FACTORS OF SEVERE INJURIES ASSOCIATED WITH SIDE POLE COLLISIONS BASED ON FIELD VEHICLE COLLISION INVESTIGATION

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ABSTRACT

Side pole collision is the most devastating road traffic injury (RTI) that causes death or severe injuries among side collisions. Since pole-type materials have a relatively narrow width and fixed rigidity, side pole collisions cause severe deformation and consequent intrusion resulting in direct contact with the occupants. This study aimed to investigate the risk factors that contributes to a severe injury of motor vehicle occupants (MVOs) in side pole collisions.

This study used the Korea In-Depth Accident Study (KIDAS) database collected from 2011 to April 2020. Among the total data, we analyzed 392 patients who were engaged in side collisions by excluding multiple collisions and rollovers. The collision type was classified into pole and non-pole (i.e., vehicle-to-rigid wall) collisions within a single collision. Moreover, we classified the collision severity according to the amount of crush extent (CE) zones.

In this study, the incidence of non-pole collisions (n=362, 92.35%) was nearly 12 times higher than pole-related collisions (n=30, 7.65%). Factors affecting severe injuries showed statistical significance in the collision object ($p<0.001$), seat location ($p=0.001$), and CE zone ($p<0.001$). However, passive safety devices, such as seatbelts and airbags, showed no significance. In the case of side collision objects, there were statistical differences between the chest ($p=0.004$), pelvis, and extremities ($p=0.016$) between pole and non-pole side collisions. Particularly, The highest risk of severe injury had dramatically increased since the amount of CE zones was higher (odds ratio OR, 9.604; confidence interval, 3.739–24.672). MVOs colliding with pole structural materials had the risk of severe injury (ISS16+) in side collisions (OR, 5.285; 95% CI, 1.358–20.571). Compared with the far-side occupant, the near-side occupant had increased risk of severe injury (OR, 3.123; 95% CI, 1.438–6.783).

In this study, factors affecting severe injuries in side collisions were identified as the collision object, seat location, and crush extent. In frontal and rear-end collisions, it is necessary to seek weakness of crashworthiness caused by the lack of structural performance (e.g., bumpers, engine room, truck leads) to protect occupants from collision capacity in side pole collisions.

In conclusion, an increase in vehicular extent also leads to a risk of intrusion, resulting in a severe injury to near side occupants. In contrast with frontal collisions, both side parts of the vehicle have a relatively low range of capacity to absorb the collision. It is difficult to evaluate severe injury of occupants after a collision at the scene. Proper evaluation on scene can improve the occupant's prognosis.

INTRODUCTION

According to the Fatality Analysis Reporting System (FARS) of the National Highway Traffic Safety Administration (NHTSA), 121,844 vehicle occupant deaths occurred in collisions over the past five years. There were 23,647 vehicle occupant deaths in 2019. Among them, 11,048 deaths were caused by in single collisions, and 5,890 by collisions with fixed objects. Side pole collisions caused 1,070 deaths, accounting for 18.17% of the total deaths. Moreover, 868 occupants died from side pole collisions. The fatality rate was the highest at 81.12% in fixed object collisions. These statistics suggest that side pole collisions can result in severe injury to the occupant [1].

Figure 1. Side pole collision and pole-type object.

Side collision has a lower rate than frontal collision but causes severe injury to occupants [2,3]. In most side collisions, near-side occupants had highest rate (53.3%) and more MAIS3+ compared to far-side occupants [4,5,6,7,8,9,10]. As such, in side pole collisions, occupants at the side parts of the vehicle had a high risk of severe injury.

Recognizing that the side parts of the vehicle can cause severe injury to occupant unlike front parts, analysis and research on the safety standards for side collisions in the United States and Europe have been conducted since the 1980s [11]. However, the Insurance Institute for Highway Safety (IIHS) conducted vehicle safety evaluations through side collision tests every year. Even though vehicles have secured five-star safety rating in evaluation results, severe side collisions continue to be reported [12].

Therefore, it is necessary for side pole collisions to be reduced and vehicle stiffness to be increased for occupant safety. This study aimed to analyze the factors affecting severe injury between side pole collisions.

METHODS

Data collection

This study used the Korean In-Depth Accident Study (KIDAS) database, which was constructed for patients who visited five emergency medical trauma centers. Data of a total of 3,899 patients between January 2011 and April 2020 were analyzed. Figure 2 presents a flowchart of the selection of patients who had side pole collision (n=30) and non-pole collision (n=362).

