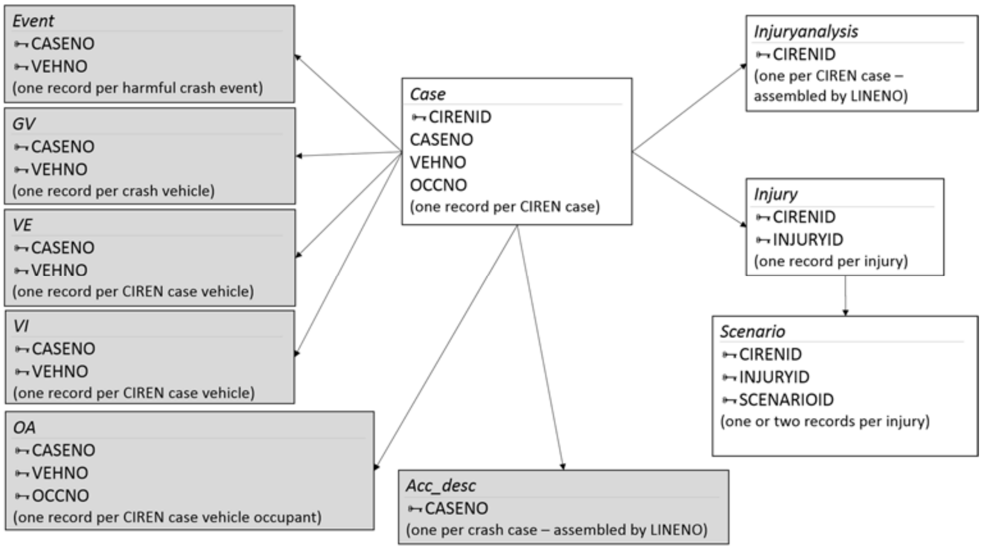

Fig. 1. CIREN data tables and linkages. Shaded boxes represent tables that mimic the NASS-CDS structure. Unshaded boxes represent tables unique to CIREN. Key variables indicated by a key symbol.

BioTab Overview

Readers are encouraged to review the Schneider *et al.* [2] publication for complete coverage of the BioTab method, but a brief overview with definitions is provided here to support the analyses presented in this paper. There are two levels of BioTab coding – long-form and short-form (also referred to as BioTab Lite) – with only minor injuries coded in the abbreviated short-form format. Most AIS2 and all AIS3 or higher injuries undergo long-form coding in CIREN. A defined list of AIS2 injuries require long-form BioTab coding due to their clinical significance and relevance to occupant protection research. The BioTab Lite coding protocol was not implemented until the beginning of calendar year 2007, so some AIS1 and the non-long-form AIS2 injuries in the tabulated data received legacy injury coding like that used in NASS-CDS. The legacy injury coding of minor injuries uses different terminology than BioTab, with causation information only given in the *Injury* table, and unless otherwise noted it will not be discussed in this work. Long-form BioTab and BioTab Lite injury causation data are documented in the *Scenario* table. Common BioTab terminology and the applicability of variables in both BioTab forms are given in Table I.

One of the fundamental elements of an injury's coding in BioTab is identification of the Body Region Injured (BRI). While all injuries are assigned an AIS code, which classifies injuries into one of eight body regions, BioTab divides the body into segments and joints such that 20 options are available for the BRI. A list of the BioTab body regions and their primary contents is provided in Table A-III of the Appendix.

One or two Injury Causation Scenarios (ICS) may be defined for each injury. The ICS contains all the data elements required to characterise an injury's causation, such as the Source of Energy (SOE), Involved Physical Component(s) (IPC), Regional Mechanism (RM), evidence, and confidence levels. Evidence and confidence are assigned for the IPC(s) as well as for the overall ICS. Additionally, Contributing Factors (CF) may be added to document non-essential conditions that affected the likelihood or severity of the injury.

Most injuries are assigned only one ICS, but a second ICS may be coded to convey a potential alternative scenario if certain conditions are met. Reasons for assigning two ICS for an injury include situations where two different SOE are potentially responsible, or if an injury may have been caused directly or induced by another injury. The SOE is the specific event that produced the injurious loading or circumstance during the crash and it is selected from one of the coded crash events, airbag deployments, pretensioner deployments, or a fire.

The IPC is, simply, the object with which the case subject interacted in the vehicle or environment to sustain the injury. Examples of IPCs include restraints, all parts of the vehicle interior, other occupants, cargo, and any external intruding structure that the occupant contacts, such as a pole or the hood of another vehicle. The IPC is associated with a Body Region Contacted (BRC), which is not necessarily the body region injured. Within an ICS, up to four separate IPCs may be coded, depending on the circumstances. Most scenarios involve a single area of contact to the occupant, though uncertainty in the exact location of contact to the vehicle may justify coding a primary and alternate IPC. Circumstances occasionally arise where two IPCs simultaneously loading the body at different anatomic locations are critical to the occurrence of a specific injury, without which the injury would not occur or the injury pattern might change. This is called a Critical IPC configuration, and the coding requires two BRC/IPC combinations.

TABLE I
BIOTAB DEFINITIONS AND APPLICABILITY

Initialism	Name	Description	Long-Form	Short-Form
BRI	Body Region Injured	BioTab body region sustaining injury	✓	✓
ICS	Injury Causation Scenario	Story of how injury occurred	✓	✓
SOE	Source of Energy	Event resulting in transfer of energy to/from occupant	✓	✓
IPC	Involved Physical Component	Objects contacting and loading occupant	✓	✓*
BRC	Body Region Contacted	BioTab body region interacting with IPC	✓	✓*
CF	Contributing Factor	Non-essential features that increase likelihood or severity	✓	-
RM	Regional Mechanism	Physical action producing injury within BRI	✓	-
-	ICS Evidence†	Crash and medical evidence to support the overall ICS	✓	-
-	ICS Confidence	Confidence in the overall ICS	✓	✓
-	IPC Evidence†	Crash and medical evidence to support an IPC/BRC interaction	✓	-
-	IPC Confidence	Confidence for the IPC/BRC interaction	✓	✓

* The short-form coding only allows a single IPC and BRC interaction.

