Sex-Specific Differences in Thoracic Injury Prevalence and Causation: a CIREN Database Investigation

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Abstract The objective of the study was to identify and quantify sex-specific disparities in thoracic injury patterns and causation among seriously injured first-row occupants in frontal motor vehicle collisions (MVC) from the Crash Injury Research and Engineering Network (CIREN) database, years 2005-2022. The sample comprised front-seat CIREN occupants (ages 16+; 54% female) with AIS 2+ thoracic injuries. Injuries were categorized into six types. The involved physical components (IPCs) were grouped for injury causation analysis into seven groups. Logistic regression analysis explored associations between injury types, IPC types, confounding variables, and sex. There were 1,952 AIS 2+ thoracic injuries sustained by the 966 occupants. Females had higher odds of heart injuries and lower odds of lung injuries. In females, the IPC attributed to the thoracic injury had higher odds of being the seatbelt and lower odds of being the instrument panel. The results of this study impact thoracic trauma prevention, emphasizing the need for detailed data on injury causation in MVCs. Identifying factors influencing thoracic injury outcomes can guide effective prevention and treatment strategies, stressing the importance of considering sex-specificity in vehicle safety system development and assessment.

Keywords Injury outcome, injury causation, injury prevalence, sex-specific differences, crash data analysis.

I. INTRODUCTION

Despite significant advancements in vehicle safety technologies and the rigorous enforcement of traffic regulations, motor vehicle collisions (MVCs) remain a formidable public health challenge. Annually, they are responsible for approximately 1.35 million fatalities and inflict injuries on up to 50 million individuals worldwide, underlining their persistent threat to global health and safety [1]. Among the spectrum of potential injuries resulting from MVCs, thoracic injuries stand out due to their prevalence and potential severity [2,3]. Furthermore, these injuries are of particular concern because of the thorax's susceptibility to the high-impact forces experienced during crashes and its enclosure of critical organs. The comprehensive range of thoracic injuries spans from relatively more common conditions such as rib fractures and pulmonary contusions to severe life-threatening injuries like aortic laceration and cardiac trauma. Each of these conditions not only contributes significantly to the morbidity and mortality associated with MVCs [4-8], but also poses substantial challenges in terms of medical management [9-11] and rehabilitation [12-14]. As such, the severity and complexity of thoracic injuries highlight the urgent need for focused research aimed at understanding these conditions in greater depth.

Prior research into MVC-related injuries has consistently underscored disparities in injury outcomes among different demographic groups, particularly emphasizing sex-specific differences between males and females. Notably, several studies have pinpointed that females are at a heightened risk of sustaining more severe injuries, classified as abbreviated injury scale (AIS) 2 and above [15-17], when involved in comparable crash scenarios to their male counterparts. Specifically, within the realm of thoracic injuries, this sex disparity becomes more pronounced with research indicating sex differences in susceptibility to thoracic trauma, with variations in injury presence and prevalence observed between males and females [15,18-20]. Recent progress is highlighted in a 2022 report by the National Highway Traffic Safety Administration (NHTSA) [21], which focuses on the relative risk of crash fatalities between females and males under similar physical impacts. This report found that disparities between sexes in fatality rates are diminishing, thanks to advancements in vehicle safety technologies. It further suggests that these technologies are particularly effective in reducing fatalities among females, and advocates for more sex-specific research to further narrow the gap in fatality rates between males and females.

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However, despite the acknowledged progress in addressing sex-specific differences in MVC injury outcomes, a significant gap persists in the literature, particularly regarding the comprehensive and detailed analysis of thoracic injuries and their causation. The current study aims to fill this gap by focusing on seriously injured first-row MVC occupants and analyzing a wide array of variables from the Crash Injury Research and Engineering Network (CIREN) database, this research seeks to identify and quantify the sex-specific disparities in thoracic injury patterns and causation. Through this approach, the study contributes to an understanding of the factors influencing injury mechanisms and outcomes, setting the stage for advancements in vehicle safety and occupant protection with sex-specific considerations. Additionally, this knowledge can inform the creation of more personalized and effective medical response strategies, ultimately improving outcomes for individuals involved in MVCs.

II. METHODS

The MVC data from the CIREN database from the years 2005 to 2022 were used for the analysis in this study. The CIREN database collects comprehensive MVC data within the United States, which operates with left-hand-drive vehicles, relevant for understanding the context of driver and passenger positions. The CIREN methodology involves a systematic and thorough process of evaluating injury causation in MVCs. Through multiple rounds of expert review, medical and engineering specialists critically evaluate and revise initial assessments, integrating trauma medicine, biomechanics, crash reconstruction, and vehicle engineering perspectives to ensure minimal subjectivity while following established protocols.

CIREN inclusion criteria for MVC cases specify that all occupants must have sustained at least one AIS 3+ injury or specific AIS 2 injuries or combinations thereof. Vehicle eligibility hinges on the model year in combination with specific crash types, necessitating those vehicles generally be within Calendar Year minus 6 (CY-6) for adults and Calendar Year minus 8 (CY-8) for children, with extended ranges in certain circumstances. These criteria cover various crash types, including frontal impacts within a 10 o'clock to 2 o'clock angle, side crashes, rear impacts, and rollovers, with stipulations for belt use status, airbag deployment, and occupant positioning. Essential to the inclusion of “Preferred” cases is the appropriate use of 3-point seatbelts or child restraint systems, strictly without gross misuse. Cases are excluded if they involve catastrophic vehicle damage, incomplete injury documentation of qualifying injuries, fire damage to the relevant portion of the occupant compartment, or unavailability of child restraint systems for inspection. In general, these guidelines outline the basic requirements for “Preferred” case inclusion. However, CIREN also considers "Extended" cases, allowing enrollment of cases that may not meet all “Preferred” criteria but that offer significant research value. These might include unique or rare injuries, newer vehicles, emerging technologies, and otherwise "Preferred" cases with unbelted occupants or older vehicles.

The data used for this study include MVC data from three phases of the CIREN database. The data from the years 2005-2016 (Phase II-Phase III) is available publicly [22] and the data from Phase IV (2017-2022) was pulled from an internal database from the Department of Transportation (DOT) servers. The data from all three phases were combined into one single dataset and filtered to occupants who had AIS 2+ thoracic injuries in frontal crashes. The principal direction of force (PDOF) and general area of deformation (GAD) were used to categorize crashes as frontal, based on established definitions in the literature [23]. Specifically, collisions were considered frontal if the PDOF was between 300 and 60 degrees and had a GAD of 'frontal', or if the PDOF was greater than 330 or less than 30 degrees with any GAD. The focus of the study was limited to the front-row occupants who were at least 16 years old. The data included variables like age, sex, height, weight, seatbelt status, occupant position, airbag deployment status, AIS code for injury, injury localizers, contributing factors such as comorbidity, intrusion, and entrapment for the injury, primary involved physical component (IPC), delta-V (ΔV: total delta-V if available, or barrier equivalent speed otherwise), vehicle model, vehicle make, vehicle model year, vehicle curb weight, and vehicle body type. The body mass index (BMI) was calculated for each occupant and added to the dataset.

