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Predictive Factors of Severe Abdominal Injuries due to Seat-belt Compression in Motor Vehicle Passengers: A Nationwide Collision Data-based Study

Kiyoshi Ikegami[1], Masahito Hitosugi[1]*, Kohei Takashima[1], Yuki Sugitani[1], Hitoshi Ida[2], Masashi Aoki[2] and Michihisa Asaoka[2]

[1]*Department of Legal Medicine, Shiga University of Medical Science, Shiga 520-2192, Japan*
[2]*Toyoda Gosei Co., Ltd., 1 Haruhinagahata, Kiyosu, Aichi 452-8564, Japan*

Abstract

Background: Abdominal injuries due to seatbelt have often occurred in motor vehicle passengers. Although seatbelt-induced moderate and severe abdominal injuries have been reported, factors associated with the occurrence of severe abdominal injuries were not examined.

Objectives: To clarify the pattern and severity of seatbelt-induced abdominal injuries and determine the predictive factors of severe abdominal injuries.

Methods: Among the data set of the National Automotive Sampling System/Crashworthiness Data System of collisions that occurred from 1995 to 2011, we chose right front-seat passengers with a height of >140 cm who developed seatbelt-induced abdominal injuries with an Abbreviated Injury Scale score of ≥ 2 during a frontal collision.

Results: The study population comprised 79 persons (24 male, 55 female; mean age, 37.5 years) with 136 abdominal injuries. Spleen, kidney, and liver injuries were the three most common seatbelt-induced injuries. The spleen was the most commonly injured site in both the moderate and severe injury groups. The liver was the second most commonly injured site in the moderate injury group, but no liver injuries occurred in the severe injury group (p=0.001). The multivariable logistic regression analysis revealed that force to the lower abdomen positively influenced the occurrence of severe injuries and that airbag deployment negatively influenced the occurrence of severe injuries.

Conclusions: Correct seatbelt use and airbag deployment can prevent severe seatbelt-induced abdominal injuries. Forensic pathologists should still suspect moderate abdominal injuries even in correct restrained vehicle passengers.

Keywords: Abdominal injuries • Predictive factors • Data-based study

Introduction

The number of Motor Vehicle Collisions (MVCs) has been continuously increasing worldwide, causing 1.35 million fatalities in 2016 [1]. MVCs are predicted to be an even bigger problem by 2030, by which time they will have become the fifth most common cause of fatalities globally [1]. Most MVC-related fatalities involve the death of vehicle passengers, accounting for 29% of MVC-related deaths worldwide [1]. Therefore, preventing fatalities and severe injuries of vehicle passengers is a priority for traffic safety.

Seatbelts are major safety devices, and their correct use is legally required in many countries. The effect of seatbelt use has been scientifically confirmed. A study in the United States suggested that use of a lap-shoulder seatbelt decreased fatality by 72% [2]. Another study in the United States revealed that use of a seatbelt reduced mortality by 51% [3]. According to a Canadian study, a 1% increase in the use of seatbelts was associated with a 0.17% to 0.21% reduction in fatality [4]. Therefore, failure to use a seatbelt is a major risk factor for road traffic deaths among vehicle occupants. However, incorrect seatbelt use has also been associated with some adverse outcomes. Severe and even fatal deceleration injuries can occur as a result of incorrectly used seatbelts [5]. Lap belts have caused abdominal, pelvic, or spinal injuries because of their incorrect belt path. Shoulder belts produce a high local load, resulting in large chest deflection. In such cases, rib fractures and upper abdominal organ or digestive tract injuries have occurred. Intra-abdominal injuries may occur when a lap belt is not placed below the bilateral anterior superior iliac spines, instead crossing and compressing the abdomen. At the time of collision, the body slides below the belt, acting like a hinge; this has been called the submarine effect. Weaver AA, et al. [6] suggested that at the time of frontal impact at a velocity of 56 km/h, 3.4% of passengers sustained abdominal injuries with an Abbreviated Injury Scale (AIS) score of ≥ and 1.4% had an AIS score of ≥ 3 owing to the incorrect belt path. Therefore, if the seatbelt is used, some of passengers suffer from severe of fatal injuries due to seatbelt compression.