† ICS Evidence and IPC Evidence data elements are not included in the tabulated data sets.

Comorbidities as Contributing Factors

One of the advantages of the CIREN program's consent-based approach is the extensive medical documentation available to better understand a case occupant's overall physical condition and injury outcome. In addition to collecting information on comorbidities of CIREN occupants, the BioTab allows association of specific comorbidities with injuries if the teams determine during case review that injury causation or severity may have been related to a documented health condition. The multi-disciplinary teams that review and code CIREN cases consider the roles played by case subjects' conditions, and indicate relevance by selecting the comorbidity as a Contributing Factor in an injury's long-form BioTab coding. Up to two of these comorbidity factors (COMOR_FCT1, COMOR_FCT2) are included in the public data *Scenario* file for each record. Other Contributing Factors, unrelated to the case subject's health condition, that may be coded include items such as intrusion, high crash severity, and if an occupant was unbelted (ICS_FACTOR1, ICS_FACTOR2, ICS_FACTOR3).

Analysis was performed to evaluate prevalence of comorbidities as contributing factors for all long-form BioTab injuries and also broken down by body region injured (BT_BR_INJ). The counts from COMOR_FCT1 and COMOR_FCT2 were summed to determine overall frequencies of use. Common comorbidities were explored further by examining the associated body regions and occupant characteristics.

Source of Energy for Injury Causation

As noted above, the BioTab identifies specific events as the causal source of energy for each ICS. A SOE is coded in all long-form BioTab scenarios as well as in BioTab-Lite short-form scenarios, but is not a variable in the legacy injury causation coding protocol. Thus, the SOE analysis was only conducted for the BioTab long-form and short-form injuries using the SOE variable in the *Scenario* file.

The first-level SOE analysis performed for this paper identified which type of event was implicated in the injury's causation (crash, airbag, etc.). Crash event-related injuries were then explored further to determine how often the most significant event was implicated by comparing the *Scenario* file's S_ACCSEQ variable identifying the causal event sequence number with the case vehicle's ACCSEQ1 and ACCSEQ2 variables in the *VE* file. An example of the logic to link the tables is provided in the Appendix.

Scenarios where an airbag was listed as the SOE were explored further to identify whether the airbag was also the IPC or whether they were deemed fling-type injuries (as indicated by the IPC being something other than an airbag). For this analysis, the PRIM_AREA variable in the *Scenario* table was used to identify the location of the Primary IPC.

Further analysis of airbag SOE cases was performed by separating by body region and crash type. Specifically, all spleen injuries to drivers (left front, SEATPOS=11) in left-side impacts (GAD1=L) were extracted to examine the types of SOE coding. All spleen injury codes were considered (544299.2, 544210.2, 544212.2, 544214.3, 544220.2, 544222.2, 544224.3, 544226.4, 544228.5, and 544240.3).

Critical IPC – Required Involvement of Multiple Components

Critical IPCs should be assigned when, essentially, the injury mechanism requires a body region to be loaded between two distinct points. This capability exists only for long-form BioTab scenarios. For Critical IPCs, the *Scenario* file's C1P_IPC and C2P_IPC are populated instead of the PRIM_IPC field. An analysis of IPCs was conducted for this paper where the long-form scenarios were searched for injuries coded with Critical IPCs. These Critical IPC scenarios were analysed by body region injured (BT_BR_INJ) and associated crash type (event-specific GAD from *VE* table linked via S_ACCSEQ in *Scenario*).

The body regions most often coded with Critical IPC scenarios were examined further by identifying the dominant associated crash modes. Specifically, tibia plateau fractures associated with frontal crash events were extracted. Injury codes differed for the two different AIS versions included in the database – codes of 853406.2 and 853408.3 identified tibia plateau fractures coded in AIS 1990/98, while 854111.2, 854112.3, 854151.2, 854152.3, 854161.2, 854162.3, 854171.2, and 854172.3 identified those coded in AIS 2005/08. Scenarios for all tibia plateau fractures in frontal crashes were examined to determine prevalence of Critical IPC coding.

Regional Mechanism

The Regional Mechanism is the physical mechanism occurring within the body region to produce the injury (e.g., compression, bending, shear, etc.). The specific nature of the injury provides some evidence to support the mechanism of loading to the injured body region (e.g., a butterfly fragment generally suggests that a long bone fractured due to bending). The CIREN biomechanical engineers rely on radiology and medical input combined with knowledge of the literature to assign Regional Mechanisms. It is important to understand that the RM is the loading experienced by the BioTab body region. The organ- or tissue-level mechanism may not be the same (e.g., flexion of the cervical spine region may lead to a tension injury of a posterior cervical ligament).

BioTab coding allows assignment of a Primary and a Secondary RM for long-form scenarios. Analysis of the Primary RM was performed for various body regions by looking at the P_REG_MECH variable based on the BT_BR_INJ body region in the *Scenario* table.

III. RESULTS

The tabular public CIREN data contains information on 2,104 case occupants from 1,896 vehicles involved in 1,869 crashes. Age and sex breakdown for the CIREN case subjects is shown in Fig. 2. Fifty-five percent of the case occupants were female, and there were 94 paediatric subjects under 13 years of age. The distribution of crash type, as indicated by first plane contacted for the most significant event (GAD1), is shown in Fig. 3. Frontal crashes were most common, comprising 63% of the cases based on most significant impact event. Belted occupants accounted for 76% of the case subjects. The distribution of case vehicle age is shown in Fig. 4, where the calculated age was based on the difference between the calendar year of the crash and the CIREN case vehicle's model year. A chart showing the distribution of vehicle model year in the public data set is provided in Fig. A-1 of the Appendix.