Each IPC, representing the physical part/component of the vehicle implicated in causing the injury, is assigned a confidence level by investigators [24]. These levels—Certain, Probable, Possible, or Unknown—reflect the likelihood that the selected IPC is the actual cause of the injury, and assigning such is aimed at limiting subjectivity. When injuries are associated with multiple IPCs, the analysis prioritizes the IPC with the highest confidence as the primary cause. In cases with tandem IPCs, where multiple IPCs sequentially contribute to the injury, if one IPC within the tandem has a higher confidence, that IPC is selected. However, this method may not fully capture the biomechanical interactions necessary for the injury that the tandem configuration represents. For instances where multiple IPCs have the same confidence level, we reviewed the entire database for occurrences of that injury and exact IPC configuration, then calculated the average confidence for the IPCs involved. This approach allows us to determine which IPC historically has a higher confidence or likelihood of causing the injury. Doing so simplifies and harmonizes the data analysis process and addresses the evolving nature of the CIREN database through its phases, ensuring consistency and focus on the most significant contributors to injury outcomes.

The public dataset used in this study contains data from Phase II (AIS version 1998) and Phase III (AIS version 2005), with additional data joined from Phase IV (AIS version 2015). The 1998 version of the AIS manual included codes that combined multiple injuries, which in later AIS versions were separated into individual injury codes. To address this issue in our study when consolidating injury codes into the established categories, we separated combined injuries into their individual components while maintaining the original injury severity levels. For example, a rib fracture with pneumothorax (AIS 90/98 code: 450214.3) was categorized as two injuries: a rib fracture injury and a hemo/pneumothorax injury, both with an AIS severity of 3. This separation allowed for a more accurate representation of injury types, but consequently also affects the AIS severity distribution and, as such, is a limitation of the study and should be considered when interpreting the data.

The distribution of occupants based on sex, role, seatbelt status, and airbag deployment status were calculated. The frequency of male and female occupants was calculated for various groups by age, weight, height, BMI, ΔV, vehicle model year, and vehicle curb weight. All the thoracic injuries were categorized into six groups (heart, hemo/pneumothorax, lung, rib fracture, sternum fracture, and other injuries) based on the AIS codes [25-27], and IPCs were grouped into seven categories (Airbag, Instrument Panel, Seatbelt, Steering Wheel, Door, Interior, and Other) (Fig. 1). The decision about the number of categories was influenced by the number of injuries and IPCs present in the database for each group. Some of the lowest-frequency injury categories (vessel and diaphragm injuries) were added to the "Other" category due to their insufficient sample size for meaningful analysis. Vehicle body types were categorized into either "Passenger Car" or "SUV/Truck/Van" based on body type, curb weight, and/or occupant compartment design. The database includes detailed information about the number of fractured ribs which was used to calculate the frequency of rib fractures for various occupant types (i.e. driver, passenger, belted, and unbelted). Chi-squared tests were used to explore the association of sex with the number of rib fractures for each rib and the logistic regression with generalized estimating equations (GEEs) were used for injury type and IPC type. Because IPC type and injury type included more than two categories, we generated corresponding binary variables for either IPC type or injury type. Using IPC type as an example, it included seven categories and seven binary variables were generated (airbag vs. no airbag, instrument panel vs. no instrument panel, seatbelt vs. no seatbelt, steering wheel vs. no steering wheel, door vs. no door, interior vs. no interior, and other vs. no other). The odds ratios (ORs) and 95% confidence intervals were calculated to determine the associations between each binary outcome variable for injury type and IPC type and the predictors. All predictors and outcome variables utilized in the model are detailed in TABLE A I and TABLE A II. Predictors were fitted in the model simultaneously. However, owing to the substantial correlation observed between certain predictor variables and the outcome measures, few predictors were excluded from the model to ensure convergence. For example, the driver/passenger (Role) was not fitted in the model when the outcome measure was injury due to the steering wheel. If height and weight were fitted in the model, BMI would be removed. To avoid overadjustment, if the outcome measure was injury due to seatbelt, then seatbelt use was removed from the model.

III. RESULTS

The dataset used for the study includes data from a total of 966 occupants out of which 523 were female and 443 were male. All front-seat occupants were included in the study and there were 788 (50% females) drivers and 178 (72% females) passengers. Almost 20% of occupants were unbelted and airbags did not deploy for 13% of occupants. Among males, 24% were unbelted compared to 16% of females. Among drivers, 21% were unbelted at the time of the crash. A detailed distribution of all the occupants by sex, seatbelt status, role, and airbag deployment status is provided in TABLE I. The summary statistics of occupants are listed in TABLE II, including age, weight, height, BMI, ΔV (n=773), and vehicle curb weight (n=964). The minimum, median, maximum, mean, and standard deviation for each variable are provided in the table. The histogram of each variable mentioned in TABLE II and vehicle model year by sex are shown in Fig. 2 - Fig. 6, Fig. A1, and Fig. A2. The frequency in each plot is mentioned as a percentage relative to the number of occupants in each sex category. The mean age was higher for females; other variables like weight, height, ΔV, and vehicle curb weight were higher for males (TABLE II). The data suggest that the males were involved in higher ΔV crashes in larger vehicles than females. The BMI was similar between males and females.