When the fatal MVC is occurred, we forensic pathologists have to examine involved passengers and determine the cause and manner of death. Because considerable numbers of vehicle passengers have suffered from abdominal injuries due to lap belt compression, we forensic pathologists have to understand the trends and causative factors of seatbelt-induced serious abdominal injuries. Although several reports have described seatbelt-induced moderate and severe abdominal injuries, factors associated with the occurrence of severe abdominal injuries were not examined [7-15].

***Address for Correspondence:** Masahito Hitosugi, Department of Legal Medicine, Shiga University of Medical Science, Shiga 520-2192, Japan, E-mail: hitosugi@belle.shiga-med.ac.jp*

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The objectives of this study were to clarify the pattern and severity of seatbelt-induced abdominal injuries using real-world accident data and to determine the predictive factors of severe abdominal injuries.

Materials and Methods

Study design and patient selection

We performed a retrospective analysis using the data set of the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) [16,17]. The NASS/CDS is generated by the United States National Highway Traffic Safety Administration. This is a publicly available, de-identified data set that provides data for approximately 5000 collisions every year. The database includes collisions in which at least one of the vehicles involved was damaged and had to be towed from the scene. The data in each case were collected from interviews with the people involved, police records, medical records, vehicle inspection, and scene inspection. Well-trained inspectors summarized data on over 600 factors regarding the collision event, damage to the vehicle, collision forces involved, injuries sustained by the victim, and mechanisms of injuries. The factors include the item "injury source" and here whatever caused each injury is listed. Selection of "seatbelt" accesses the injuries caused by seatbelt compression.

Among the individuals registered in the NASS/CDS from 1995 to 2011, the data of 5280 occupants whose height was >140 cm in the right front passenger seat of a passenger vehicle or commercial vehicle involved in a frontal vehicle collision were extracted. In this study, frontal collision was defined as an impact in the direction from the 11- to 1-o'clock position as viewed from above the vehicle. Because the seatbelt system in use at the time of the study was considered safe for passengers with a height of ≥140 cm, we limited the passengers to those with this height range. After reviewing the use of seatbelts, 3596 persons who used a lap and shoulder belt were selected. Finally, we chose those persons who sustained seatbelt-related abdominal injuries with an AIS score of ≥2. The final study population comprised 79 persons with 136 abdominal injuries (Figure 1).

Data collection

The following information was collected from the database for each person involved in a collision:

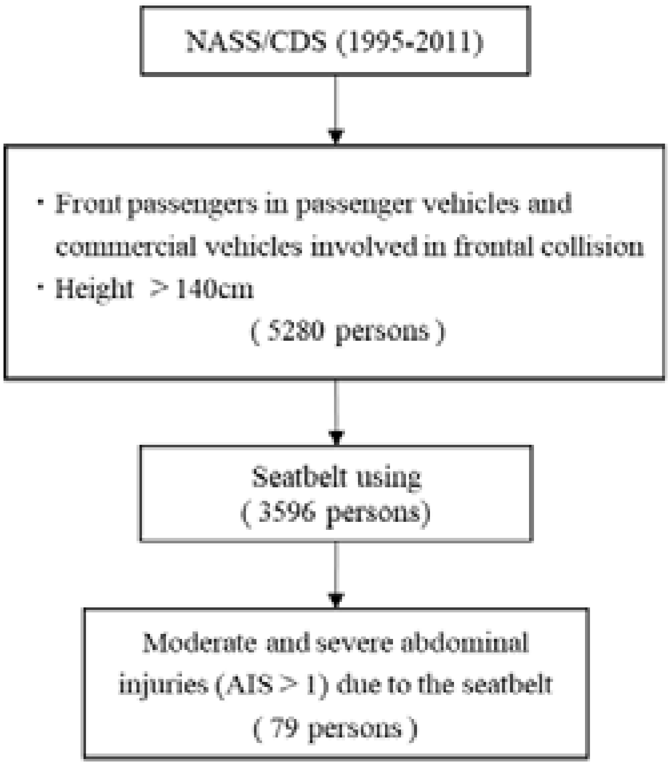

Figure 1. Flowchart of enrollment in the study.