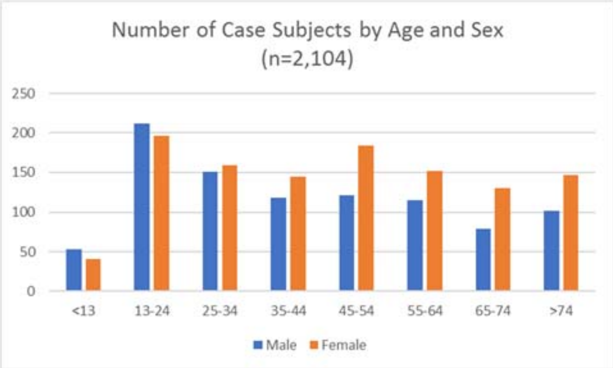

Fig. 2. Age and sex distribution of case subjects.

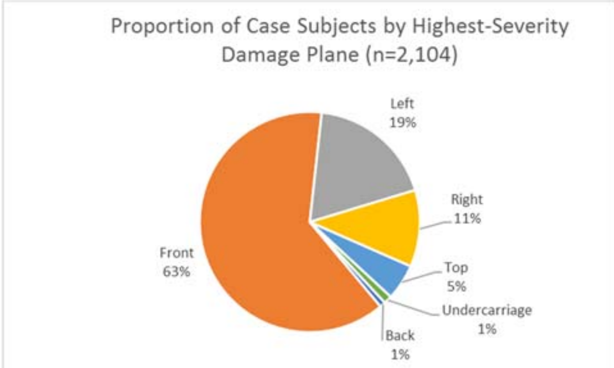

Fig. 3. Breakdown of plane contacted for most significant event.

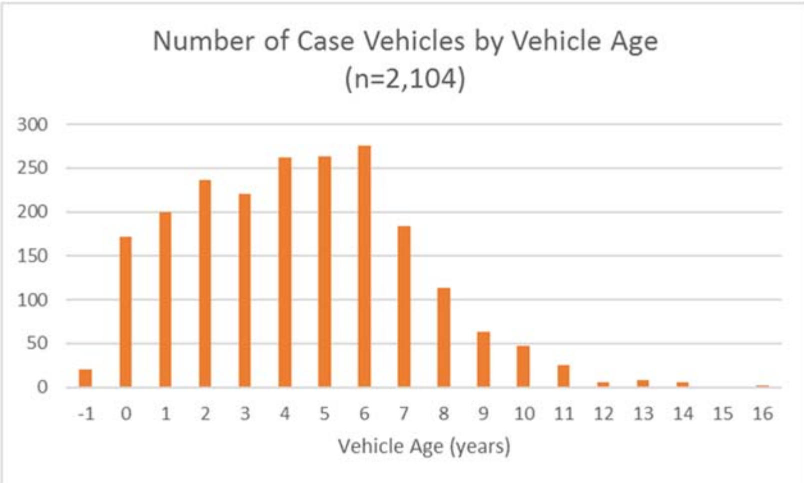

Fig. 4. Distribution of vehicle age for all CIREN case subjects. Vehicle age calculated as the difference between the crash calendar year and vehicle model year.

The data set contains 21,398 coded injuries with the distribution of AIS severity shown in Fig. 5. Of those, 7,832 received long-form BioTab ICS coding, with 423 also having a second ICS coded.

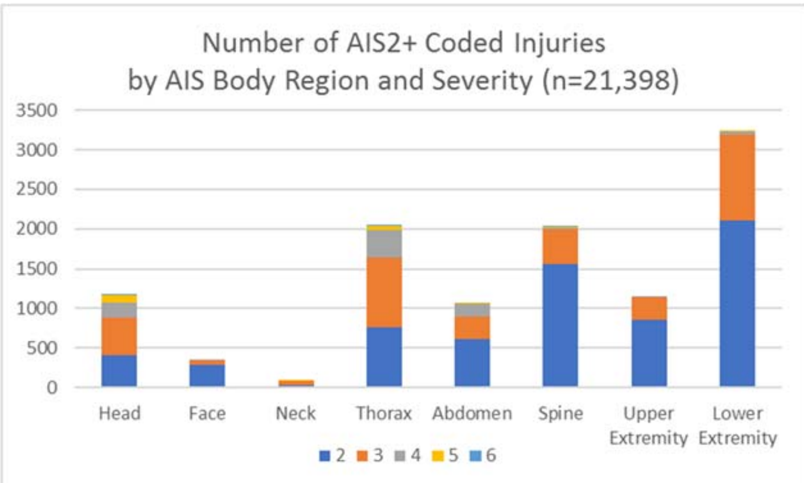

Fig. 5. Distribution of coded AIS2+ injuries in data set by AIS body region and severity level. The data set includes coding for more than 10,000 AIS1 injuries, which are not depicted in this chart.

Comorbidities as Contributing Factors

Table II includes the number of causation scenarios with different comorbidities as a CF. Note that while 668 scenarios included comorbidities as CF, there were 638 injuries associated with those scenarios, meaning some injuries received two ICS with the comorbidities noted in both records. The two most commonly coded occupant comorbidities in the CIREN database are obesity and osteoporosis.

TABLE II
COMORBIDITY AS CONTRIBUTING FACTOR COUNTS IN 7,832 ICS

Comorbidity	**# of ICS**
Obesity	276
Osteoporosis	275
Other (specify)*	58
Blood Thinner Therapy	12
Prior Joint Replacement	10
Pregnancy	7
Liver Disease	6
Remaining (5 or fewer scenarios each)	24

* Specific condition not included in public data.