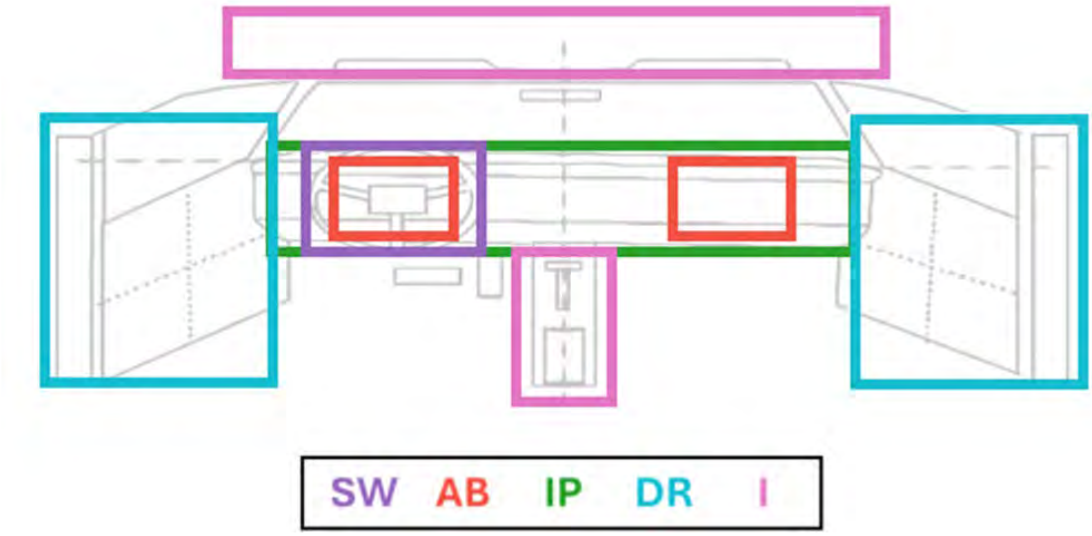


Fig. 1. Schematics of a general vehicle interior showing various consolidated IPC groups. The Seatbelt and Other IPC group is not displayed. SW: steering wheel, AB: airbag, IP: instrument panel, I: interior, and DR: Door.

The study included 1,952 AIS 2+ thoracic injuries that were classified into different severities by sex (Fig. 7). All the thoracic injuries were categorized into six injury types (i.e. heart, hemo/pneumothorax, lung, rib fracture, sternum fracture, and other injuries) and broken up by sex (Fig. 8). Lung injuries were more prevalent among males (p=0.009) than females whereas females were over two times as likely to sustain an injury to the heart than males (p=0.014) (TABLE A III). There were no other significances seen in other injury categories (TABLE A III).

TABLE I
DISTRIBUTION OF OCCUPANTS BY SEX, SEATBELT STATUS, ROLE, AND AIRBAG DEPLOYMENT STATUS

Sex	Count	Seatbelt Status	Count	Role	Count	Airbag Status	Count
Female	523	Belted	438	Driver	322	Not Deployed	32
						Deployed	290
				Passenger	116	Not Deployed	18
						Deployed	98
		Unbelted	85	Driver	72	Not Deployed	5
						Deployed	67
				Passenger	13	Not Deployed	1
						Deployed	12
Male	443	Belted	337	Driver	298	Not Deployed	43
						Deployed	255
				Passenger	39	Not Deployed	10
						Deployed	29
		Unbelted	106	Driver	96	Not Deployed	10
						Deployed	86
				Passenger	10	Not Deployed	2
						Deployed	8
Total	966		966		966		966

TABLE II
SUMMARY OF OCCUPANTS' AGE, WEIGHT, HEIGHT, BMI, ΔV, AND VEHICLE CURB WEIGHT

Variable	Female (n=523)					Male (n=443)				
	min.	median	max.	mean	std	min.	median	max.	mean	std
AGE (years)	16	54	94	53	19.8	16	50	94	50.1	20.7
Weight (kg)	41	71	182	77	22.1	57	87	209	91.6	22.4
Height (cm)	135	165	183	163.6	7.3	160	178	201	179	7.2
BMI	16.6	26.8	66.9	28.7	7.9	17.6	27.3	59.1	28.5	6.3
ΔV (km/h)	12	45.7	125	48.3	20.1	11	48	146	51.1	22.4
Curb Weight (kg)	820	1499.5	2710	1534.1	308.5	1019	1524.5	3400	1624	377.6

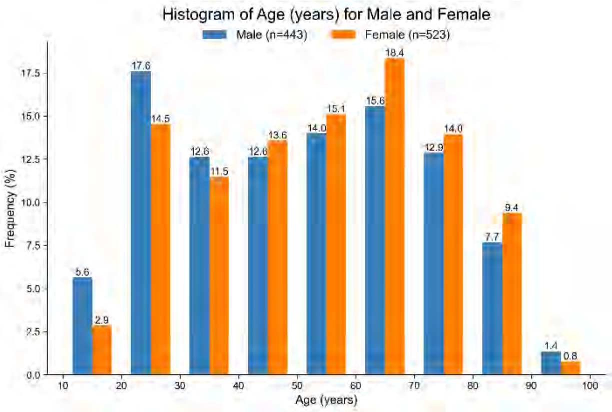


Fig. 2. Distribution of occupants within different age groups for males and females.

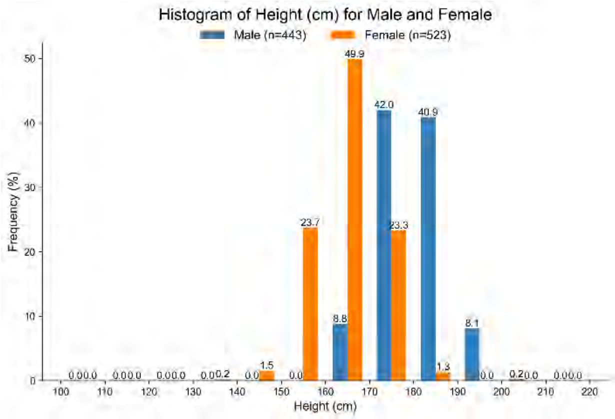


Fig. 3. Distribution of occupants within different height groups for males and females.

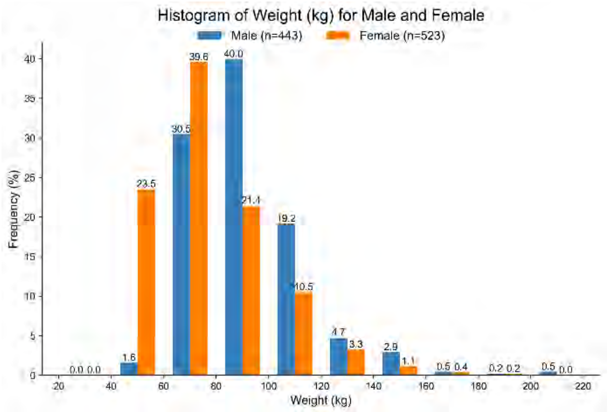


Fig. 4. Distribution of occupants within different weight groups for males and females.

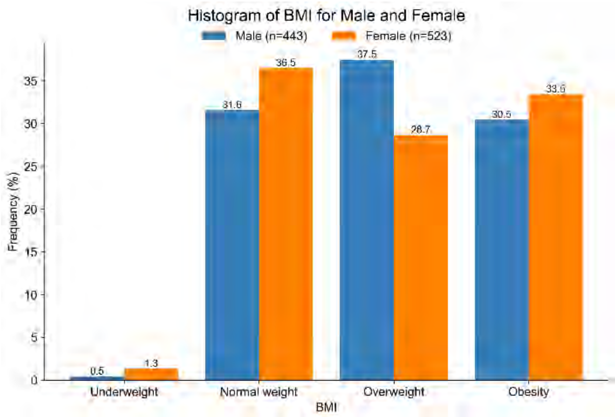


Fig. 5. Distribution of occupants within different BMI groups for males and females.