(1) General characteristics including sex, age, height, weight, and Body Mass Index (BMI)

(2) Airbag deployment

(3) Collision velocity described using the Equivalent Barrier Velocity (EBV). The EBV of the involved vehicles was calculated from the damage measurements and the known weight of the vehicles.

(4) Body position when forces were applied

(5) Type and severity of each injury sustained by the occupant, described using the AIS score. The AIS score is used to categorize the injury type and anatomical severity in each body region using a scale from 1 (minor) to 6 (clinically untreatable) [18]. Injuries with an AIS score of 2 were defined as moderate, and those with an AIS score of ≥3 were defined as severe. The maximum AIS was defined as the highest AIS score.

Statistical analysis

Categorical variables are summarized in the form of a numerical value with proportion or frequency. Continuous variables are summarized as mean ± standard deviation for values that followed a normal distribution. The chi-square test was used to compare prevalence between the two groups. Student's t-test was used to identify differences in values between the groups. A multivariable logistic regression analysis was performed to determine which variables were independently associated with severe injuries. We applied the Hosmer-Lemeshow test to determine the goodness-of-fit of the regression models (higher probability indicates better fit). Additionally, we calculated pseudo R2 (Nagelkerke's R2) as an index of the degree of proportion explainable by the regression equation (a larger R2 indicates a better model). The statistical analyses were performed with IBM SPSS version 23 (IBM Corp., Armonk, NY, USA). A p value of <0.05 was considered statistically significant.

Results

General characteristics

The 79 persons analyzed in this study comprised 24 male and 55 female individuals. Their mean age was 37.5 ± 22.3 years (range, 7–88 years). Their mean height was 165.4 ± 10.5 cm (range, 140–196 cm), mean weight was 67.4 ± 16.0 kg (range, 32–113 kg), and mean BMI was 24.6 ± 5.3 kg/m^2 (range, 13.9–36.8 kg/m^2). Their mean EBV at the time of the collision was 45.2 ± 15.9 km/h (range, 12–91 km/h), and an airbag was deployed in the vehicles of 39 passengers.

The distribution of the 136 injury sites is shown in Table 1. The spleen was the most commonly injured site, followed by the kidneys, liver, and mesentery. Because the liver, gallbladder, spleen, stomach, duodenum, omentum, and pancreas are located in the upper abdomen, these injuries were considered to have been caused by forces applied to the upper abdomen. Other injuries were considered to have been caused by forces applied to the lower abdomen. Excluding the category "others," forces applied to the upper abdomen caused 71 injuries and forces applied to the lower abdomen caused 62 injuries. When further classified according to deployment of airbags, these injuries occurred in the situations of both airbag deployment and not (Table 1).

Comparison of passengers with moderate and severe injuries

We created two data sets for the current study: passengers with moderate injuries (45 persons) and passengers with severe injuries (34 persons). First, we compared the basic characteristics between the two groups. No significant differences were found in any items (Table 2).

Next, the distribution of the injured sites was compared. In both groups, the spleen was the most commonly injured site. The liver was the second most commonly injured site among the passengers with moderate injuries, whereas no liver injuries occurred among the passengers with severe injuries (p=0.001) (Table 3).

Table 1. Injuries distribution in all cases.