The Body Mass Index (BMI) of each adult (>19 years) occupant in the CIREN database was calculated and categorised from the recorded height (STATURE) and weight (WEIGHT) in the *Case* table. Children and teenagers were excluded since their BMI must be interpreted differently [8]. A BMI of 30 or greater is classified as obese by the US Centers for Disease Control. The distribution of CIREN case subjects by BMI category is shown in Fig. 6. Further examination of the case subjects classified as obese broke the scenarios down by body region to show the prevalence of obesity as a coded comorbidity among that subgroup. Figure 7 shows the proportion of injuries in each BRI for all obese occupants in all crash types where obesity was deemed a Contributing Factor.

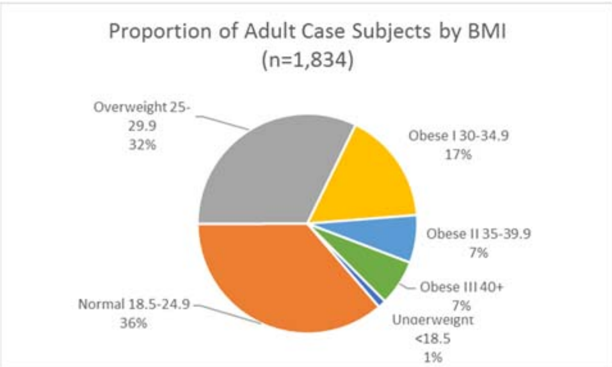

Fig. 6. Distribution of adult CIREN case subjects by Body Mass Index category.

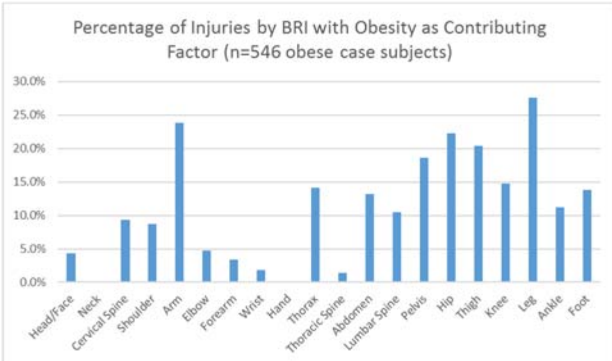

Fig. 7. Proportion of injuries with obesity as Contributing Factor for all obese case subjects (BMI ≥30 and age≥20 years) in all crashes.

Source of Energy for Injury Causation

Of the 17,346 BioTab ICS associated with 16,925 individual injuries, 93.7% were linked to a crash event (Table III). Further investigation of those ICS associated with a crash event shows that 91.7% were linked to the most significant crash event and 5.2% to the second-highest severity crash event. The scenarios with airbag as SOE were broken down further to examine the body regions and involved components (Fig. 8), which shows most of the scenarios assigned the airbag as the IPC when the airbag was the SOE, meaning that direct loading by the airbag during inflation was deemed to be responsible for the injury's causation. Of those with a different IPC, the most common scenario was a fling injury of the arms contacting the vehicle interior or the head/face of the same occupant.

TABLE III
SOURCE OF ENERGY (SOE) COUNTS

SOE	**# of ICS**	**% of ICS**
Crash Event	16,251	93.7
Airbag	239	1.4
Pretensioner	1	0.0
Caused by other injury	169	1.0
Unknown	686	4.0

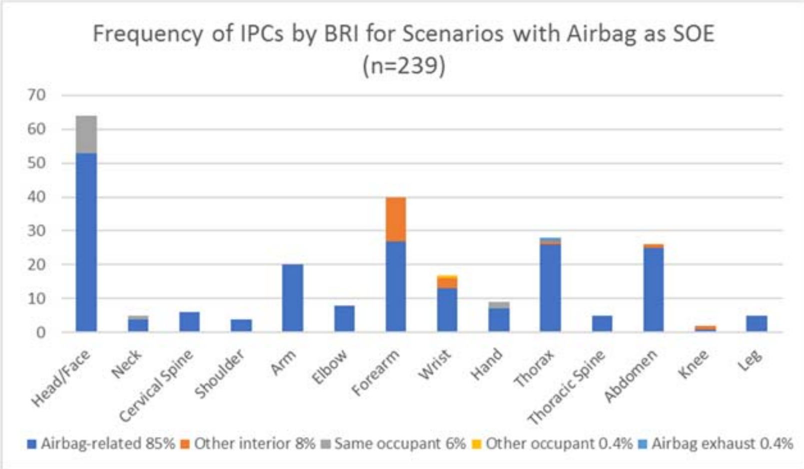

Fig. 8. Involved Physical Components by Body Region Injured for scenarios with airbag as Source of Energy.

For frontal crashes (classified as GAD1=F), there were 201 ICS with the SOE attributed to airbag deployment. The most common body regions injured with the airbag as SOE in frontal crashes were the upper extremities (87), head/face (59), and thorax (21). For side-impact crashes (classified as GAD1 of L or R), there were 36 injuries with the SOE attributed to airbag deployment. The most common body regions injured with the airbag as SOE in side-impact crashes were the abdomen (14) and the upper extremities (10).

There were 90 drivers in left side-impact crashes that sustained spleen injuries, with 44 in vehicles not equipped with a torso side airbag (either door- or seat-mounted). Torso side airbags were available in 46 of the vehicles and deployed from the seat in 41. Table IV shows the SOE and Primary IPC for the 48 ICS associated with the 41 driver spleen injuries in crashes where the torso side airbag deployed (some injuries were assigned two ICS to show the potential for two different injurious scenarios). Eight of those scenarios cited the side airbag as the SOE for the injury causation, with either the airbag or the seat as the IPC contacting the BRC.