Data selection criteria

Figure 3 shows the Collision Deformation Classification (CDC) code with seven columns (text and number) of vehicle collision deformation by the Society of Automotive Engineers (SAE International). In this study, side collisions were defined using the codes in Table 1.

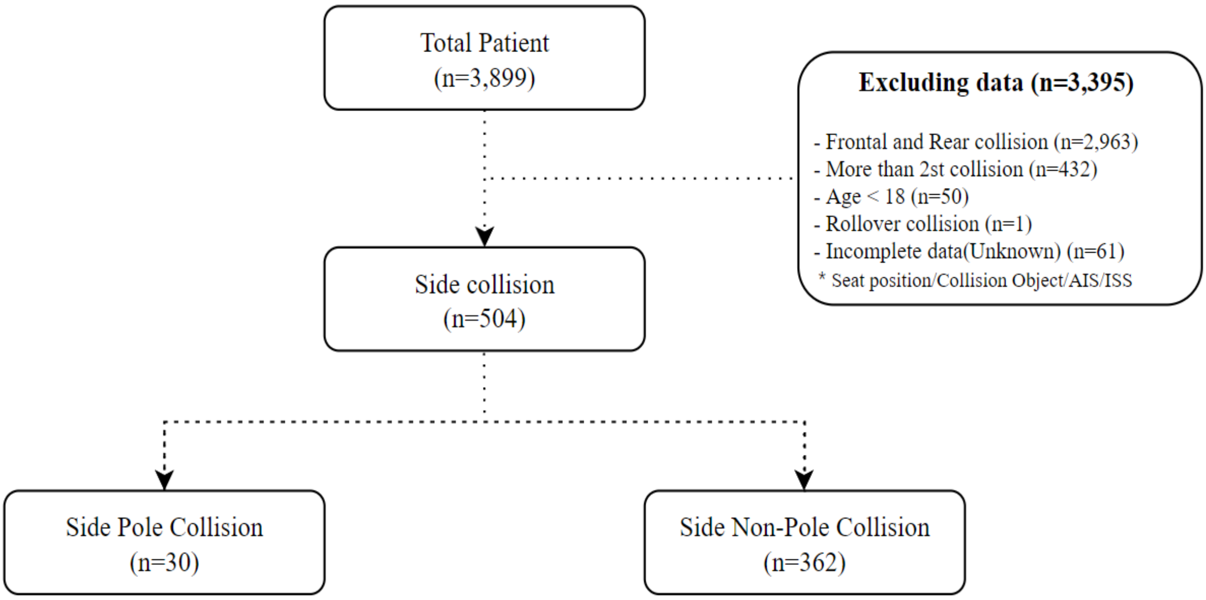

Figure 2. Data selection flowchart.

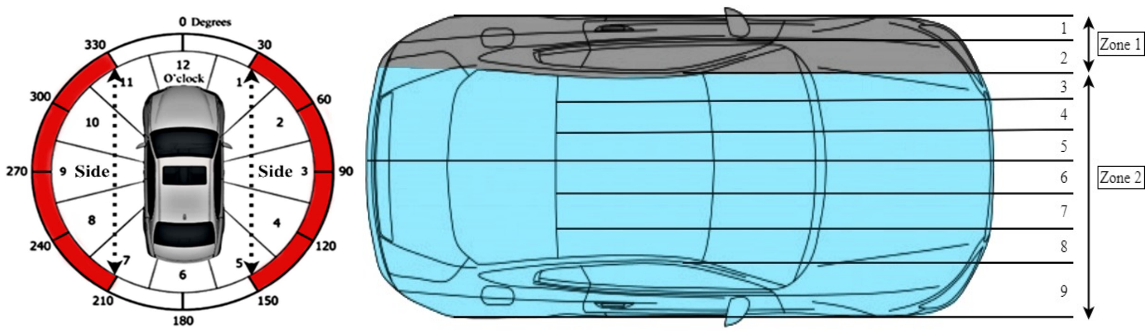

Figure 3. Collision Deformation Classification code.

Table 1.
Selection Collision Deformation Classification Code for Data Analysis

Column	Contents	Used code
1, 2	Principal direction of force	1–5, 7–11
3	Vehicle deformation location	L, R
4	Specific longitudinal or lateral area	F, P, B, Y, Z, D
5	Specific vertical or lateral area	L, M, G, E, H, A
6	Type of damage distribution	W, E, N, S
7	Vehicle crush extents	1–9

1) The direction of collision (principal direction of force [PDOF]) was at 1–5 o'clock and 7–11 o'clock of the CDC code in columns 1 and 2, and vehicle collision deformation location in column 3 was Left (L), Right (R). Data other than the codes were excluded.