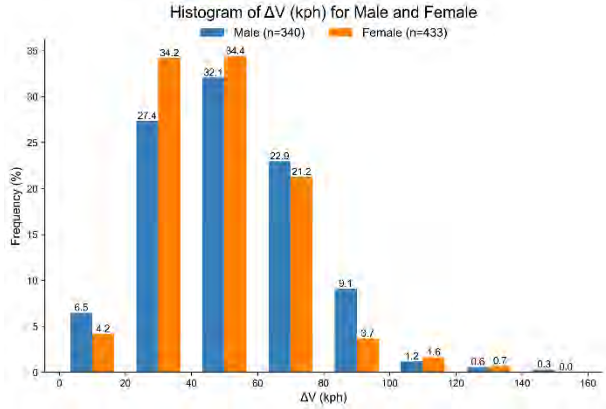
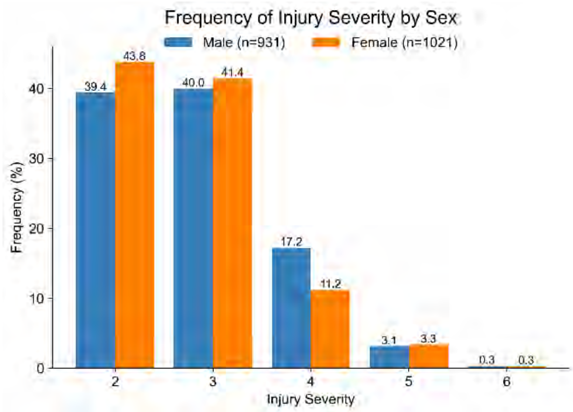


Fig. 6. Distribution of occupants within different ΔV groups for males and females.



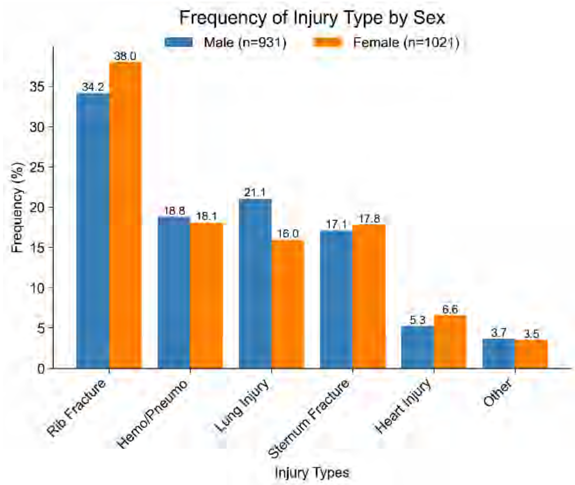


Fig. 7. Distribution of occupants within different AIS injury severity groups for males and females.

Fig. 8. Distribution of injuries within different injury types for males and females.

Similar to injuries, IPCs were categorized into seven groups and were split by sex (Fig. 9) and further by role (driver: Fig. 10 and passenger: Fig. 11). Out of the seven IPC types, two were found to be significantly associated with sex (TABLE A IV). Specifically, seatbelt (OR=1.83, 95% CI: 1.13-2.95, p=0.014) and instrument panel (OR=0.25, 95% CI: 0.07-0.85, p=0.027) IPC types showed strong associations with sex. The instrument panel was found to be involved more frequently in causing thoracic injuries to males than females, whereas seatbelts were more likely to be associated with injuries in females.

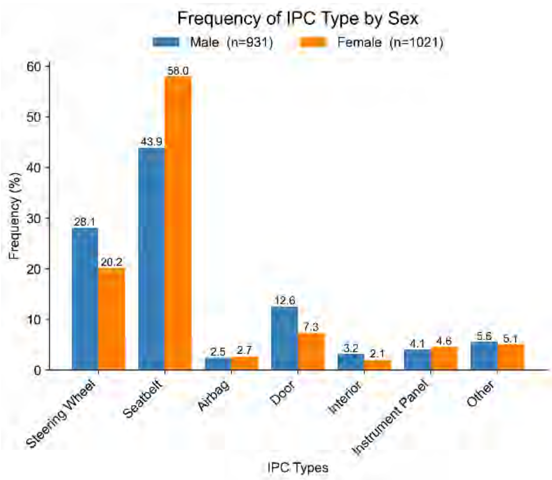


Fig. 9. Distribution of IPC within different IPC groups

for all males and females.

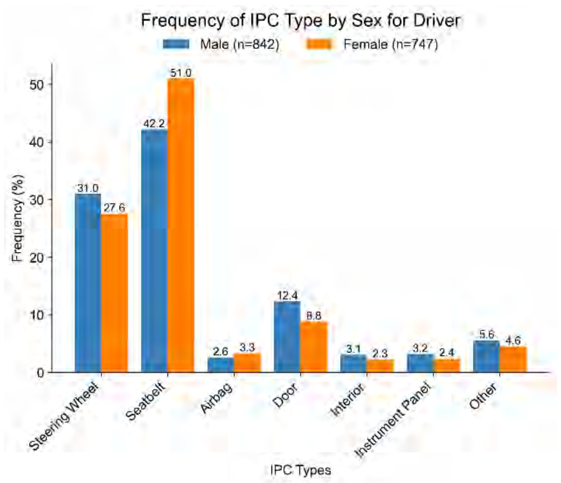


Fig. 10. Distribution of IPC within different IPC groups for male and female drivers.