TABLE IV
SOURCE OF ENERGY AND INVOLVED PHYSICAL COMPONENT FOR DRIVER SPLEEN INJURY SCENARIOS IN LEFT SIDE IMPACTS WITH TORSO SIDE AIRBAG DEPLOYMENT

SOE	Steering Wheel Rim	Door/armrest Hardware	B-Pillar	Seat	Seat Belt	Airbag	Total
Crash Event	2	30	4	3	1	0	40
Airbag	0	0	0	1	0	7	8

Required Involvement of Multiple Components

The data set contained 570 ICS coded with Critical IPCs, with the breakdown by body region injured and scenario-specific crash type shown in Fig. 9 only for front-, left-, and right-plane impacts. Most of the ICS with Critical IPCs were for lower extremity injuries. Frontal crash events were most often implicated for the knee and leg, while side crash events most often implicated for the hip and pelvis.

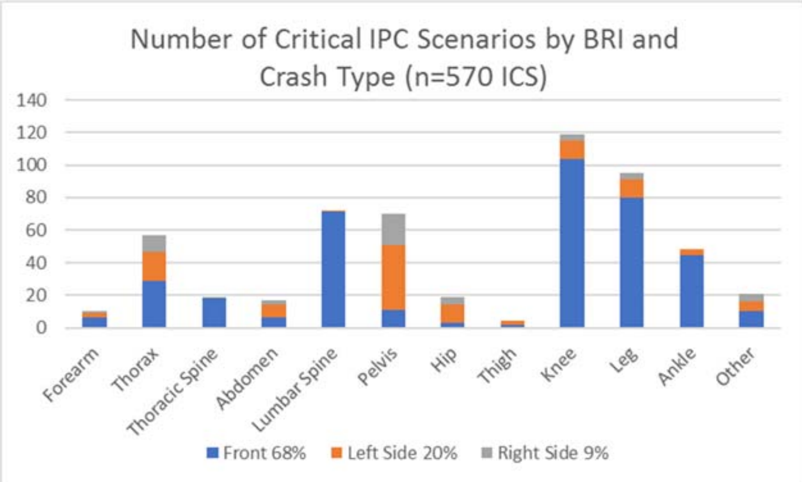

Fig. 9. Frequency of Critical IPC scenarios by Body Region Injured and crash type (only showing Front, Left side, and Right side crash types – other crash types accounted for 19 scenarios). Indicated crash types are those events identified by the SOE.

Further examination of the knee body region reveals that most of the injuries represented are tibia plateau fractures. Considering all tibia plateau fractures sustained in frontal crashes (GAD1=F), the associated causation scenarios show that Critical IPCs were used for 76% of the injuries. A similar query for distal tibia injuries reveals that Critical IPCs were used for 15% of the injuries.

Regional Mechanism

Due to the large number of BioTab body regions and Regional Mechanisms, only selected body regions were analysed for illustration and some types of mechanism were combined for easier interpretation. Table V shows Regional Mechanisms for the thorax and abdomen BioTab body regions and Table VI shows the knee, leg, and ankle regions. Note that only primary mechanisms are shown and that some of the scenarios would also have a secondary mechanism, though the primary mechanism is the dominant mechanism as determined by the CIREN teams. For these BRIs, the most frequent RMs were compression alone and compression combined with rate of compression.

TABLE V

REGIONAL MECHANISMS FOR THORAX AND ABDOMEN INJURY CAUSATION SCENARIOS

BioTab BRI	Compression	Shear	Puncture	Cutting	Tension	Flex./ Ext.	Comp. and Rate of Comp.	Accel.	Total
Thorax	1,350	2	2	1	0	3	644	0	2,002
Abdomen	329	3	0	0	1	0	358	5	696

TABLE VI

REGIONAL MECHANISMS FOR LOWER EXTREMITY INJURY CAUSATION SCENARIOS

BioTab BRI	Comp.	Shear	Bending	Flexion	Med./ Lat. Bend.	Inv./ Ev.	Other	Total
Knee	293	8	0	1	1	0	9	312
Leg	129	9	29	0	0	0	10	177
Ankle	346	4	1	15	0	83	2	451

IV. DISCUSSION

The publicly available CIREN case files contain unique injury causation data not previously available in NHTSA field crash data sets. While the case makeup may be heavily influenced by the program's inclusion criteria, and not suitable for analysis requiring a probability sample, the in-depth review and documentation of injury causation remain a valuable resource to investigate vehicle crashworthiness and occupant biomechanical response. Used on its own, CIREN public data facilitate in-depth review of many factors associated with motor vehicle crash injury causation. CIREN case data are suitable for use in case series studies, and the inclusion of crash data files that mimic the structure of those in NASS-CDS positions the CIREN data set as a supplemental tool to be used alongside analyses performed with the nationally representative US NASS-CDS data. Studies can be performed by combining data from the CIREN and NASS-CDS files using the similar data elements (e.g., vehicle types, occupant characteristics, crash parameters). Such an approach would not be appropriate for making statistical estimates, but would provide a greater number of cases than using CIREN or NASS-CDS alone.

CIREN data alone should not be used to examine injury risk – such analysis is inappropriate and would produce misleading results based on the inherent bias of the selection criteria. Combining CIREN with the control and exposure data from NASS-CDS may lead to increased sample size for risk assessments or for analyses where CIREN provides detail not otherwise available. One such methodology was presented by Elliot et al. [9] where pseudo-weights were created for CIREN cases based on a model derived from NASS-CDS to estimate probability of selection. This methodology has been used in other works to combine cases from both data sets for matched cohort studies [10-11].