2) The single side collision was classified as primary, excluding more than multiple collisions. This study analyzed the severe injuries of adult patients. Age < 18 years and rollover code (O) of the CDC code column 6 were excluded.

3) For the severity of collision, the crush extent of the CDC code in column 7 was used. Side collision severity was indicated by vehicle collision deformation Zone 1 for scores ranging from 1 to 2 and Zone 2 for scores ranging from 3 to 9.

Table 2.
Pole vs Non-pole

Pole	Non-pole
Light pole	Motorcycle
	Sedan
	SUV*
	Light truck
Telegraph pole	Van
	Bus
	Middle truck
	Heavy truck
	Tractor with trailer
Tree	Guardrail
	Train
	Median strip
	Wall
	Others

**SUV, sports utility vehicle*

Table 2 presents the definitions of collision objects. Collision objects in the KIDAS database coding book version 3.0 defined light poles, telephone poles, and trees as pole objects and all other collision objects as non-pole objects.

Table 3.
Selection Variables for Data Analysis

Variable	Details	Type
Age	≥ 18 years	Numerical
Sex	Male, female	Categorical
Vehicle type	Passenger car, sports utility vehicle, light truck, van	Categorical
Collision object	Pole, non-pole	Categorical
Collision direction	Left, right	Categorical
Seat location	Near side, far side	Categorical
Crush extent	Zone 1 (extent, 1–2), zone 2 (extent, 3–9)	Categorical
Seatbelt fastened	Fastened, unfastened	Categorical
Airbag deployment (Front, side, curtain, knee)	Deployed, undeployed	Categorical
ISS	>16, ≤16	Categorical
AIS	>3, ≤3	Categorical

Risk factors affecting severe injuries of the patient were analyzed using the variables presented in Table 3. In Figure 4, occupants close to the collision object were defined as near side occupants and occupants far from the collision object were defined far side occupants.

The Abbreviated Injury Scale (AIS) code devised by the Association for the Advancement of Automotive Medicine was used in the classification of injury severity. Scores were recorded in eight body regions from 1 to 6 according to the injury severity, and the highest score was defined using the Maximum Abbreviated Injury Scale (MAIS). The Injury Severity Score (ISS) was the sum of squares of more than three AIS scores by the range of 1–75. In this study, severe injury was defined as AIS3+ and ISS16+.