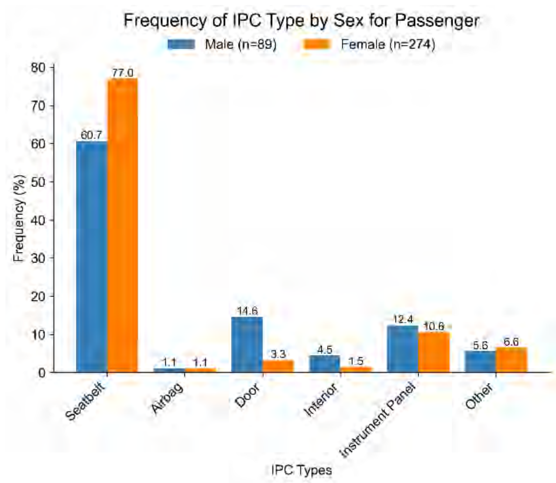
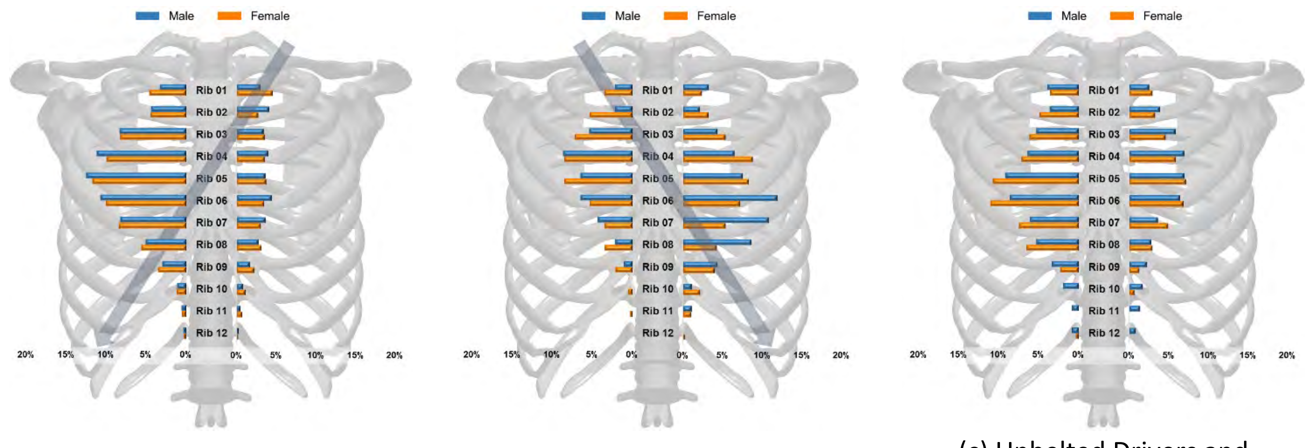


Fig. 11. Distribution of IPC within different IPC groups for male and female passengers.

A total of 3,055 ribs of 666 occupants (371 females) were fractured. Of these, 418 were belted drivers, 106 were belted passengers and 142 were unbelted occupants. The number of ribs fractured for unbelted occupants was 22% of the total number of ribs fractured. The distribution of rib fractures for each rib for belted male and female drivers is shown in Fig. 12(a), whereas for belted male and female passengers, it is plotted in Fig. 12(b), and the distribution of all unbelted male and female occupants is shown in Fig. 12(c). The Chi-square test did not find any association between sex and rib fracture distribution for any group shown in Fig. 12. However, the presence of seatbelts was found to be associated with rib fractures in males (p=0.017). It was interesting to note that the number of rib fractures was more on the opposite side of the shoulder belt's adjustable upper anchorage device for both belted drivers and passengers. In contrast, for unbelted occupants, the distribution was similar on both sides.



(a) Belted Drivers (b) Belted Passengers (c) Unbelted Drivers and Passengers

Fig. 12. Normalized distribution of rib fractures for each rib by sex (male and female), seatbelt status (belted and unbelted), and role (driver and passenger).

The results of the logistic regression analysis of injury type and IPC type are reported in TABLE A III and TABLE A IV, respectively. The odds ratios comparing females to males are presented graphically using forest plots for injury type in Fig. 13 and IPC type in Fig. 14. Each forest plot has a vertical line at an odds ratio of 1, which shows equal odds for males and females. If the odds ratio is greater than 1, then females have higher odds than males, and less than 1 means lower odds for females. Females had a higher chance of getting rib fractures, hemo/pneumothorax, and heart injuries, whereas males had a higher risk of lung, sternum fracture, and other thoracic injuries. However, the results showing females having a lower chance of lung injuries (p=0.0087) and a higher risk of heart injuries (p=0.0139) were statistically significant. Similarly, females had a higher chance of seatbelt and other IPC-induced injuries. In contrast, males were more prone to injuries due to the steering wheel, airbag, door, interior, and instrument panel. However, higher odds of seatbelt injuries for females and instrument panel-induced injuries in males were statistically significant. Statistically significant results are shown with * in the forest plots and highlighted with bold text in the tables.

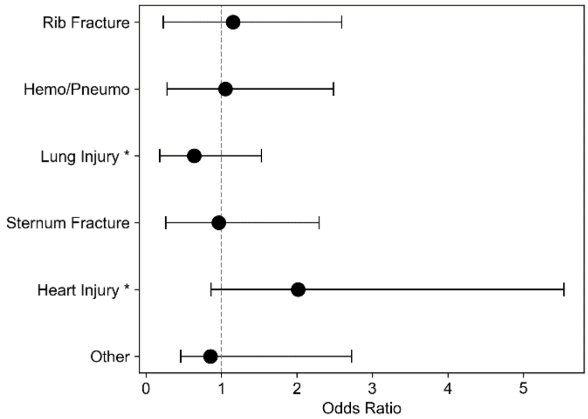


Fig. 13. Odds ratio comparing female to male Injury type, using a logistic regression model with multiple predictor variables listed in TABLE A I.

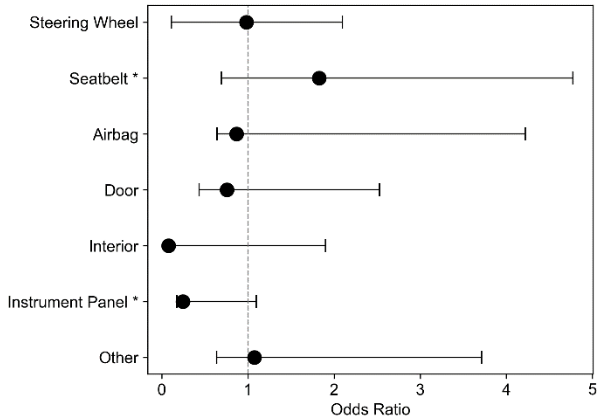


Fig. 14. Odds ratio comparing female to male IPC type, using a logistic regression model with multiple predictor variables listed in TABLE A II.

IV. DISCUSSION

An analysis of detailed MVC data from 966 occupants with 1,952 thoracic injuries revealed some sex-specific differences in injury prevalence and causation. Odds of injuries attributed to seatbelts as the IPC were higher in females (OR=1.83, p=0.0136) than in males, potentially due to the lower average mass of females (Fig. 4), which allows seatbelts to restrain them more effectively. This minimizes their contact with instrument panels, doors, and steering wheels, common injury mechanisms for males. The lower risk of injuries due to instrument panels in females (OR=0.25, p=0.027) was statistically significant. Conversely, males are typically heavier than females (Fig. 4) and were found to be involved in higher ΔV collisions (Fig. 6). This leads to more frequent and severe interactions with the steering wheel and door, contributing to the observed higher injury severity in males, which is likely the cause for males interacting more with the steering wheel and door than females (Fig. 7). A higher odds ratio for high-severity thoracic injuries was reported by Craig et al. [15] which is in line with the results of this study.