The analyses presented in this paper were intended to highlight some of the capabilities of the SAS-readable CIREN data sets and do not provide an exhaustive review of the available data. Analysts should consult the CIREN Data Dictionary to fully understand the scope of the data and potential analyses. Analysts should also familiarise themselves with the limitations of the CIREN sample, understand the case selection process, and only perform appropriate analyses given the nature of the available data.

The nature of the CIREN program, and its focus on injury biomechanics of seriously injured occupants in newer vehicles, intends to provide relevant data to support injury prevention research. Based on the vehicle age distribution shown in Fig. 4, most CIREN cases involve occupants in vehicles newer than about six years old at the time of the crash. When collecting cases, the program must balance case count goals with qualifying case subject availability and consent. The emphasis on newer vehicles enables CIREN researchers and engineers to assess field performance of new safety designs relatively soon after deployment into the fleet, although cases involving older vehicles still offer value in understanding injury causation. The inclusion criteria make allowances for older vehicles under some circumstances that include special-interest crash modes or injury types, and older vehicles meeting “sisters and clones” criteria are also accepted. Overall, this strategy produces cases based on newer vehicles at the time a case is reviewed, but the collection of cases over many years will naturally be biased toward older vehicles as shown in Fig. A-1.

CIREN teams benefit from access to comprehensive medical documentation, and therefore can document conditions, outcomes, and treatments for each case subject. The analysis of occupant comorbidities as Contributing Factors to injury causation revealed that osteoporosis and obesity were the most common health conditions thought to influence likelihood or severity of injury. CIREN teams call upon their own experience and findings in the literature before associating comorbidities with an ICS. The obesity data shown in Fig. 7 show that, overall, obesity was cited as a contributing factor in about 12% of the long-form BioTab injuries sustained by obese occupants. Prior studies have suggested that obese occupants will experience additional excursion during crash events due to a combination of greater mass that must be managed by the restraint systems and excess adipose tissue that affects belt fit in a way that effectively introduces slack [12]. The higher prevalence of obesity as a CF for lower extremity injuries, as well as for the abdomen and thorax, tends to agree with those claims. Additional variables could be easily brought into the investigation of the injuries to look at crash and restraint conditions and the associated Involved Physical Components.

One of the hallmark features introduced in the BioTab coding methodology was the ability to identify specific causal events for each injury. Not only does this approach allow specific crash events to be identified, it also allows injuries to be associated with deployment of specific airbags. In general, most injuries are associated with the highest-severity crash event. BioTab also allows injuries to be coded with two different scenarios when there is uncertainty in the associated causal event. This approach provides users with added documentation of the possibilities envisioned by the reviewing CIREN teams. Extending the analysis of the spleen injuries in side impacts, one case with two different ICS was chosen for discussion.

In CIREN case 352240671, the 24-year-old female case occupant, weighing 54 kg with a stature of 165 cm, was the belt-restrained driver of a 2010 Honda Civic 4-door sedan, which was primarily involved in a moderate (15 kmph Delta-V), 10 o'clock, near-side impact with the frontal plane of a 1995 Ford Escort 4-door hatchback (Fig.

10 and Fig. 11). During the impact, the case occupant was projected mostly left and a little forward, in reference to the vehicle, as left side components of the vehicle interior intruded laterally inward (door panel/B-pillar/sill) and the left side airbags deployed (curtain and side hip/torso airbags). The case occupant's only injury was a Grade III spleen laceration (AIS 544224.3), which was coded with a primary ICS of the airbag deployment as the SOE, the side airbag as the IPC, and an ICS confidence of probable. The alternate ICS, with an ICS confidence of possible, documented the side crash event as the SOE, and the left armrest/hardware in rear lower door quadrant, which had intruded less than 2 cm, as the IPC contacted through the airbag. A tabular summary of the ICS coding is given in Table A-IV of the Appendix.

Fig. 10. Exterior photograph of the case vehicle from CIRENID 352240671.

Fig. 11. Interior photograph of the case vehicle side airbags from CIRENID 352240671.

The nature of the injury relative to the severity of the crash event led the CIREN teams to assign two causation scenarios, with the most likely one, associating the side airbag deployment with the injury, assigned a higher confidence level of probable versus possible. The deployment of airbags as a SOE for injury has been studied in the literature [13], with such findings undoubtedly influencing the assessments by the CIREN teams. The ability to codify both scenarios given the uncertainty of which was ultimately the cause provides analysts with a more comprehensive record of the case review process.

While occupant interaction with the vehicle and environment in crashes is typically complex, most injuries can be readily characterised by describing the loading in a body region due to a single interaction between the occupant and surroundings. Recognising that some crash injuries are more adequately characterised by loading via two distinct contact points on the body, the BioTab was developed to accommodate multiple BRC/IPC interactions using a Critical IPC scenario. This was found to be coded most often for lower extremity injuries in Fig. 9, with the tibia plateau (knee BioTab body region) being most likely to require two-point contact. A case with this type of scenario was identified and examined in the case viewer for discussion.

In CIREN case 360241814, the 64-year-old male, weighing 125 kg and with a stature of 188 cm, was the belt-restrained front right passenger of a 2009 Subaru Impreza WRX four-door sedan that was involved in a moderate severity frontal impact with a 1992 Pontiac Sunbird GT 2-door coupé (Fig. 12 and Fig. 13). The principal direction of force was 1 o'clock at 20°, with the belt pretensioner and the front instrument panel airbag deploying. There were no intrusions documented in the case vehicle. The case occupant moved forward and the seat belt restrained his torso, with loading evidence on the webbing. Both knees and lower legs impacted and scuffed the glove box and it was inferred that both feet contacted the toe pan. It should be noted that the tabular data do not include coded IPC evidence, but such details are visible in the case viewer. This patient suffered bilateral tibial plateau fractures, which were coded with matching ICS of the crash as the SOE, the foot-to-toe pan as the first Critical IPC and the knee-to-glove compartment as the second Critical IPC. A tabular summary of the ICS coding is given in Table A-V of the Appendix.