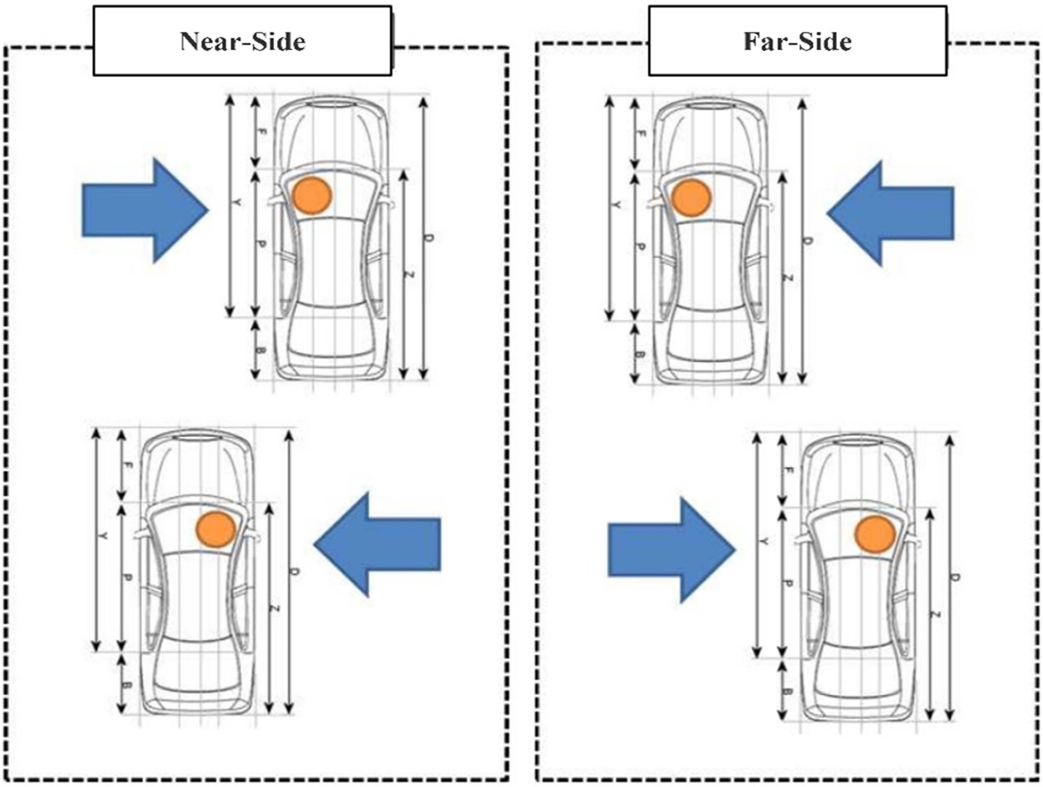

Figure 4. Near side and far side.

Statistics analysis

Dependent and independent variables in each group were analyzed by frequencies and percentages using the chi-square test and Fisher's exact test. The t-test analyzed average and standard deviation values for continuous variables. For AIS and ISS scores that did not follow a normal distribution, the median and quartile were obtained using the Mann–Whitney U test or Kruskal–Wallis H test. Airbag deployment variables in < 30 patients were analyzed using the nonparametric test. This study evaluated injury severity risk factors of patients with pole collisions using the logistic regression analysis. Statistical significance was defined as a P-value <0.05. SPSS (version 26.0, IBM Inc, Chicago, USA) was used in the analysis.

RESULTS

Table 4 presents the general characteristics of side collisions according to occupant severity. There are compared between two groups. The incidence of severe injury (17.5%) was higher in pole collisions (p<0.001). Based on vehicle seat location, near side occupants accounted for 72.1% of the severe group, which was higher than that in far side occupants (p=0.001). Based on vehicle collision deformation, the rate of Zone 2 in the severe group was 83.8%, which was higher than that of Zone 1 (p<0.001).

Table 4.

General Characteristics of Severe Injury Occupant in Side Collision

	ISS<16		ISS≥16		Total		P-value
	N=324	%	N=68	%	N=392	%	
Sex							
Male	193	59.6	48	70.6	241	61.5	0.090
Female	131	40.4	20	29.4	151	38.5	
Age (mean±S.D.)*	46.73±16.33		47.71±17.69		46.9±16.56		0.907
Vehicle type							
Sedan	206	63.6	40	58.8	246	62.8	0.325
SUV**	62	19.1	11	16.2	73	18.6	
Van	37	11.4	9	13.2	46	11.7	
Light truck	19	5.9	8	11.8	27	6.9	
Collision direction							
Left	168	51.9	43	63.2	211	53.8	0.087
Right	156	48.1	25	26.8	181	46.2	
Collision object							
Pole	15	4.6	15	22.1	30	7.7	0.000
Non-pole	309	95.4	53	77.9	362	92.3	
Seat location							
Near side	164	50.6	49	72.1	213	54.3	0.001
Far side	160	49.4	19	27.9	179	45.7	
Crush extent							
Zone 1	191	59.0	11	16.2	202	51.5	0.000
Zone 2	133	41.0	57	83.8	190	48.5	
Seatbelt							
Fastened	223	71.7	40	60.6	263	69.8	0.075
Unfastened	88	28.3	26	39.4	114	30.2	
Airbag							
Deployment	45	18.7	5	10.4	50	17.3	0.167
Undeployment	196	81.3	43	89.6	239	82.7	

**Mean±standard deviation (S.D.), **SUV, sport utility vehicle*

Table 5 shows a comparison of the severity of each body part according to the impact object. The incidence of chest injury AIS3+ was higher in the pole group (40%) compared to that in the non-pole group (18.2%) (p=0.004). Moreover, the incidence of pelvis and extremities AIS3+ was higher in the pole group (13.3%) than that in the non-pole group (2.8%) (p=0.016). Between the two groups, the median and quartile of MAIS and ISS in the pole group were higher than those in the non-pole group (p=0.001)..

Table 5.