Injury Sites by the Organ	Total (%)	Airbag	
		+	-
Stomach	1 (0.7)	0	1
Duodenum	5 (3.7)	2	3
Omentum	1 (0.7)	0	1
Liver	17 (12.5)	10	7
Gallbladder	1 (0.7)	0	1
Spleen	43 (31.6)	17	26
Pancreas	3 (2.2)	0	3
Adrenal glands	1 (0.7)	0	1
Kidney	23 (16.9)	11	12
Abdominal aorta	1 (0.7)	0	1
Jejunum	10 (7.4)	6	4
Colon	8 (5.9)	6	2
Mesenterium	16 (11.8)	11	5
Retroperitoneum	1 (0.7)	0	1
Bladder	1 (0.7)	1	0
Rectum	1 (0.7)	1	0
Others	3 (2.2)	2	1

Table 2. Comparison of general characteristics between persons with moderate and severe injuries.

		Moderate (AIS2)		Severe (AIS3+)		
		N=45		N=34		
		Mean ± SD / N (%)	Range	Mean ± SD / N (%)	Range	*P* Value
Sex	Male	15 (33.3)	-	9 (26.5)	-	-
	Female	30 (66.7)	-	25 (73.5)	-	0.51
	Age (years)	36.0 ± 22.3	7-84	39.4 ± 22.6	8-84	0.51
	Height (cm)	166.1 ± 9.9	147 - 185	164.4 ± 11.4	140 - 196	0.87
	Weight (kg)	69.0 ± 15.8	41 - 106	65.3 ± 16.4	32 - 113	0.52
	BMI (kg/m^2)	23.6 ± 4.7	13.9 - 36.7	26.0 ± 5.9	15.4 - 36.8	0.53
	EBV (km/h)	36.2 ± 16.0	18 - 91	43.9 ± 16.0	12-73	0.52
	Airbag deployment	26 (57.8)	-	13 (38.2)	-	0.08

AIS: Abbreviated Injury Scale; SD: Standard Deviation; BMI: Body Mass Index; EBV: Equivalent Barrier Velocity

Factors associated with severe injuries

To identify the variables that were independently associated with the occurrence of severe injuries, we conducted a multivariate logistic regression analysis using the forced input method. The independent variables were age, sex (reference: male), BMI, airbag deployment (reference: no), EBV, and body region corresponding to the maximum AIS score (reference: upper abdomen). The results showed that a force to the lower abdomen positively influenced the occurrence of severe injuries (odds ratio, 3.507) and that airbag deployment negatively influenced the occurrence of severe injuries (odds ratio, 0.279). The Hosmer–Lemeshow test indicated a good fit (p=0.341), and Nagelkerke's R2 was 0.236. This analysis was not affected by multicollinearity, variance inflation factors being <1.374 for six variables (Table 4).

Discussion

A systematic review and meta-analysis of cohort studies revealed that the risk of any major injuries was significantly lower in seatbelt users than non-users with a relative risk of 0.47 [18]. Additionally, although statistical significance was obtained in the analyses of injuries in each body region, the relative risk for abdominal injuries (0.87) was higher than that for head (0.49), neck (0.69), and lower limb injuries (0.77) [18]. This fact is substantially due to seatbelt-induced abdominal injuries. A recent study based on nationwide hospital data suggested that the AIS score of the abdomen was the single significant influencing factor for fatalities of motor vehicle passengers [19]. The authors also suggested that seatbelt compression might somewhat contribute to the occurrence of abdominal organ injuries.

In the present study, spleen, kidney, and liver injuries were the three most common injuries induced by seatbelts. This finding is in accordance with previous reports showing that the liver, spleen, and digestive system are the most frequently injured among all abdominal organs in frontal collisions [7,8]; additionally, research has shown that seatbelts are associated with renal injuries and high odds of liver injuries [9,10]. Spleen injury was the most common in this study (likely because the spleen is located in the left hypochondrium, which corresponds to the path of the shoulder belt in the right front passenger seat). Our study also revealed that the severity of all liver injuries was moderate and not severe. According to a large retrospective study, MVC-related liver injuries in patients who used a seatbelt with airbag deployment were the least likely to sustain severe injuries and/or death and had fewer complications, whereas patients with no protective device had the highest risk of these outcomes [11]. Our analysis also confirmed that seatbelt-induced liver injuries were not severe.