Fig. 12. Exterior photograph of the case vehicle from CIRENID 360241814.

Fig. 13. Interior photograph of the case vehicle's glove box door from CIRENID 360241814.

Fracture at the proximal tibia with the primary axial loading being applied through the foot generally requires a boundary condition at the proximal end of the tibia to generate injurious loads at the knee. This is another example showing the knowledge of the literature and involvement of biomechanical engineers influencing the coding. The prevalence of Critical IPC scenarios for compressive injuries of the tibia plateau compared to the ankle is further evidence of the thought process and collective experience in CIREN.

The brief analysis of the coded Regional Mechanisms presented here revealed the overall dominance of compression-related injuries in motor vehicle crashes. While every effort is made to select the most appropriate mechanism for each scenario, the teams' assessments are limited in that they are based on the available evidence. For some injuries, the vehicle evidence and injury patterns may not support the same level of confidence in the assignment of the mechanism – users should consider the ICS Confidence level when conducting analyses of the coded Regional Mechanisms. Furthermore, the selection of RM may have been influenced by biases and the state of the art at the time. One specific example is the mechanism "angular acceleration" that was used for many brain injuries. That mechanism should be viewed as a surrogate for rotational kinematics in general, given the developments in the understanding of brain injury causation [14].

Since its inception, the BioTab coding method has undergone minor revisions, though the overall approach to assigning causation has remained consistent. One of the biggest challenges with the method has been consistency in the use of certain database attributes given the diverse nature of available evidence in field data collection efforts. In some cases, the applicability of an attribute for a variable may be unclear if the available evidence does not conform with the stated usage rules for that attribute. Therefore, rules specific to some attributes have evolved as a result of lessons learned and the desire to provide the most meaningful data. For example, some Contributing Factor attributes were retired after a few years of applying the BioTab methodology. Other attributes have been used only rarely. The biomechanical engineers in CIREN deliberated relevance of attributes and their rules, and have sought to evolve the rules, definitions, and methodology.

The accessible cases, in both the individual case viewer and in the tabulated files, have undergone extensive review between inception and publication. Efforts have been made to make all case data accurate and internally consistent, though the data set may contain questionable or erroneous elements in some cases. Users are encouraged to review all case data to more thoroughly understand case coding and the reasoning behind the BioTab coding. Furthermore, the narrative of the causation in the *Injuryanalysis* table may provide added commentary.

The CIREN process exposes participants to valuable real-world crash outcomes and the data collected have many potential uses. While the in-depth expert review leads to more injury-specific biomechanics data, the cases are not a representative sample of crashes. Users must consider the appropriateness of analyses using CIREN data, which should be used to gain a deeper understanding of injury causation.

Since NHTSA's Data Modernization effort has resulted in the development of entirely new data systems, the CIREN data provided for 2004–2016 will not be expanded any further. Future CIREN case data will be made available as a separate data set. Moving forward, the CIREN program will release similar data with similar intended use for standalone analyses of injury causation, or as a companion to the nationally representative CISS data set.

V. CONCLUSIONS

The multi-disciplinary review of case evidence and the resulting structured coding of injury causation scenarios in CIREN provide a unique and more comprehensive documentation of the injuries for analytical use. Using the same field investigation techniques and crash data structure as in other NHTSA field crash studies permits analysts to apply similar crash- and occupant-based queries to the CIREN data. As the CIREN program is a purposive sample, the data are not statistically representative of crashes in the USA, and the findings must be interpreted appropriately. Data from CIREN cases may be used to examine the biomechanical mechanisms and the factors associated with injury causation that are not available in other data sets. Due to the lack of control data, CIREN data should not be used on their own to make risk estimates.

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VIII. Appendix

CIREN Inclusion Criteria

TABLE A-I

PRIMARY CIREN TARGET CASE INCLUSION CRITERIA

Crash Type	Vehicle Criteria	Restraint Criteria	Occupant Position	Injury Threshold
Adult (13+ years)				
Frontal	Six years old at time of crash[1]	Airbag[2], airbag and three-point belt	Row 1	AIS≥3 or AIS2 in two body regions[3]
		Three-point belt	Rows 2+	
Side		Any	Any	
Rollover[4]		Any	Any	
Child (12 years and under)				
Frontal Side	Eight years old at time of crash[1]	Child Restraint System (CRS) or three-point belt used	Any	AIS≥2
Rear				
Rollover				

[1] Vehicle age may be older if no significant changes in make and model design between cutoff year and model year (sisters and clones)

[2] Unbelted occupants in frontal crashes are allowable, but their inclusion is intentionally minimised

[3] Some AIS3 codes were downgraded to AIS2 when AIS 2005/08 was implemented for CIREN in calendar year 2010. Injuries with downgraded severity score qualify as AIS3 for inclusion purposes in CIREN.