Two previous studies, one that analyzed 76 frontal MVCs [28] and the other with 10 frontal MVCs [29], reported the steering wheel and instrument panel as the main cause of lung injuries, and males had a higher prevalence of steering wheel-related injuries than females. These findings align with our observation of a higher incidence of lung injuries in males than females (OR=0.64, p=0.0087), with 33.3% (67 out of 201) of male lung injuries attributed to the steering wheel compared to 23.3% (38 out of 163) in females. This approximately 10% difference suggests the potential influence of sex-specific interactions with vehicle components during crashes. Additionally, our findings resonate with established sex differences in lung anatomy and physiology, such as variations in lung volume, airway diameter, and chest wall composition [30-34]. These differences could potentially explain the observed variance in susceptibility to lung injuries between sexes, as anatomical and physiological disparities may influence how individuals respond to traumatic forces in MVCs. The higher susceptibility among males to severe lung injuries might, therefore, be attributed to these underlying biomechanical and physiological factors.

While the differences in rib fracture prevalence between sexes in our study (Fig. 8) did not reach statistical significance, potential explanations for any observed disparities might involve the interactions between bone mineral density (BMD) and specific anatomical variations in rib cage morphology. Literature suggests that BMD plays a significant role in the susceptibility to rib fractures, with numerous studies indicating that individuals with lower BMD are at an increased risk for such injuries [35-38]. Given that females, particularly with advancing age, tend to have lower BMD than males [39-43], this factor may contribute to the differences seen in rib fracture outcomes post-MVC. This connection between lower BMD and increased fracture risk aligns with the broader understanding of osteoporosis and bone fragility in females as they age, further supported by research highlighting sex differences in bone strength and fracture patterns [44,45].

This study's examination of injury causation through the CIREN database represents a significant effort to understand the mechanisms behind MVC injuries, an area not widely covered in existing research. CIREN's detailed collection of crash and injury data, combined with a rigorous, iterative review process by a multidisciplinary team, allows for a detailed analysis that enhances our understanding of injury causation. However, it's important to note that the dataset's lack of a population-based cohort could lead to potential selection bias and is not a nationally representative sample. Additionally, while our method of selecting the highest confidence IPC allows for consistent analysis across different phases of the CIREN data, it does not fully capture the complex biomechanical interactions involved in injury mechanisms. The tandem IPC configuration, which was more prominent in the 2017-2022 data, provides a better representation of load sharing among various components during a crash. By distilling the loading to a single IPC, some aspects of these interactions may be lost. This limitation should be considered when interpreting the results, and future studies should explore phase-specific analyses to better understand these complexities.

Vehicle safety has significantly improved over the years due to advancements in vehicle safety technologies and changes in testing protocols (FMVSS, NCAP, IIHS), which could affect the analysis. The time period from 2005 to 2022 was chosen to maximize the sample size, as limiting the data to more recent years would result in insufficient data for robust analysis. However, this approach may skew findings due to the inclusion of older vehicles, potentially diminishing observed sex disparities in newer models. Additionally, despite efforts towards objectivity, the inherent subjectivity in analyzing the specifics of each injury cannot be entirely eliminated. The focus of our analysis was on identifying associations between sex and various factors such as injury type, the involved physical component (IPC), and rib fracture presence, within the constraints and strengths of the CIREN methodology. A future study investigating the effect size and effects of other factors, such as impact speed, age, height, weight, BMI, airbag deployment, and seatbelt status can be carried out using statistical methods like multinomial logistic regression, multivariate linear regression, and odds ratio.

V. CONCLUSION

This is the first study that analyzed the CIREN crash data from 2005 to 2022 to find if there are any sex-specific differences in thoracic injury prevalence and causation in front-seat occupants in frontal crashes. Males tend to get more injuries due to the instrument panel, whereas females are injured more due to seatbelt loading. The results of the logistic regression analysis showed females at a higher risk of heart injuries and a lower risk of lung injuries. No association between sex and rib fractures was found but seatbelt presence was found to be associated with rib fractures in male occupants.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

[1] WHO. Global status report on road safety 2018: Summary. 2018, World Health Organization.

[2] Cooper, A. Thoracic injuries. *Seminars in pediatric surgery*, 1995. 4 2: p. 109-15

[3] Rao, R.D., Berry, C.A., Yoganandan, N., and Agarwal, A. Occupant and crash characteristics in thoracic and lumbar spine injuries resulting from motor vehicle collisions. *The spine journal: official journal of the North American Spine Society*, 2014. 14 10: p. 2355-65

[4] El-Menyar, A., Abdelrahman, H., et al. Clinical presentation and time-based mortality in patients with chest injuries associated with road traffic accidents. *Archives of trauma research*, 2016. 5(1)

[5] Lin, F.C.-F., Li, R.-Y., Tung, Y.-W., Jeng, K.-C., and Tsai, S.C.-S. Morbidity, mortality, associated injuries, and management of traumatic rib fractures. *Journal of the Chinese Medical Association*, 2016. 79(6): p. 329-334

[6] Lien, Y.-C., Chen, C.-H., and Lin, H.-C. Risk factors for 24-hour mortality after traumatic rib fractures owing to motor vehicle accidents: a nationwide population-based study. *The Annals of thoracic surgery*, 2009. 88(4): p. 1124-1130

[7] Markogiannakis, H., Sanidas, E., et al. Predictors of in-hospital mortality of trauma patients injured in vehicle accidents. *Ulus Travma Acil Cerrahi Derg*, 2008. 14(2): p. 125-31

[8] Bayer, J., Lefering, R., et al. Thoracic trauma severity contributes to differences in intensive care therapy and mortality of severely injured patients: analysis based on the TraumaRegister DGU®. *World journal of emergency surgery*, 2017. 12: p. 1-9

[9] Lodhia, J., Eyre, L., et al. Management of thoracic trauma. *Anaesthesia*, 2023. 78(2): p. 225-235

[10] Sirmali, M., Türüt, H., et al. A comprehensive analysis of traumatic rib fractures: morbidity, mortality and management. *European Journal of Cardio-Thoracic Surgery*, 2003. 24(1): p. 133-138

[11] Albadani, M.N. and Alabsi, N.A. Management of chest injuries: a prospective study. *Yemeni Journal for medical sciences*, 2011. 5(1): p. 23-27

[12] Baker, E., Xyrichis, A., Norton, C., Hopkins, P., and Lee, G. Challenges associated with recovery from blunt thoracic injuries from hospital admission to six-months after discharge: A qualitative interview study. *International emergency nursing*, 2021. 57: p. 101045