Injury Severity for Body Regions According to Collision Object

	Pole		Non-pole		Total		P-value
	N=30	%	N=362	%	N=392	%	
Head and neck							
AIS < 3*	23	76.7	316	87.3	339	86.5	0.158
AIS ≥ 3	7	23.3	46	12.7	53	13.5	
Face							
AIS < 3	30	100.0	359	99.2	389	99.2	1.000
AIS ≥ 3	0	0.0	3	0.8	3	0.8	
Thorax							
AIS < 3	18	60.0	296	81.8	314	80.1	0.004
AIS ≥ 3	12	40.0	66	18.2	78	19.9	
Abdomen							
AIS < 3	27	90.0	351	97.0	378	96.4	0.083
AIS ≥ 3	3	10.0	11	3.0	14	3.6	
Pelvis and extremities							
AIS < 3	26	86.7	352	97.2	378	96.4	0.016
AIS ≥ 3	4	13.3	10	2.8	14	3.6	
MAIS**, median [IQR]***	3 (2-4)		2 (1-3)		2 (1-3)		0.001
ISS, median [IQR]	15 (5-34.25)		4.5 (2-10)		5 (2-11)		0.001

**AIS, Abbreviated Injury Scale; **MAIS, Maximum Abbreviated Injury Scale; ***IQR, interquartile range*

Table 6 presents a logistic regression analysis for risk factors of severe injury in side collision. There was a statistical significance in the collision object, seat location, and vehicle damage severity. In crush extents, Zone 2 risk was 9.545 times higher (95% CI, 3.739–24.672; p=0.001) than Zone 1 risk. In the collision object, pole collision showed a 5.285 times (95% CI, 1.358–20.571; p=0.016) higher risk than non-pole collision. Near side occupants had a higher risk (95% CI, 1.438–6.783; p=0.004) than far side occupants by 3.123 times.

Table 6.

Logistic Regression Analysis for Risk Factors of Severe Injury in Side Collision

Variables	OR	95% CI	P-Value
Crush extent			
Zone 1	Reference		
Zone 2	9.604	3.739–24.672	0.001
Collision object			
Non-pole	Reference		
Pole	5.285	1.358–20.571	0.016
Seat location			
Far side	Reference		
Near side	3.123	1.438–6.783	0.004

*Adjusted for sex, seatbelt use, airbag deployment, and vehicle type. CI, confidence interval; OR, odds ratio.

DISCUSSION

This study aimed to identify the factors affecting severe injury of occupants in side pole collisions. It is difficult to evaluate severe injury of ccupants after a collision at the scene. Proper evaluation on scene can improve the occupant's prognosis. This study suggests that side ollision, near side location, pole object, increased vehicle collision deformation increases the risk of severe injury.

As vehicle deformation increases, occupant injury increases. In the results of this study, as the vehicle deformation increased in a side pole collision, the rate of injury increased ($p<0.001$), and the risk increased 9.6 times in vehicle deformation intrusion ($p<0.005$). In a previous study, there was no difference in occupant injuries in extent 1–2 in a side collision, but injuries increased in extent 3+ [13]. In another study in which a vehicle was equipped with a dummy, vehicle deformation intrusion was shown by direct collision with the dummy in the side pole collision test [3]. The more the vehicle collision deformation increase, the more interior and direct the collision with the occupants.

In a previous study, the risk of severe damage was 2.26 times higher in a side collision with a pole object than in a vehicle-to-vehicle collision [3]. In this study, the risk of side pole collision was 5.29 times higher than that of side non-pole collision. Matthew et. al. reported that 59% of chest injuries and 33% of pelvic injuries occurred in side collisions with narrow objects around the road [12]. In this study, the comparison of severe injuries by body regions according to the collision object (40% of the chest and 13.3% of the pelvis and extremities in the severe group) showed statistical significance ($p<0.005$). Therefore, a side collision with a pole object increases the risk of severe injury to the occupant.

Therefore, there is a high risk of severe injury to patients after a side pole collision. Even in vehicles with fivestar safety ratings, since the effectiveness of the safety device for preventing occupant injury is insufficient, structural design improvement for vehicular intrusion should be considered for side pole collisions. Moreover, paramedics dispatched to on scene must check on the patient's status and improve the rognosis of the patient by speedy transport.

CONCLUSIONS

In this study, we analyzed the factors affecting severe injuries of occupants in side collisions based on real-world data. It has been confirmed that side collisions caused by pole objects have a higher rate of severe injury to the occupant than a collision with a non-pole object. Near side occupants had an increased risk of severe injury than far-side occupants. The intrusion distance of vehicle collision deformation increases during a side collision with a pole object, a major factor affecting severe injuries. Unlike front collision, side collisions seems to cause direct collision to the vehicle with the occupants as the vehicle collision deformation is intruded because the collision is concentrated when colliding with the pole object. Therefore, it is necessary to supplement the vehicle design to respond to side pole collision by reflecting these characteristics. This study is expected to be used as basic research to predict risk factors of severe injury on scene.

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