[4] Fully ejected occupants excluded

Data Structure Overview

TABLE A-II

DESCRIPTION OF DATA TABLES AND LINKAGE VARIABLES

Table/SAS file	Record level	Key variable(s)	Comment
Case	CIREN case subject	CIRENID	In CIREN, a case is based on an occupant (case subject)
Injury	Injury	CIRENID INJURYID	One record for each of the CIREN case subject's injuries
Scenario	Injury scenario	CIRENID INJURYID SCENARIOID	One or two records for each of the CIREN case subject's injuries (only applies to BioTab and BioTab Lite injuries)
Injuryanalysis	CIREN case subject	CIRENID	Multiple records per CIRENID identified by LINENO to assemble injury analysis narrative
Event	Crash event	CASENO VEHNO	One record for each injurious event in crash
GV	Vehicle	CASENO VEHNO	One record for each vehicle in crash
VE	Vehicle[1]	CASENO VEHNO	One record for CIREN case subject's vehicle
VI	Vehicle[1]	CASENO VEHNO	One record for CIREN case subject's vehicle
OA	Occupant	CASENO VEHNO OCCNO	One record for each occupant of CIREN case subject's vehicle[1]
Acc_desc	Crash	CASENO	Multiple records per CASENO identified by LINENO to assemble crash summary narrative

[1] CIREN does not routinely perform inspections on crash-involved vehicles that do not contain a consented CIREN case occupant

BioTab Body Regions

TABLE A-III
BIOTAB BODY REGION ORGANS AND COMPONENTS

Body region	Organs and components
Head/Face	Skull or cranial vault, base of skull, brain, facial bones, eyes, ears, nose, mouth
Neck	Trachea, oesophagus, carotid and vertebral arteries
Cervical Spine	Vertebrae, discs, ligaments, spinal cord
Shoulder	Clavicle, scapula, humeral head
Arm	Shaft of humerus
Elbow	Distal humerus, proximal radius, proximal ulna
Forearm	Shaft of radius, shaft of ulna
Wrist	Distal radius, distal ulna, carpal bones
Hand	Metacarpals, phalanges
Thorax	Ribs and sternum, hollow organs, diaphragm, airways, great vessels
Thoracic Spine	Vertebrae, discs, ligaments, spinal cord, great vessels and connecting vasculature
Abdomen	Multiple hollow organs, liver, spleen, kidney, pancreas, peritoneum, uterus, abdominal aorta and connecting vasculature
Lumbar Spine	Vertebrae, discs, ligaments, spinal cord
Pelvis	Pelvic bones, blood vessels
Hip	Head of femur, neck of femur, intertrochanteric region, acetabulum of pelvis, blood vessels
Thigh	Shaft of femur, subtrochanteric region, supracondylar region
Knee	Patella, femoral condyles, proximal tibia, proximal fibula
Leg	Shaft of tibia, shaft of fibula
Ankle	Distal tibia, distal fibula, talus
Foot	Metatarsal bones, phalangeal bones, tarsal bones (includes calcaneus)

Sample Code to Link Causation and Crash Data for Source of Energy Comparison

This example of Structured Query Language (SQL) logic demonstrates how the crash-related details from the *VE* table can be associated with the ICS in the *Scenario* table. After linking the ACCSEQ1 and ACCSEQ2 variables, a comparison could be made with the S_ACCSEQ variable. Users are encouraged to refer to the CIREN Data Dictionary for variable and attribute definitions.

```
create table soe1 as
select a.*, b.CASENO, b.VEHNO
from Scenario a left join Case b on a.CIRENID=b.CIRENID
where a.SOE=1 and a.BT_LITE in(0,1) and 1≤a.S_ACCSEQ≤30;
create table soe2 as
select a.*, b.ACCSEQ1, b.ACCSEQ2
from testsoe1 a left join VE b on a.CASENO=b.CASENO and a.VEHNO=b.VEHNO;
```

Case Vehicle Model Year Distribution

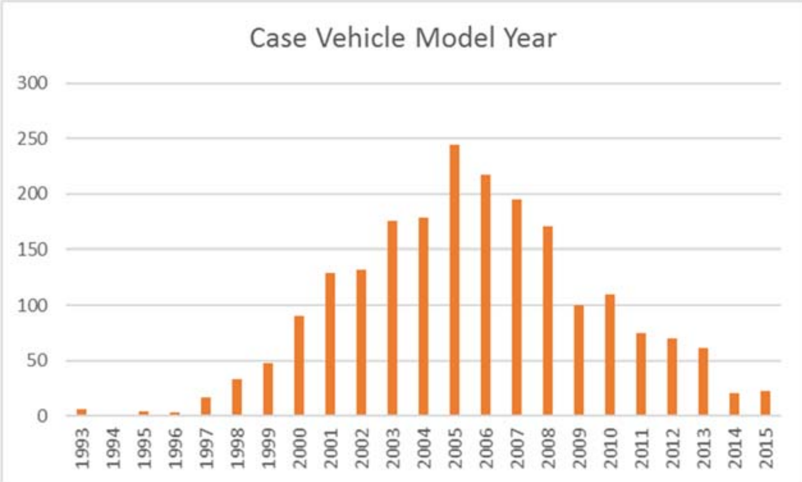

Fig. A-1. Distribution of vehicle model year for all CIREN case subjects in public SAS files. Crash years span the period from 2005 through 2016.

Injury Causation Scenarios for Discussion Cases

TABLE A-IV
INJURY CAUSATION SCENARIO CODING FOR CIRENID 352240671
AIS CODE 544224.3 – GRADE III SPLEEN LACERATION

BRI	ICS #	SOE	Primary IPC	BRC	IPC Conf.	ICS Conf.	RM
Abdomen	1	Airbag	Airbag	Abdomen	Probable	Probable	Comp. and Rate of comp.
Abdomen	2	Crash	Left door panel	Abdomen	Probable	Possible	Comp. and Rate of comp.

TABLE A-V
INJURY CAUSATION SCENARIO CODING FOR CIRENID 360241814
AIS CODE 854171.2 – TIBIA PLATEAU FRACTURE

BRI	SOE	1st Crit. IPC	1st BRC	1st IPC Conf.	2nd Crit. IPC	2nd BRC	2nd IPC Conf.	ICS Conf.	RM
Knee	Crash	Glove box door	Knee	Certain	Floor	Foot	Probable	Certain	Comp.