[13] Claydon, J., Maniatopoulos, G., Robinson, L., and Fearon, P. Challenges experienced during rehabilitation after traumatic multiple rib fractures: a qualitative study. *Disability and Rehabilitation*, 2018. 40(23): p. 2780-2789

[14] Baker, E., Xyrichis, A., Norton, C., Hopkins, P., and Lee, G. The long-term outcomes and health-related quality of life of patients following blunt thoracic injury: a narrative literature review. *Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine*, 2018. 26: p. 1-16

[15] Craig, M.J., Liu, C., Zhang, F., and Enriquez, J. Sex-based differences in odds of motor vehicle crash injury outcomes. *Accident Analysis & Prevention*, 2024. 195: p. 107100

[16] Forman, J., Poplin, G.S., et al. Automobile injury trends in the contemporary fleet: Belted occupants in frontal collisions. *Traffic injury prevention*, 2019. 20(6): p. 607-612

[17] Carter, P.M., Flannagan, C.A., Reed, M.P., Cunningham, R.M., and Rupp, J.D. Comparing the effects of age, BMI and gender on severe injury (AIS 3+) in motor-vehicle crashes. *Accident Analysis & Prevention*, 2014. 72: p. 146-160

[18] Ryan, A., Tainter, F., et al. The impact of sex on motor vehicle crash injury outcomes. *Journal of Transportation Safety & Security*, 2022. 14(5): p. 818-842

[19] Hulse, C.N., Stull, K.E., and Weaver, A. Rib Fracture Frequency and Location Using Vehicular Crash Data. *Forensic Anthropology (University of Florida)*, 2019. 2(1)

[20] Choi, D., Lee, K.H., et al. Risk factors affecting severe thoracic injuries in motor vehicle collisions based on age group and collision directions. *European journal of trauma and emergency surgery*, 2023. 49(6): p. 2429-2437

[21] Noh, E.Y., Atwood, J.R.E., Lee, E., and Craig, M. Female crash fatality risk relative to males for similar physical impacts. *Report no. DOT HS*, 2022. 813: p. 358

[22] Rudd, R.W. and Lockerby, J. Applications of Occupant and Injury Biomechanics Data Available in the CIREN Public Data Set, in *IRCOBI*. 2018: Athens, Greece.

[23] Stitzel, J.D., Weaver, A.A., et al. An injury severity-, time sensitivity-, and predictability-based advanced automatic crash notification algorithm improves motor vehicle crash occupant triage. *Journal of the American College of Surgeons*, 2016. 222(6): p. 1211-1219. e6

[24] Schneider, L.W., Rupp, J.D., et al. BioTab—a new method for analyzing and documenting injury causation in motor-vehicle crashes. *Traffic injury prevention*, 2011. 12(3): p. 256-265

[25] Gennarelli, T.A., Wodzin, E., and Barrington, I. Association for the Advancement of Automotive Medicine: The Abbreviated Injury Scale 2005-Update 2008. 2016, Association for the Advancement of Automative Medicine: Chicago, Illinois.

[26] Gennarelli, T.A., Wodzin, E., and Barrington, I. Association for the Advancement of Automotive Medicine: The Abbreviated Injury Scale 1990-Update 1998. 1998, Association for the Advancement of Automative Medicine: Chicago, Illinois.

[27] "Abbreviated injury scale: 2015 Revision ". 6 ed. 2018: American Association for Automotive Medicine.

[28] Siegel, J.H., Mason-Gonzalez, S., et al. Safety belt restraints and compartment intrusions in frontal and lateral motor vehicle crashes: mechanisms of injuries, complications, and acute care costs. *Journal of Trauma and Acute Care Surgery*, 1993. 34(5): p. 736-759

[29] Weaver, A.A., Danelson, K.A., Armstrong, E.G., Hoth, J.J., and Stitzel, J.D. Investigation of pulmonary contusion extent and its correlation to crash, occupant, and injury characteristics in motor vehicle crashes. *Accid Anal Prev*, 2013. 50: p. 223-33

[30] García-Martínez, D., Torres-Tamayo, N., Torres-Sanchez, I., García-Río, F., and Bastir, M. Morphological and functional implications of sexual dimorphism in the human skeletal thorax. *American Journal of Physical Anthropology*, 2016. 161(3): p. 467-477

[31] Bellemare, F., Jeanneret, A., and Couture, J. Sex differences in thoracic dimensions and configuration. *American journal of respiratory and critical care medicine*, 2003. 168(3): p. 305-312

[32] Dominelli, P.B. and Molgat-Seon, Y. Sex, gender and the pulmonary physiology of exercise. *European Respiratory Review*, 2022. 31(163)

[33] LoMauro, A. and Aliverti, A. Sex differences in respiratory function. *Breathe*, 2018. 14(2): p. 131-140

[34] Molgat-Seon, Y., Peters, C.M., and Sheel, A.W. Sex-differences in the human respiratory system and their impact on resting pulmonary function and the integrative response to exercise. *Current Opinion in Physiology*, 2018. 6: p. 21-27

[35] Tang, Y., Hong, W., Xu, X., Li, M., and Jin, L. Traumatic rib fracture patterns associated with bone mineral density statuses derived from CT images. *Frontiers in Endocrinology*, 2023. 14: p. 1304219

[36] Prins, J., Van Lieshout, E., Reijnders, M., Verhofstad, M., and Wijffels, M. Rib fractures after blunt thoracic trauma in patients with normal versus diminished bone mineral density: a retrospective cohort study. *Osteoporosis International*, 2020. 31(2): p. 225-231

[37] Mai, H.T., Tran, T.S., et al. Low-trauma rib fracture in the elderly: Risk factors and mortality consequence. *Bone*, 2018. 116: p. 295-300

[38] Wuermser, L.-A., Achenbach, S.J., Amin, S., Khosla, S., and Melton, L.J. What Accounts for Rib Fractures in Older Adults? *Journal of Osteoporosis*, 2011. 2011: p. 457591

[39] Havill, L.M., Mahaney, M.C., L Binkley, T., and L Specker, B. Effects of genes, sex, age, and activity on BMC, bone size, and areal and volumetric BMD. *Journal of Bone and Mineral Research*, 2007. 22(5): p. 737-746

[40] De Martinis, M., Sirufo, M.M., et al. Gender differences in osteoporosis: a single-center observational study. *The world journal of men's health*, 2021. 39(4): p. 750

[41] Kelly, P.J., Twomey, L., Sambrook, P.N., and Dr. Eisman, J.A. Sex differences in peak adult bone mineral density. *Journal of Bone and Mineral Research*, 1990. 5(11): p. 1169-1175

[42] Alswat, K.A. Gender disparities in osteoporosis. *Journal of clinical medicine research*, 2017. 9(5): p. 382