In this study, we confirmed that force applied to the lower abdomen was a positive predictor and that airbag deployment was a negative predictor of seatbelt-induced severe injuries. Forces to the lower abdomen were due to compression by lap belts with an incorrect belt path. Even if passengers basically use seatbelts correctly, errors sometimes occur. A recent study of seatbelt position among rear-seat passengers showed that the lap belt was placed above the correct position (on the anterior superior iliac spine) in 40%

Table 3. Comparison of prevalence of each injury between persons with moderate and severe injuries.

	Moderate (AIS2)	Severe (AIS3+)	*P* Value
	N=91	N=45	
Stomach	0 (0)	1 (2.2)	0.15
Duodenum	3 (3.3)	2 (4.4)	0.74
Omentum	1 (1.1)	0 (0)	0.48
Liver	17 (18.7)	0 (0)	0.001
Gallbladder	1 (1.1)	0 (0)	0.61
Spleen	27 (29.7)	16 (35.6)	0.49
Pancreas	2 (2.2)	1 (2.2)	0.99
Adrenal glands	0 (0)	1 (2.2)	0.15
Kidney	16 (17.6)	7 (15.6)	0.77
Abdominal aorta	0 (0)	1 (2.2)	0.15
Jejunum	5 (5.5)	5 (11.1)	0.45
Colon	6 (6.6)	2 (4.4)	0.62
Mesenterium	12 (13.2)	4 (8.9)	0.45
Retroperitoneum	0 (0)	1 (2.2)	0.15
Bladder	1 (1.1)	0 (0)	0.48
Rectum	0 (0)	1 (2.2)	0.15

AIS: Abbreviated Injury Scale

Table 4. Results of multivariate logistic regression analysis.

Independent Variable	Coefficient	OR (95% CI)	*P* Value
EBV	-0.004	0.996 (0.964—1.03)	0.83
Age	0.008	1.008 (0.982—1.035)	0.56
Airbag deployment (Ref. No)	-1.275	0.279 (0.09—0.868)	0.03
Sex (Ref. Male)	0.71	2.034 (0.604—6.848)	0.25
BMI	0.051	1.052 (0.942—1.175)	0.37
Body region corresponding to MAIS (Ref. upper abdomen)	1.255	3.507 (1.313—9.363)	0.01

OR: Odds Ratio; CI: Confidence Interval; EBV: Equivalent Barrier Velocity; BMI: Body Mass Index; MAIS: Maximum Abbreviated Injury Scale of male passengers [20]. Therefore, health-care professionals must advise patients on the proper use of seatbelts, with a lap belt fitting the ilium under the theory that inertial loads from the body interacting with the lap belt are distributed to a greater degree over the skeleton. To decrease the applied force via the seatbelt, we propose the installment of force limiters in lap belts. Force limiters are only installed on shoulder belts and reduce the risk of upper body injuries by releasing shoulder belts at forces above a predefined threshold, thus minimizing the force on the occupant's chest. Therefore, installation of force limiters on lap belts might decrease the forces applied to the lower abdomen. However, setting the force limiter appropriately would require simulations because activation of a limiter on a lap belt could allow too much forward displacement of the occupant. Another means of decreasing the forces applied to the lower abdomen is changing the lap belt width: the wider the seatbelt, the lower the force it transmits. Further research might enable determination of the optimal seat belt width for vehicle passengers.

Airbag deployment was a negative predictor of seatbelt-induced severe injuries. Airbag deployment mitigates the seatbelt-induced forces by reducing forward movement. Although the frequency of mild injuries to the face or extremities has increased with the use of airbags, the forces to the abdomen have decreased by the distribution of blunt force energy away from the abdomen [21-24]. The purpose of a restraint system is to gradually decelerate the occupant over a longer period of time as well as distribute collision forces over a larger portion of the bony skeleton [25]. Therefore, airbag deployment in conjunction with correct seatbelt use can protect against severe abdominal injuries.