[43] Dou, Q., Xiaotian, L., et al. Gender-specific prevalence and influencing factors of osteopenia and osteoporosis in Chinese rural population: the Henan Rural Cohort Study. *BMJ Open*, 2020. 10(1): p. e028593

[44] TORUN, E. and YÜKSEL, Y. DIFFERENCES OF RIB FRACTURES IN BLUNT TRAUMA PATIENTS ACCORDING TO AGE AND GENDER: A COMPUTED TOMOGRAPHY STUDY. *SDÜ Tıp Fakültesi Dergisi*, 2023. 30(2): p. 179-184

[45] Armstrong, W., Costa, C., et al. Effects of muscle quantity and bone mineral density on injury and outcomes in older adult motor vehicle crash occupants. *Traffic injury prevention*, 2022. 23(sup1): p. S86-S91

VIII. APPENDIX

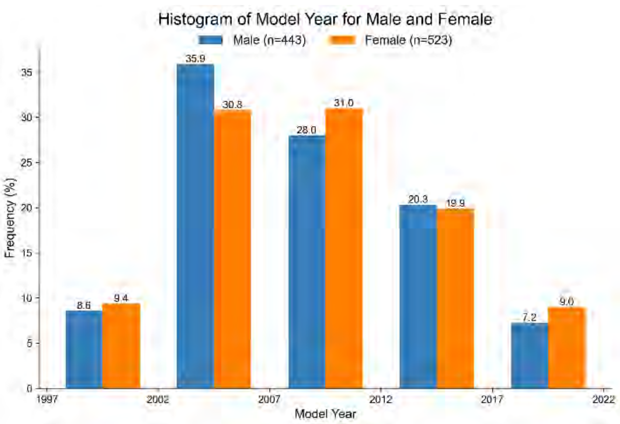

Fig. A1. Distribution of occupants within different model year groups for males and females.

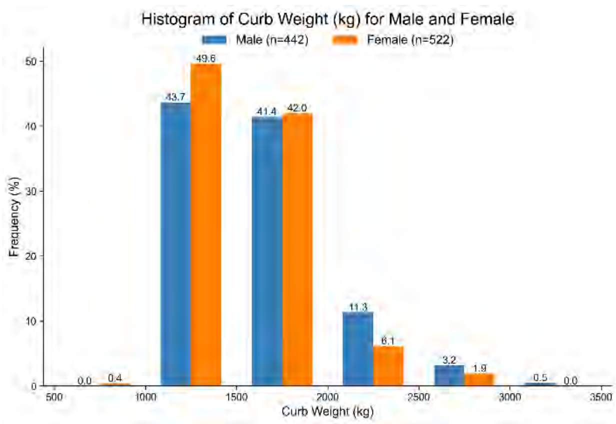

Fig. A2. Distribution of occupants within different curb weight groups for males and females.

TABLE A I
Predictor and injury type outcome variables used in the logistic regression analysis for Injury type

Predictor	Outcome
Sex	Rib Fracture
Age	Hemo/Penumo
Weight	Lung Injury
Height	Sternum Fracture
Role	Heart Injury
Comorbidity	Other
Airbag	-
Seatbelt	-
Entrapment	-
ΔV	-
Vehicle Type	-
Model Year	-
Vintage	-
Curb Weight	-
Intrusion	-

Role: driver/passenger, Comorbidity: comorbidity as a binary variable if it was a contributing factor for the injury, Entrapment: entrapment as a binary variable if it was a contributing factor for the injury, Vehicle Type: Car vs. SUV/Truck/Van, Vintage: vintage as a binary variable (1: model year <=2008, 0: otherwise), Intrusion: intrusion as a binary variable if it was a contributing factor for the injury.

TABLE A II
Predictor and IPC outcome variables used in the logistic regression analysis for IPC type

Steering Wheel	Seatbelt	Airbag	Door	Interior	Instrument Panel	Other
Sex	Sex	Sex	Sex	Sex	Sex	Sex
Age	Age	Age	Age	Age	Age	Age
Weight	Weight	Weight	Weight	Weight	Weight	Weight
Height	Height	Height	Height	Height	Height	Height
-	Role	Role	Role	Role	Role	Role
Comorbidity	Comorbidity	Comorbidity	Comorbidity	-	Comorbidity	Comorbidity
Entrapment	Entrapment	Entrapment	Entrapment	Entrapment	Entrapment	Entrapment
ΔV	ΔV	ΔV	ΔV	ΔV	ΔV	ΔV
Vehicle Type	Vehicle Type	Vehicle Type	Vehicle Type	Vehicle Type	Vehicle Type	Vehicle Type
Model Year	Model Year	Model Year	Model Year	Model Year	Model Year	Model Year
Vintage	Vintage	Vintage	Vintage	Vintage	Vintage	Vintage
Curb Weight	Curb Weight	Curb Weight	Curb Weight	Curb Weight	Curb Weight	Curb Weight
Intrusion	Intrusion	Intrusion	Intrusion	-	Intrusion	Intrusion

Role: driver/passenger, Comorbidity: comorbidity as a binary variable if it was a contributing factor for the injury, Entrapment: entrapment as a binary variable if it was a contributing factor for the injury, Vehicle Type: Car vs. SUV/Truck/Van, Vintage: vintage as a binary variable (1: model year <=2008, 0: otherwise), Intrusion: intrusion as a binary variable if it was a contributing factor for the injury. Airbag and seatbelt variables were excluded from this analysis due to their high correlation with the outcome measures.

TABLE A III
Results of logistic regression analysis for Injury type, using a model with multiple predictor variables listed in Table A1.

Injury Type	Odds Ratio	Lower Bound (95% CI)	Upper Bound (95% CI)	p-value
Rib Fracture	1.15	0.92	1.44	0.207
Hemo/Pneumo	1.05	0.77	1.43	0.750
Lung Injury	**0.64**	**0.46**	**0.89**	**0.009**
Sternum Fracture	0.97	0.70	1.33	0.832
Heart Injury	**2.01**	**1.15**	**3.52**	**0.014**
Other	0.86	0.39	1.87	0.697

TABLE A IV
Results of logistic regression analysis for IPC type, using a model with multiple predictor variables listed in Table A1.

IPC	Odds Ratio	Lower Bound (95% CI)	Upper Bound (95% CI)	p-value
Steering Wheel	0.98	0.87	1.11	0.797
Seatbelt	**1.83**	**1.13**	**2.95**	**0.014**
Airbag	0.87	0.22	3.35	0.835
Door	0.75	0.32	1.77	0.518
Interior	0.08	0.00	1.82	0.113
Instrument Panel	**0.25**	**0.07**	**0.85**	**0.027**
Other	1.08	0.44	2.64	0.873