Collision velocity was not a predictive factor for seatbelt-induced severe injuries in the present study. However, according to a previous study, the vehicle velocity at impact was directly proportional to the severity of intra-abdominal organ injuries [12]. The study showed that a rise in the impact velocity from 40 to 50 km/h led to a 2.8% higher rate of abdominal trauma and that a rise in the impact velocity from 40 to 70–79 km/h led to a 24.6% higher rate of abdominal trauma [12]. The difference between this result and present result may be due to the difference in the collision velocity; our data showed lower collision velocities (the mean EBV in the moderate and severe injury groups was 36.2 and 43.9 km/h, respectively). Additionally, the BMI was not a predictive factor for severe injuries. According to a previous study based on a huge collision database, obese occupants had a higher incidence rate of belt placement superior to the anterior superior iliac spine than occupants with a normal BMI; however, there was no significant difference between the occupants' BMI and the incidence of abdominopelvic organ injuries [14]. Therefore, our result is in accordance with this previous study.

Seatbelt use during severe MVCs may result in the transmission of significant forces to the abdomen and chest instead of hard collision with the steering or instrument panel. A seatbelt sign is a linear skin discoloration suggesting subcutaneous hemorrhage by seatbelt compression during the collision. The presence of a seatbelt sign on the abdomen implies a significant impact and transfer of kinetic energy to the abdominal wall. One study suggested that up to 10% of MVC passengers with a seatbelt sign had an underlying hollow viscus injury [14]. Another study showed that among patients with a seatbelt sign, two-thirds had an underlying bowel injury [15]. However, a recent retrospective cohort study revealed no association between a seatbelt sign and the occurrence of intra-abdominopelvic injuries [12]. Therefore, in spite of the seatbelt sign, physicians should still suspect seatbelt-induced injuries especially in the lower abdomen of restrained passengers without deployment of an airbag.

This study had some limitations. First, the data used in this study were extracted from collisions that occurred from 1995 to 2011; more recent data were not obtained. Therefore, the safety systems of the vehicles in our study may have differed from those currently in use. However, the results show the basic trends and information concerning seatbelt-induced severe abdominal injuries. When similar studies using recently obtained collision data are performed in future, they may reveal changes in the prevalence and characteristics of seatbelt-induced abdominal injuries based on the present results. Second, we used a United States vehicle collision database in this study. Because of the worldwide variations in traffic situations and collision characteristics, such as passenger body size, vehicle size, and speed limits, the present findings may not be generalizable to all countries. Additional research using data from international sources is required. Third, because we chose vehicle passengers who had injuries with AIS scores of >1, we did not identify mild injuries induced by seatbelts. However, because the objective of this study was to elucidate the characteristics and predictive factors of seatbelt-induced severe injuries, this issue might not have influenced the present results. Further research including all seatbelt-induced injuries is required to improve safety for vehicle passengers.

Conclusion

According to this retrospective analysis of the NASS/CDS database, spleen, kidney, and liver injuries were the three most common abdominal injuries induced by seatbelts. The liver was the second most commonly injured site among patients with moderate injuries, whereas no liver injuries occurred among patients with severe injuries (p=0.001). The multivariable logistic regression analysis revealed that force applied to the lower abdomen positively influenced the occurrence of severe injuries (odds ratio, 3.507) and that airbag deployment negatively influenced the occurrence of severe injuries (odds ratio, 0.279). Correct seatbelt use and airbag deployment can help to prevent severe abdominal injuries induced by seatbelts. Additionally, forensic pathologists should still suspect moderate abdominal injuries even in correctly restrained vehicle passengers.

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Authors Contribution

K.I. designed the study, analyzed the data, and drafted the manuscript.

M.H. designed the study and drafted the manuscript.

K.T. analyzed the data and performed the statistical analyses.

H.I. acquired and analyzed the data.

M. Aoki acquired and analyzed the data.

M. Asaoka critically reviewed the work for important intellectual content.

Competing Interests

The authors declare no competing interests.

Data Availability

The data presented in this study are available from the corresponding author upon request.

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